Matthias Kühle-Weidemeier, Michael Balhar
(Hrsg.)

Waste-to-Resources 2015

6. Internationale Tagung MBA, Sortierung und Recycling

Energie und Rohstoffe aus Rest- und Bioabfällen

Tagungsband
(Originalsprachenausgabe)

5. - 7. Mai 2015

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In addition to many projects for waste management companies, Wasteconsult international has also conducted several projects for the German national environment authority / (EPA / Umweltbundesamt), for example a survey of all German mechanical and mechanical biological (MBT) treatment plants for residual waste. The survey contained a very wide range of aspects like detailed description of each plant's technology, nominal and real treatment capacity / throughput, problems of mechanical treatment, problems of biological treatment, problems of exhaust gas treatment, mass balances, complying with boundary values, sale of RDF, intermediate storage and much more. Hence we have an excellent overview of the true situation of all the different MBT-technologies in Germany and due to other projects also in other countries. Wasteconsult has also elaborated the German contribution to the update of the European "Best Available Technique Reference" documents" for biological and mechanical biological waste treatment techniques.

Wasteconsult international holds patents for photovoltaic landfill covers, has done plenty of photovoltaic and other projects on landfills and prepared a report about gas emissions and performance of landfill covers with biological methane oxidation for the German EPA. Wasteconsult has also organised five German landfill conferences.

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Hinweis

Dieser Tagungsband wurde durch Wasteconsult international, Dr. Kühle-Weidemeier mit großer Sorgfalt zusammengestellt. Fehler sind trotzdem nicht auszuschließen. Für die Richtigkeit der Angaben in diesem Buch wird von Wasteconsult, der ASA und den Verfassern keinerlei Haftung oder Gewährleistung übernommen. Die Verantwortung für den Inhalt der Beiträge liegt bei den Autoren selbst.

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Grußwort von Bundesumweltministerin Barbara Hendricks für die 6. internationale Tagung MBA, Sortierung und Recycling vom 5.-8. Mai 2015 in Hannover

Sehr geehrte Teilnehmerinnen und Teilnehmer,

immer mehr Ressourcen werden zukünftig benötigt, um immer mehr Menschen mit ihren weiter wachsenden Ansprüchen adäquat versorgen zu können. Wenn wir dabei die ökologischen Grenzen unseres Planeten respektieren und die zum Teil knappen Rohstoffe nicht über Gebühr ausbeuten wollen, brauchen wir ein nachhaltiges Wachstum ohne zusätzlichen Ressourcenverbrauch. Unser Anliegen muss es vielmehr sein, den Verbrauch von Rohstoffen weiter zu reduzieren und dadurch Umwelt, Klima und Menschen zu entlasten. In einem Satz zusammengefasst: Es geht darum, mit weniger mehr zu erreichen.

Die Lösungswege dorthin liegen vor allem in der Ressourceneffizienz, also in rationaler und sparsamer Nutzung der Ressourcen in Produktion, Produkten und Konsum. Sie liegen weiterhin in qualitativem Wachstum, d.h. Qualität statt Menge. Und sie liegen in einer verstärkten Kreislaufwirtschaft, also der Rückführung der Wertstoffe aus den Abfällen als Rohstoffe für die Wirtschaft. Diese drei Elemente umfassen eine Fülle von Maßnahmen auch der Abfallwirtschaft. Dabei gilt Deutschland bereits jetzt weltweit als vorbildlich bei der Entwicklung einer „Kreislaufwirtschaft", die nicht „entsorgt", sondern Abfall als Ressource behandelt. Deutschland zeigt, dass eine große Industrienation mit höchsten Umweltstandards sogar in Krisenzeiten wachsen kann. Es kommt darauf an, jetzt nicht nachzulassen und diese Erfolgsgeschichte weiterzuschreiben.

Auf der Basis des Kreislaufwirtschaftsgesetzes von 2012 und mit der Umsetzung von EU-Regelungen werden wir noch in dieser Legislaturperiode eine Reihe rechtlicher Fragen voranbringen, mit denen wir das Recycling steigern und den Ressourcenschutz verbessern wollen. Da sind zum Beispiel das Elektro-und Elektronikaltgeräte-Gesetz, die Steigerung der Wertstofferfassung und des Recyclings von Abfällen aus Haushalten und Gewerbe durch das Wertstoff-Gesetz und die Gewerbeabfall-Verordnung, die Klärschlamm-Verordnung mit Verpflichtung zum Phosphorrecycling und die Umsetzung der Getrennterfassungspflicht für Bioabfälle. Außerdem werden wir das bundesweite Abfallvermeidungsprogramm weiter entwickeln.

Bis Anfang 2016 werden wir auch das Deutsche Ressourceneffizienzprogramm von 2012 (ProgRess) weiterentwickeln - das erste von einer Regierung beschlossene nationale Ressourceneffizienzprogramm in Europa. Neben der Materialeffizienz bei der Produktion und dem nachhaltigen Konsum von Gütern kommt darin der Kreislaufwirtschaft eine erhebliche Bedeutung zur Schonung unserer natürlichen Ressourcen zu.

Vor diesem Hintergrund hat die 6. internationale Tagung MBA, Sortierung und Recycling, die sich innerhalb ihres breit gefächerten Themenfeldes auch wichtigen Fragen des Ressourcenschutzes widmet, eine hohe Aktualität. Als Schirmherrin wünsche ich Ihnen interessante Diskussionen und der Tagung einen erfolgreichen Verlauf.

Ihre

Barbara Hendricks

Biogas production from sugarcane filter cake: Start-up strategies, co-digestion with bagasse and plant design

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Abstract

The Sugarcane Industry in Brazil is responsible for generation of different types of organic wastes. Bagasse and small share of straw have already been used as solid fuel in co-generation systems in general. Meanwhile, there are other kinds of by-products, as filter cake and vinasse, which have been completely unused from the energy point of view. The idea of converting such unused wastes into additional energy is gaining attention, especially driven by some Government commitments on increasing the renewable energy generation combined with the reduction of carbon dioxide emissions.

The anaerobic digestion process is able to contribute with additional renewable energy production, in the form of electricity from biogas or even biomethane, keeping meanwhile the current practice of recycling the nutrients contained in these wastes on the sugarcane fields. However, for a successful application in industrial scale, the anaerobic digestion process must be carefully evaluated in terms of selection of appropriate inoculum, process kinetics, and plant design, among other aspects.

The present research evaluated different inocula for the biogas reactors start-up, the utilization of filter cake as single substrate for biogas production and the combination with bagasse in a co-digestion system (70% of filter cake and 30% of bagasse in fresh basis). Moreover, different options for the biogas utilization (combined heat and power or upgrading to biomethane) integrated to an average size sugarcane plant (2.5 M ton year^{-1}) were assessed.

Therefore, six laboratory scale (5 L volume) continuous stirred tank reactors (CSTRs) were operated during approximately 140 days under mesophilic conditions (±38°C). To understand the applicability of an alternative and locally available inoculum (fresh cow manure) over the conventional start-up system (digestate from another biogas reactor), the kinetic and energy benefits of co-digestion with bagasse, and finally the simulation of biogas production in an average size sugarcane plant were analyzed.

The results demonstrate that it is possible to utilize fresh cow manure as inoculum for biogas production from sugarcane filter cake and bagasse. However, a previous acclimation of the fresh cow manure is required due to its high volatile organic acids concentration. The mono-digestion of filter cake achieved an average biogas yield of 430 mL gVS^{-1} with 59% of methane content during the steady phase (hydraulic retention time of 28 days and organic loading rate of 3.0 g VS L.d^{-1}).

In contrast, for the co-digestion of filter cake and bagasse an average biogas yield achieved 347 mL gVS^{-1} with 54% of methane content was determined during the steady phase (hydraulic retention time of 35 days and organic loading rate of 3.0 g VS $L.d^{-1}$). For the simulation of large scale biogas production, the combined heat and power unit of an average sized sugarcane plant operated as mono-digestion of filter cake would have an installed capacity of 4.3 MW_{EL} (±15,500 MWh_{EL} $year^{-1}$) or alternatively a biomethane production of ±12,000 m^3_{STP} day^{-1}.

In case of co-digestion of bagasse, the biogas plant would have a combined heat and power system with an installed capacity of 4.5 MW_{EL} (±16,500 MWh_{EL} $year^{-1}$) or alternatively a biomethane production of 12,500 m^3_{STP} day^{-1}.

The results demonstrate that co-digestion of bagasse produce less biogas than mono-fermentation of filter cake, even its substrate composition presenting a better balance of nutrients (C:N ratio of 40:1) in comparison to filter cake mono-digestion (C:N ratio of 24:1). The less biogas production of co-digestion can be explained by the high lignin content found in bagasse, which could have hampered the conversion of cellulose and hemicellulose of bagasse into biogas. To avoid this situation a more effective pre-treatment is suggested to improve the conversion of the fibers fraction of bagasse. During the present research only a physical pre-treatment by grinding in 10 mm was used.

Energetische und stoffliche Verwertung von Inkontinenz-Abfällen (INKOCYCLE): Anaerobe Behandlung von Erwachsenenwindeln

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Recycling and energy recovery of incontinence waste (INKOCYCLE) – Anaerobic treatment of adult diapers

Abstract

Due to the demographic change in Europe the amount of incontinence waste is expected to increase drastically. In Germany, the incontinence waste stream is currently estimated as 200,000 metric tonnes per year. The „INKOCYCLE”-Project focuses on a combination of energy and material recovery from adult incontinence waste. Energy recovery is pursued by anaerobic digestion of the biodegradable fraction of the diapers whereas material recovery options are targeted for the digestion residue. The anaerobic digestion of the biodegradable organic fractions results in 663 L biogas per kg organic dry residue, with an average composition of 56 % CH_4 and 44 % CO_2. Based on the original waste the gas yield is 155 L biogas per kg of used diapers. The digestion residue mostly consists of the non-biodegradable plastic components, adhering biomass and the superabsorbent polymer. The calorific value of the ‘plastics fraction’ (dry residue 42 %) is about 12 MJ per kg of washed digestion residue.

Inhaltsangabe

Infolge des demografischen Wandels in Europa wird das Aufkommen an Inkontinenzabfällen deutlich zunehmen. Deutschlandweit handelt es sich derzeit um eine geschätzte jährliche Menge von 200.000 Tonnen Inkontinenzabfall. Das Projekt „INKOCYCLE“ konzentriert sich auf eine Kombination aus energetischer und stofflicher Verwertung des Inkontinenzabfalls. Die energetische Verwertung erfolgt mittels anaerober Fermentation der biologisch abbaubaren Bestandteile des Inkontinenzproduktes, während sich die stoffliche Verwertung auf den Gärrest bezieht. Der anaerobe Abbau der organischen Fraktionen bringt 663 Liter Biogas pro kg organischer Trockenmasse, mit einer durchschnittlichen Zusammensetzung von 56 % CH_4 und 44 % CO_2. Dies entspricht 155 L Biogas pro kg Originalsubstrat. Der Gärrest besteht hauptsächlich aus den nicht abbaubaren Kunststoffbestandteilen, anhaftender Biomasse und Superabsorber. Der Heizwert der „Kunststofffraktion“ beträgt ca. 12 MJ pro kg, bei einem Feuchtigkeitsgehalt von 42 %.

Keywords

Inkontinenzabfall, Windeln, thermophiler anaerober Abbau, Biogas, kontinuierliche Nassvergärung

incontinence waste, diapers, thermophilic anaerobic digestion, biogas, continuous wet fermentation

1 Einleitung

1.1 Das Forschungsvorhaben „INKOCYCLE“

Infolge des demografischen Wandels in Europa wird das Aufkommen an Inkontinenzabfällen (gebrauchte Erwachsenenwindeln) deutlich zunehmen. Deutschlandweit handelt es sich derzeit um eine geschätzte jährliche Menge von 200.000 Tonnen Inkontinenzabfall (MEYER, 2014). Dies entspricht einem Anteil von ca. 1,4 % am gesamten in Deutschland anfallenden Restmüll (DESTATIS, 2014). Der Anteil an Inkontinenzabfall im Restmüllaufkommen von Pflegeeinrichtungen liegt bei ca. 60 bis 80 %, Tendenz steigend (BECHER, 2009). Die damit verbundenen hohen Kosten verlangen für diesen Abfallstrom ein wirtschaftliches und ökologisches Managementsystem.

Aufgrund des Verbotes der Ablagerung organischer Abfallstoffe auf Deponien besteht derzeit die einzige gesicherte Entsorgungsmöglichkeit in der Verbrennung der gebrauchten Inkontinenzprodukte. Ziele des vom Bundesministerium für Bildung und Forschung finanzierten Forschungsvorhabens „INKOCYCLE“ (Förderkennzeichen: 03FH006PX2) sind die Entwicklung einer kostengünstigen und ökologisch sinnvollen Alternative zum bestehenden Entsorgungsweg sowie die Entwicklung eines Gesamtkonzeptes zur Verwertung von Inkontinenzabfällen unter Einbeziehung eines Logistikkonzeptes. Die Verwertung erfolgt durch die anaerobe Umsetzung der biologisch abbaubaren Abfallkomponenten in Biogas kombiniert mit der Nutzung des getrockneten Gärrestes (primär Kunststoffe) als Ersatzbrennstoff.

1.2 Inkontinenzprodukte

Inkontinenzprodukte für Erwachsene wurden in Europa in den späten 1960er Jahren eingeführt. Die Produkte sind an die Bedürfnisse der Anwender, deren Geschlecht und die Stärke der Inkontinenz angepasst. Die Verwendung von Inkontinenzprodukten ermöglicht es den Benutzern ihre Menschenwürde zu wahren und sich ohne negative Auswirkungen ihrer Erkrankung in ihrem sozialen Umfeld zu bewegen. Des Weiteren können moderne Inkontinenzprodukte den Ausschlag dafür geben, ob an Inkontinenz leidende Personen in ihrem häuslichen Umfeld wohnen bleiben können oder in eine Pflegeeinrichtung umziehen müssen (EDANA, 2012).

Innerhalb des Forschungsvorhabens wurden drei Typen von Inkontinenzprodukten unterschieden: Windeln für Stuhl- und Urininkontinenz, Vorlagen für Urininkontinenz und Bettauflagen für den zusätzlichen Schutz von Betten, Rollstühlen und Sitzmöbeln. Diese Produkttypen haben aufgrund ihrer verschiedenen Anforderungen unterschiedlich Formen, sind aber in ihrem Prinzip ähnlich aufgebaut und weisen die gleichen Produktkomponenten bei jedoch unterschiedlichen Massenanteilen auf.

Ein modernes Inkontinenzprodukt besteht zum größten Teil aus einem mehrlagigen Zellstoffkörper und einem darin eingearbeiteten absorbierenden Polymer (Superabsorber). Die Aufgabe des Superabsorbers ist die Aufnahme und Speicherung des Urins. Darüber hinaus verhindert er die bakterielle Zersetzung des Urins in Ammoniak und Kohlenstoffdioxid, somit wird einer Geruchsbildung vorgebeugt. Auf der körperzugewandten Seite ist ein hautverträgliches Vlies aus Polypropylen eingearbeitet. Eine flüssigkeitsundurchlässige Folie aus Polyethylen sorgt für den Schutz der Kleidung und der Umgebung des Betroffenen. Elastische Bündchen gewährleisten eine gute Passform und verhindern ein Austreten von Urin oder Fäkalien.

Im Folgenden sind die prozentualen Zusammensetzungen der unterschiedlichen Typen von Inkontinenzprodukten grafisch dargestellt. Unter der Kategorie „Sonstiges“ sind Komponenten wie Klebestreifen (zum Fixieren) und Gummibänder (für den angenehmeren Tragekomfort) zusammengefasst.

Erwachsenenwindeln unterscheiden sich von ihrem strukturellen Aufbau nicht wesentlich von Babywindeln. Die Konstruktion muss sich allerdings an die herrschenden Gegebenheiten, wie das höhere Gewicht und Volumen der Ausscheidungen anpassen, daher gibt es Unterschiede in der Verteilung der Produktkomponenten.

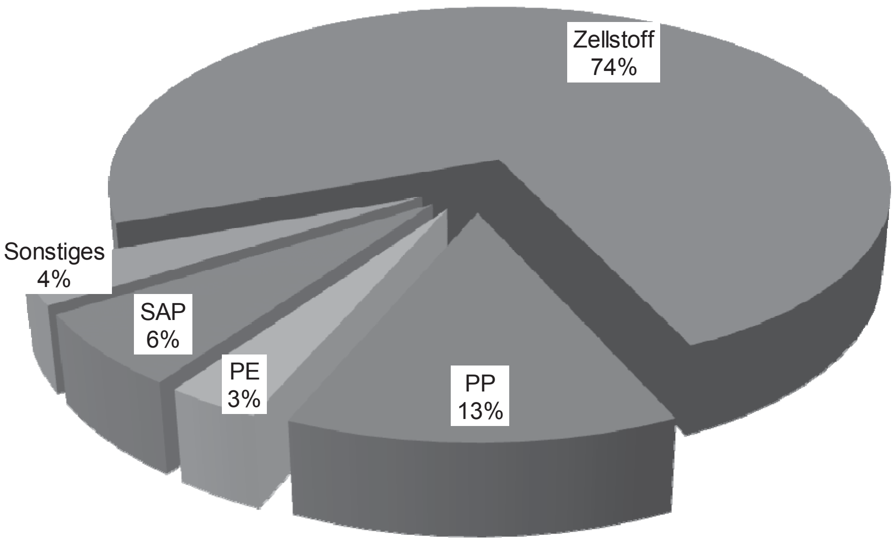

Abbildung 1 prozentuale Zusammensetzung von Erwachsenenwindeln (ABENA, 2013)

Inkontinenzvorlagen sind ähnlich aufgebaut wie Windeln, allerdings fehlen ihnen die seitlichen Flügel sowie eine Fixiermöglichkeit am Körper. Zur Fixierung werden spezielle Netz- oder Schutzhosen verwendet.

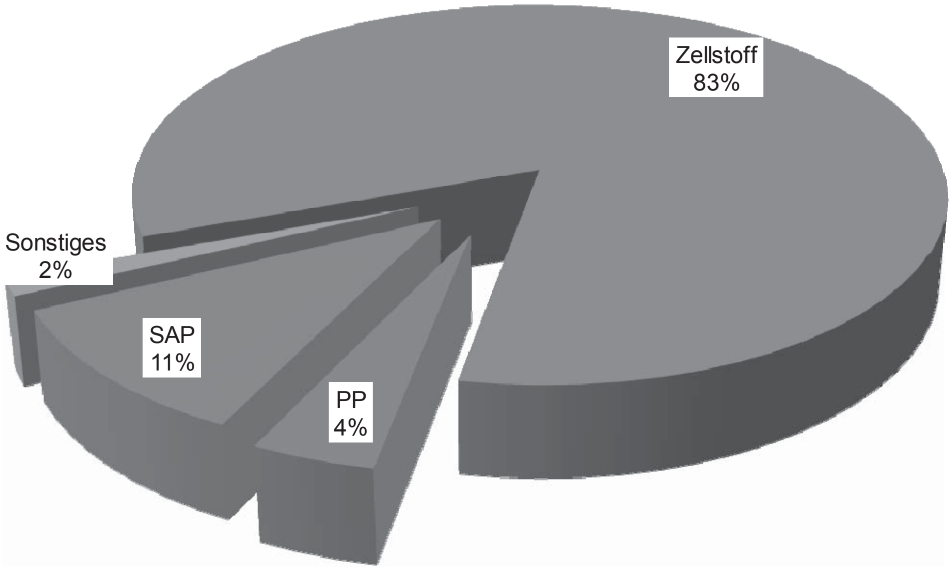

Abbildung 2 prozentuale Zusammensetzung von Inkontinenzvorlagen (ABENA, 2013)

Bett- oder Krankenunterlagen gehören zu den körperfernen Hilfsmitteln und bestehen meist aus mehreren Lagen Zellstoff und einer Folie als Feuchtigkeitsschutz. Es gibt Arten mit und ohne den Zusatz von Superabsorbern.

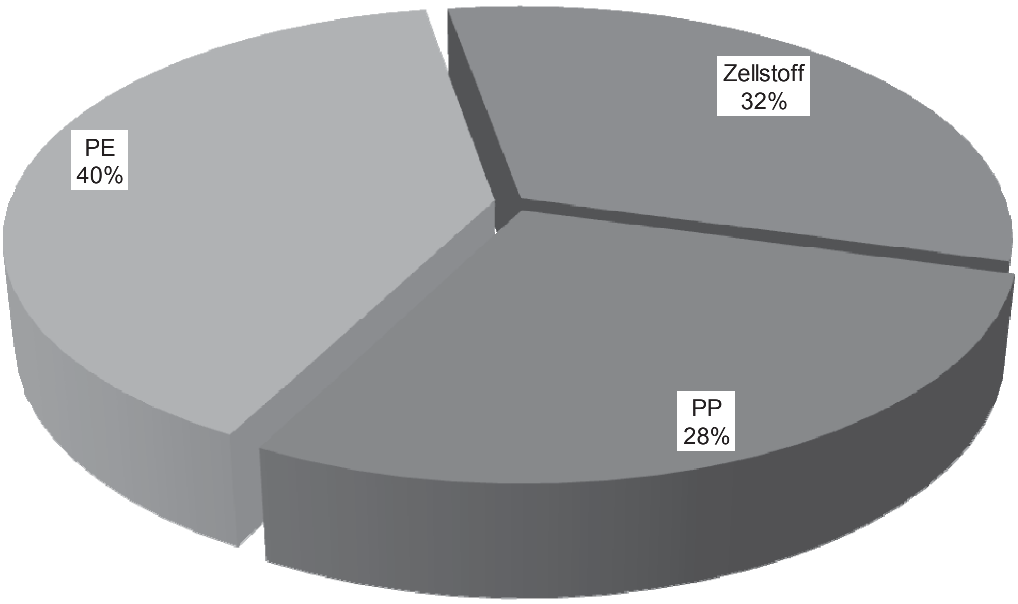

Abbildung 3 prozentuale Zusammensetzung von Bettauflagen (ABENA,2013)

2 Material und Methoden

2.1 Trennungs- und Sammelkonzept

Die Sammlung von Inkontinenzabfällen in Pflegeheimen ist aufgrund des zentralen Anfalls wesentlich einfacher als eine Sammlung in Einzelhaushalten. Im Rahmen des Forschungsvorhabens „INKOCYCLE“ werden die Inkontinenzabfälle auf einer Pflegestation mit einer vollstationären Pflege von 21 Bewohnern erfasst.

Das medizinische Fachpersonal sammelt die gebrauchten Inkontinenzprodukte direkt in den Patientenzimmern in getrennten Behältern. Dies verhindert eine Vermischung mit anderen Abfallfraktionen. Mit Hilfe eines dezentralen Hygiene Systems, [Inko)(naut, THEOcare GmbH] wird der getrennt erfasste Inkontinenzabfall anschließend vakuumiert. Diese Behandlung ermöglicht zum einen eine hygienische Lagerung und führt zum anderen zu einer erheblichen Volumenreduktion, zeitgleich erfolgt eine Geruchsminimierung. (THEOCARE, 2014)

Zu Beginn der Sammlung wurde ein besonderes Augenmerk auf eventuelle Fehlwürfe durch das Pflegepersonal gerichtet. Durch die Einbindung der Mitarbeiter in das Forschungsvorhaben und eine gezielte Unterweisung, konnte sichergestellt werden, dass es zu keiner Vermischung des Inkontinenzabfalls mit anderen Abfallfraktionen, insbesondere mit potentiell infektiösem Material oder spitzen Gegenständen, kam.

2.2 Erfassung und Bilanzierung des Inkontinenzabfalls

Aufgrund der Vielzahl verwendeter Inkontinenzprodukte erfolgten zunächst eine genaue Erfassung und eine anschließende Bilanzierung des Inkontinenzabfalls. Hierzu wurden die Inkontinenzprodukte aus den vakuumierten Säcken identifiziert und sortiert, anschließend gezählt und gewogen.

Auf Grundlage der Herstellerangaben über die im Produkt enthaltenen Komponenten sowie deren typbezogenen Massenanteile (ABENA, 2013) und den Sortierergebnissen konnten einerseits die stoffliche Zusammensetzung des Inkontinenzabfalls bestimmt und andererseits auf Parameter wie die durchschnittliche Beladung mit Urin und/oder Fäzes sowie auf die Massen der biologisch abbaubaren Bestandteile geschlossen werden.

Die Grundlage für die Berechnung der organisch abbaubaren Anteile des Inkontinenzabfalls ist in Abbildung 4 grafisch dargestellt. Die Beladung der verschiedenen Produkttypen wurde während der Sortierung abgeschätzt und folgendermaßen festgelegt: Windeln sind zu 80 % mit Urin und 20 % mit Fäzes, Vorlagen und Bettauflagen zu 90 % mit Urin und 10 % mit Fäzes beladen. Die in Abbildung 4 aufgeführten Werte für den organischen Trockensubstanzgehalt (oTR) stammen aus der Literatur (DWA, 2008) und aus eigenen Messungen.

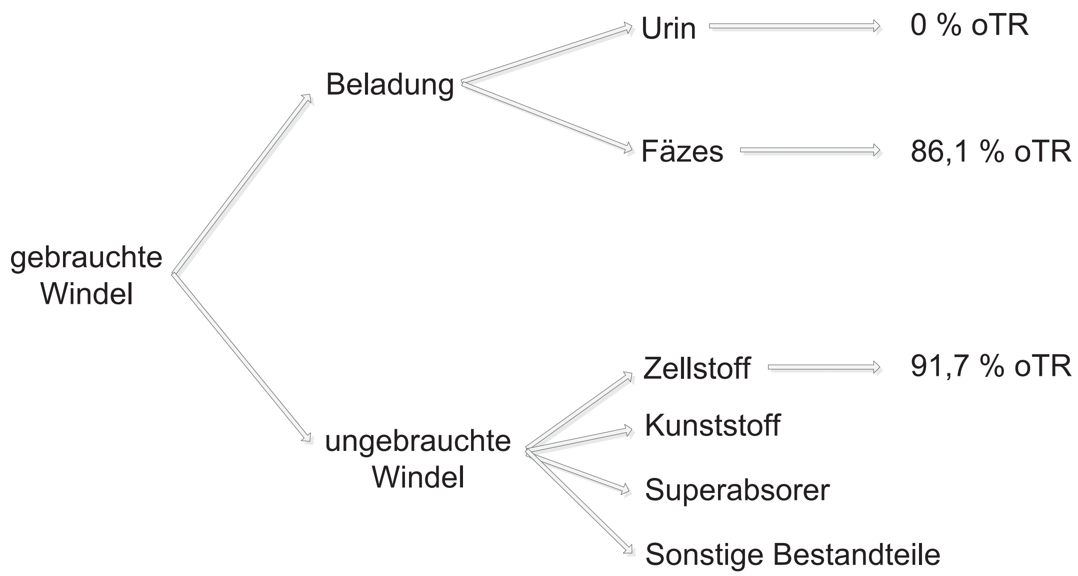

Abbildung 4 grafische Darstellung der Grundlage für die Berechnung der organisch abbaubaren Anteile des Inkontinenzabfalls

2.3 Thermophile anaerobe Behandlung

Die anaerobe Behandlung der gebrauchten Inkontinenzprodukte erfolgt mittels thermophiler Nassfermentation nach Animpfung mit Faulschlamm aus einer kommunalen Kläranlage. Der horizontal liegende Fermenter weist ein Volumen von ca. 1000 Liter auf und wird in einem Temperaturbereich von 53 bis 57 °C betrieben.

Die gebrauchten Inkontinenzprodukte werden nach ihrer Erfassung mithilfe eines Zerkleinerungsaggregats geschreddert und in zerkleinerter Form in den Aufgabetrichter des Eintragssystems gegeben. Die hierin befindliche Förderschnecke beschickt den Reaktor über einen hydraulisch dichten Aufgabetrichter in getakteten Intervallen. Zeitgleich mit der Substratzugabe erfolgt die Dosierung von Prozesswasser in den Aufgabetrichter, um das Einbringen des Materials in den Fermenter zu erleichtern. Ein intervallweise betriebenes horizontal liegendes Paddelrührwerk sorgt für eine homogene Umwälzung des Fermenterinhalts und erleichtert den Austrag des gebildeten Biogases. Das Biogas wird über einen Gasdom abgeleitet und das Volumen mittels Trommelgaszähler erfasst. Die Gaszusammensetzung wird diskontinuierlich gemessen (Probenahme mittels Gassack). Der Gärrest wird durch Verdrängung über einen Siphon auf ein 2 mm Sieb ausgetragen und hierbei vom Prozesswasser getrennt. Das Prozesswasser wird als Rezyklat in den Fermenter zurückgeführt.

2.4 Behandlung des Gärrestes

Der Gärrest besteht nach Passage des Fermenters und der Entfernung des Prozesswassers überwiegend aus den nicht biologisch abbaubaren Kunststoffbestandteilen der Inkontinenzprodukte. Ebenfalls enthalten sind daran anhaftende Biomasse, ein Teil des in den Inkontinenzprodukten verwendeten superabsorbierenden Polymers und ein großer Anteil anhaftender Flüssigkeit.

Für eine weitergehende Behandlung des Gärrestes muss die Kunststofffraktion zwingend von dem anhaftenden Superabsorber befreit werden, da aufgrund dessen gallertartiger Konsistenz eine Entwässerung nur schwer möglich ist. Die Abtrennung des Superabsorbers erfolgt durch zwei aufeinander folgende Waschgänge. Hierzu werden 10 kg des Gärrestes in eine Waschtrommel gegeben und jeweils mit 40 Liter Brauchwasser behandelt. Das Waschwasser wird durch Siebung (0,1 mm) von dem darin befindlichen Superabsorber befreit und anschließend in einer aeroben Laborkläranlage behandelt.

Der gewaschene Gärrest besteht zum überwiegenden Teil aus den Kunststoffbestandteilen und wird nunmehr als „Kunststofffraktion“ bezeichnet. Die weitere Entwässerung erfolgt mithilfe einer Hydropresse bei einem Arbeitsdruck von 3 bar.

2.5 Hygienisierungsuntersuchungen

Für eine weitere Verwendung der Kunststofffraktion ist es notwendig dessen hygienische Unbedenklichkeit sicherzustellen. Des Weiteren muss die Hygienisierungsleistung des Fermentationsprozesses gemäß gültiger Rechtsvorschriften (DüMV, BioAbfV) nachgewiesen werden.

Unter Hygienisierung versteht man eine Reduktion aktiver bzw. koloniebildender Einheiten um mindestens 4, typischerweise 5 log-Stufen, also um 99,99 bzw. 99,999 %. Der Nachweis der Hygienisierungsleistung des eingesetzten anaeroben Fermenters wurde mittels mikrobiologischer Untersuchungen von In- und Outputproben (zerkleinerter Inkontinenzabfall, ungewaschener Gärrest) durchgeführt. Im Zeitraum von 10 Tagen wurden jeweils 5 Proben vor und nach der Behandlung genommen und mikrobiologisch auf die Gesamtkeimzahl bei 37 °C, E. coli, Fäkalstreptokokken und Salmonellen untersucht.

3 Ergebnisse und Diskussion

3.1 Zusammensetzung des Inkontinenzabfalls

Der Inkontinenzabfall der Pflegestation setzt sich aus 72 % Windeln, 20 % Bettauflagen und 8 % Vorlagen zusammen.

Darin enthalten sind 38 % organisch abbaubare Bestandteile und 18 % nicht organische Bestandteile. Die größten Bestandteile des Inkontinenzabfalls bestehen aus Urin (37 %) und Zellstoff (35 %).

Sowohl die Zusammensetzung des Abfalls, als auch die Verteilung der organischen und nicht organischen Bestandteile sind von dem Typ (siehe Abbildung 1 bis 3) und dem Hersteller der verwendeten Inkontinenzprodukte abhängig. Es ist daher zu erwarten, dass sich die Abfälle einzelner Pflegeeinrichtungen unterscheiden.

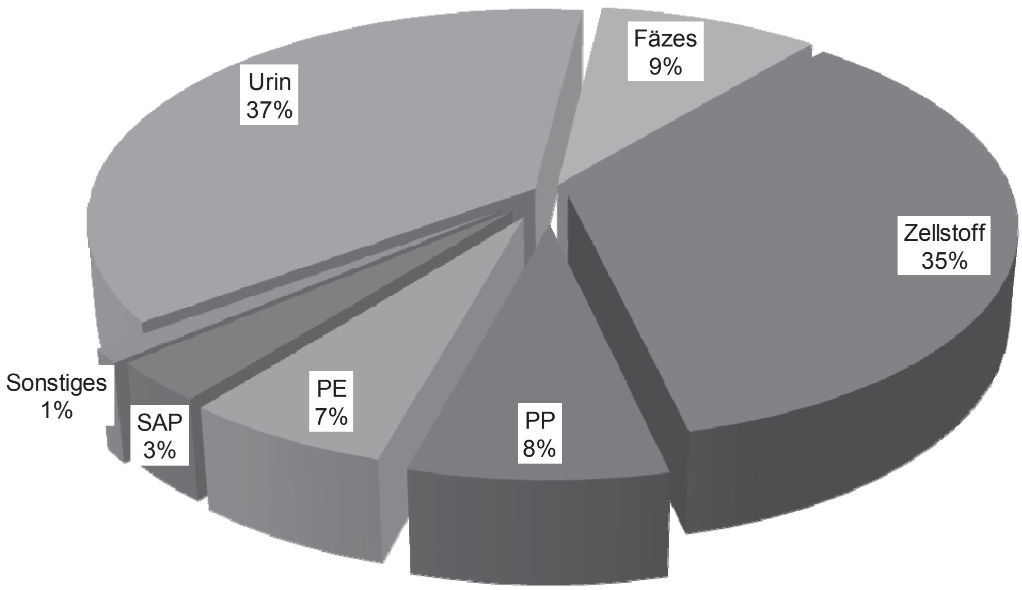

Abbildung 5 prozentuale Zusammensetzung des Inkontinenzabfalls aus einer Pflegeeinrichtung

3.2 Anaerober biologischer Abbau

3.2.1 Adaptionsphase

Der Fermenter wurde zu Versuchsbeginn mit kommunalem mesophilen Faulschlamm befüllt. Die Umstellung von mesophilen (35 °C) auf thermophile (55 °C) Temperaturbedingungen erfolgte durch zwei Temperaturerhöhungsschritte. In der ersten Aufheizphase wurde die Fermenterinnentemperatur innerhalb von drei Tagen auf 42 °C angehoben. Nach einer Haltezeit von 5 Tagen erfolgte die zweite Temperaturerhöhung ebenfalls innerhalb von drei Tagen auf die Endtemperatur von 55 °C. Als Substrat diente während dieser Phasen eine tägliche Zugabe von im Mittel 15 kg Klärschlamm.

Der Umstellungsprozess wurde durch die Messung der organischen Säuren überwacht. Bei einem stabilen Faulprozess befindet sich die Hydrolyse mit der acidogenen, der acetogenen und der methanogenen Phase im Gleichgewicht. Eine Störung des anaeroben Abbaus zeigt sich durch eine Zunahme der Konzentration organischer Säuren. Während der Umstellung auf den thermophilen Betrieb kommt es zu einer Veränderung des Gleichgewichtes, da eine höhere Temperatur die Hydrolysekonstante anhebt, bis sich die Biomasse an die geänderten Bedingungen angepasst hat. Nach 16 Tagen Umstellphase wurde keine Schwankung in dem oben genannten Parameter festgestellt und ein stabiler thermophiler Betrieb hatte sich eingestellt.

Nach Erreichen des stabilen thermophilen Prozesses wurde die Umstellung auf das Substrat Inkontinenzabfall vorgenommen. Die Klärschlammzugabe in den Fermenter wurde eingestellt und als Startwert eine tägliche Zugabemenge von 4 kg Inkontinenzabfall (Frischmasse) gewählt. Die Substratmenge wurde in 2 kg Schritten alle 5 Tage bis auf 8 kg erhöht. Hierbei kam es nicht zu Störungen des anaeroben Abbaus. Im Verlauf des Betriebs der Versuchsanlage wurde die Substratmenge bis auf max. 12 kg/d gesteigert.

3.2.2 Gasproduktion und -qualität

Durch den anaeroben biologischen Abbau der organischen Bestandteile der Inkontinenzprodukte konnten durchschnittlich 663 Liter Biogas pro Kilogramm organischem Trockenrückstand gebildet werden, dies entspricht einer Biogasproduktion von 155 Liter pro Kilogramm Frischmasse. Das Biogas bestand im Mittel aus 56 % Methan und 44 % Kohlendioxid, Schwefelwasserstoff war durchschnittlich mit 250 ppm enthalten. Die erzielten Werte sind vergleichbar mit den in der Literatur angegebenen Werten für Roggenganzpflanzen oder Grassilage (FNR, 2004). Abbildung 6 zeigt den zeitlichen Verlauf der Konzentrationen der Biogasbestandteile.

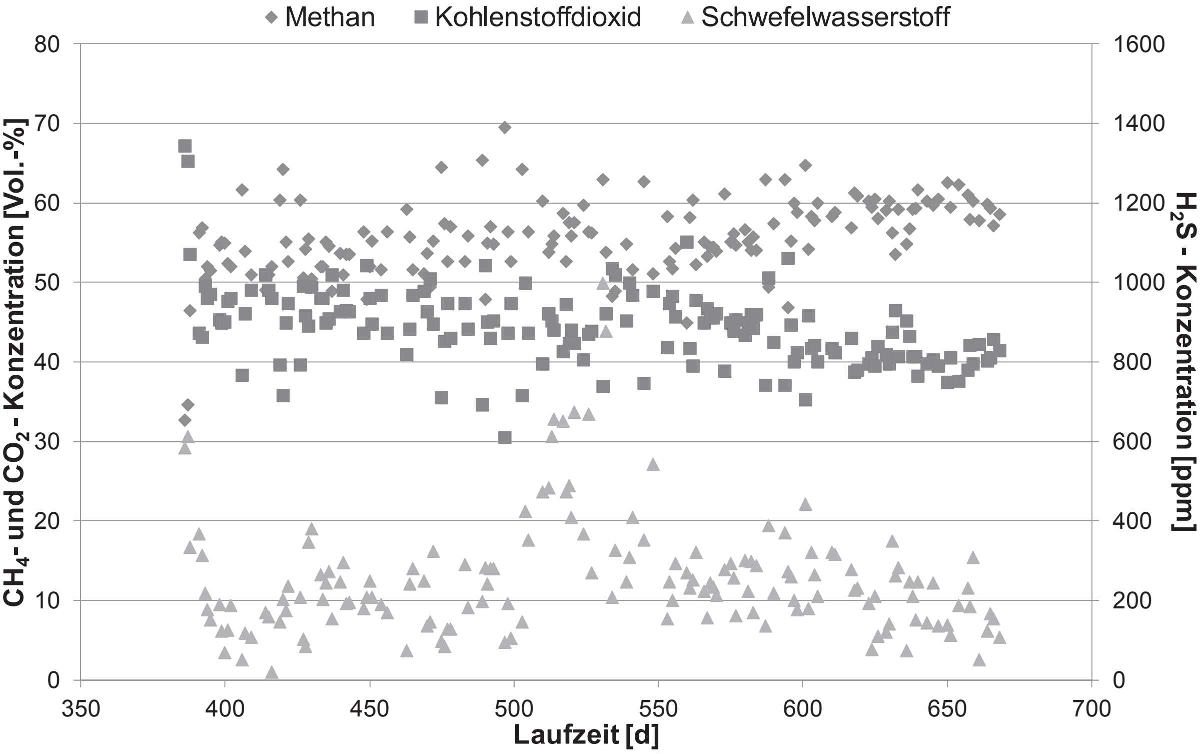

Abbildung 6 zeitlicher Verlauf der Konzentration der Biogasbestandteile

3.3 Zusammensetzung und Verwertbarkeit der Kunststofffraktion

Die aus dem Gärrest stammende Kunststofffraktion beinhaltet alle nicht biologisch abbaubaren Bestandteile der Inkontinenzprodukte, eine geringe Menge Biomasse (ca. 2 %) und weist einen Feuchtegehalt von 58 % auf. In Abbildung 7 ist die prozentuale Zusammensetzung der Kunststofffraktion dargestellt.

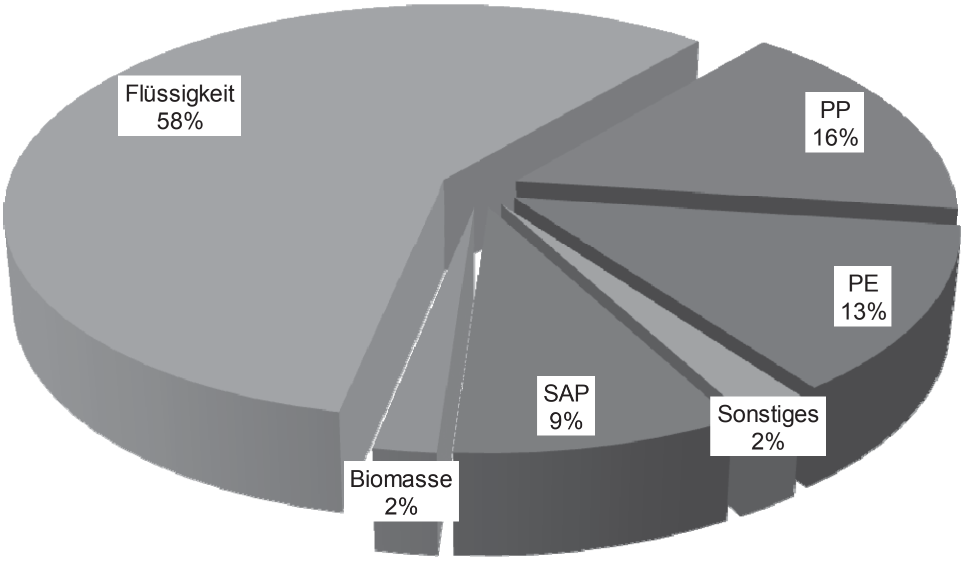

Abbildung 7 prozentuale Zusammensetzung der Kunststofffraktion

Ein möglicher Verwertungsweg für die Kunststofffraktion wäre das werkstoffliche Recycling. Die Kunststoffe könnten somit in neuen Produkten eine weitere Verwendung finden. Die Kunststoffmischung scheint grundsätzlich für ein werkstoffliches Recycling geeignet, da die Komponenten PP und PE miteinander verträglich sind. Das Kunststoffrecycling wird allerdings durch hohe Ansprüche an die Sortenreinheit und das Mengenaufkommen erschwert. Alle bisher angesprochenen Kunststoff recycelnden Firmen wollten die „Kunststofffraktion" trotz des Nachweises der Hygienisierung (siehe Absatz 3.4) aufgrund ihrer Zusammensetzung, aber auch ihrer zu geringen Menge nicht annehmen.

Eine weitere Möglichkeit stellt die thermische Verwertung der Kunststofffraktion dar. Der Heizwert gebrauchter Inkontinenzprodukte liegt bei 7.400 bis 9.000 kJ/kg (MEIER-CIOSTO, 2002). Dieser Wert liegt deutlich unterhalb der gesetzlich festgelegten Grenze von 11.000 kJ/kg, daher kann gemäß §6 Abs. 2 KrW-/AbfG nicht von einer energetischen Verwertung gesprochen werden.

Da dies möglicherweise auf den Gärrest nicht zutrifft wurde die Kunststofffraktion wurde kalorimetrischen Messungen unterzogen. Im Mittel weist sie einen Heizwert von 11.862 ± 578 kJ/kg Originalsubstanz, bei einem Feuchtigkeitsgehalt von 58 % auf. Somit ist es durch die vollzogene Behandlung möglich, die Inkontinenzprodukte statt einer Beseitigung einer Verwertung zuzuführen. Mit der Verringerung des Feuchtigkeitsgehaltes der Kunststofffraktion wird der Heizwert weiter ansteigen.

3.4 Ergebnisse der mikrobiologischen Untersuchungen

Vor der Behandlung wurden mindestens 11.000.000 KBE/g Fäkalstreptokokken nachgewiesen, die Konzentration der E. coli bewegte sich im Bereich 9.300 bis 11.000.000 KBE/g. Der Salmonellenbefund war sowohl im Input als auch im Output negativ. Fäkalstreptokokken und E. coli zeigten im Output eine Reduktion der Koloniebildenden Einheiten (< 5.000 KBE/g für Fäkalstreptokokken, < 3 bzw. 4 bis 460 KBE/g) (INFU, 2015).

4 Schlussfolgerung

Es konnte gezeigt werden, dass durch die Auftrennung des Inkontinenzabfalls in eine biologisch abbaubare und eine nicht abbaubare Fraktion gelingen kann den Entsorgungsweg für Inkontinenzabfälle in Richtung einer Verwertung umzustellen. Die Kunststofffraktion aus den Inkontinenzprodukten kann als Ersatzbrennstoff möglicherweise in thermischen Verfahren eingesetzt werden. Durch die Verringerung des Feuchtigkeitsgehalts steigt deren Heizwert weiter an. Entsprechende Versuche mit unterschiedlichen Trocknungsverfahren sind in Planung.

Durch den anaeroben Abbau der biologischen Bestandteile kann aus dem Inkontinenzabfall ein Biogas verwertbarer Qualität gewonnen werden. Nach Abscheidung des Schwefelwasserstoffs kann in einem BHKW Strom gewonnen werden.

5 Ausblick

Im Verlauf des Projektes werden weitere Standorte des beteiligten Klinikverbundes in die Untersuchungen einbezogen. Ein Ziel ist es, den anfallenden Massenstrom an Inkontinenzabfall theoretisch zu erhöhen. Dies erfolgt zunächst durch Einbeziehung der anderen Klinikstandorte, gegebenenfalls wird das Einzugsgebiet auf weitere Pflegeeinrichtungen in direkter Nachbarschaft zu den Klinikstandorten ausgeweitet. Mithilfe dieser Daten sollte es möglich sein, eine großtechnische Anlage zu planen und deren Effizienz zu bestimmen. Des Weiteren sollen die Auswirkungen der logistischen Aufwendungen (Fahrstrecken, Abholhäufigkeit, etc.) erfasst werden. Der herkömmliche Entsorgungsweg durch Verbrennung wird mit der anaeroben Behandlung kombiniert mit dem Einsatz der Kunststofffraktion als Ersatzbrennstoff, unter Einbeziehung einer Energie- und CO_2-Bilanz verglichen.

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Maßnahmen zur Optimierung der Funktionalität und Energieeffizienz bei der Vergärung von Bio- und Grünabfällen

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Increase of Functionality and Energy Efficiency in Organic Waste Recovery

Abstract

The effective exploitation of biogenic residues can be an important contribution to resource and climate protection. This includes biomass based products that are generated as side products, residues or waste/wastewater in manifold economic sectors along with the primary product. In this context the research project "Increase of energy efficiency in recovering biogenic residues"(FKZ-Nr.: 03KB022) assessed the currently applied technologies for treatment and recovery of biogenic residues with regard to the energy efficiency and identified optimization potentials.

The R&D project was supposed to determine the status quo and the potential for development and optimization in anaerobic digestion processes of solid wastes such as biowaste and green waste as well as residual wastes, focussing on material flow management, concept and technology. Optimization measures that had been developed at single plants already served as essential data source.

The data also served for testing if the different applied process technologies and control measures lead to differences in efficiency in the energy supply for the fermentation process itself, thus offering optimization approaches. This report also shows the development of the last years with the objective to derive potential future tendencies in process technolgy and control.

Inhaltsangabe

Die effektive Nutzung biogener Reststoffe leistet einen wichtigen Beitrag zur Schonung von Ressourcen und zum Klimaschutz. Hierzu gehören auch Biomasseprodukte, die als Nebenprodukt, Reststoff oder Abfall/Abwasser in unterschiedlichen Wirtschaftsbereichen neben dem eigentlichen Produkt entstehen. In diesem Zusammenhang wurden im Rahmen des Forschungsprojektes „Steigerung der Energieeffizienz in der Verwertung biogener Reststoffe“ (FKZ-Nr.: 03KB022) die derzeit eingesetzten Technologien zur Behandlung und Verwertung biogener Reststoffe hinsichtlich deren energetischen Effizienz untersucht und Optimierungspotenziale aufgezeigt.

Im Rahmen des FuE-Vorhabens wurde der Status quo und das Entwicklungs- und Optimierungspotenzial bei der Vergärung fester Abfallstoffe wie Bio- und Grünabfälle sowie Restabfälle ermittelt. Der Fokus lag hierbei in den Segmenten Stoffstrommanagement sowie Konzeption und Technik. Auf einzelnen Anlagen entwickelte und bereits praktizierte Optimierungen dienten hierfür als wesentliche Datenquelle.

Mit Hilfe der Daten wurde weiterhin geprüft, ob die unterschiedlichen angewandten Verfahrenstechnologien und Prozessführungen bei der Fermentation selbst Effizienzunterschiede in der Energiebereitstellung aufweisen und somit Ansätze zur Optimierung bieten. Im vorliegenden Beitrag werden auch Entwicklungen der vergangenen Jahre abgebildet mit dem Ziel, mögliche zukünftige Tendenzen in der Verfahrenstechnologie und Prozessführung abzuleiten.

Keywords

Organischer Abfall, Bioabfall, Grünabfall, Biogene Reststoffe, Abfallverwertung, Vergärung fester Abfallstoffe, Stoffstrommanagement, Energieeffizienz, Verfahrenstechnologie, Prozessführung.

Organic waste, biowaste, green waste, biogenic residues, waste recovery, anaerobic digestion, material flow management, energy efficiency, process technology, process control.

1 Methodik zur Datenerfassung

Für die Biogasproduktion sind, neben den grundsätzlichen Arten der Verfahrens-technik und der Prozessführung, verschiedene überlagernde Parameter einflussgebend. Insbesondere die spezifische Qualität des Fermenter-Inputs ist hierbei maßgeblich, wie regional unterschiedliche Materialqualitäten, Anteil an Küchenabfällen etc.. Eine ausreichend befriedigende Datengrundlage insbesondere zu den materialspezifischen Einflüssen konnten durch die vorliegende Erhebung nicht bereitgestellt werden.

Die Bestimmung der Biogasmenge wird auf den Anlagen nicht einheitlich vorgenommen. Sie erfolgte zum Teil direkt durch Messung des Gasstroms und zum Teil indirekt durch Rückrechnung der erzeugten Strommenge. Bei letzterer Methodik ist mit nicht unerheblichen Fehlangaben zu rechnen, beeinflusst z.B. durch die Verfüg-barkeit der BHKW. Außergewöhnlich geringe Biogasausbeuten, die von den Befragten eindeutig auf verfahrensunabhängige betriebliche Probleme zurückzuführen waren, sind nicht in die Bewertung eingeflossen.

Die Datenermittlung zu den Energieverbräuchen hat sich als sehr problematisch erwiesen, da keine der betrachteten Vergärungsanlagen über Daten zu spezifischen Energieverbräuchen differenziert nach Prozessabschnitten verfügt. Häufig lagen sogar nur Daten zu Energieverbräuchen zu den Gesamtanlagen – Kompostierung und Vergärung – vor, eine Identifikation von Energieeinsparpotenzialen einzelner Verfahrenssegmente war somit nicht gegeben.

Belastbare Daten zum Wärmebedarf aus der Befragung lagen nur von wenigen Anlagen vor. Zur Abschätzung des Wärmebedarfs wurden Sekundärdaten verwendet. Sie stammen aus gutachterlichen Tätigkeiten im Rahmen von Anlagensanierungsmaßnahmen, aus Angaben von Anlagenlieferanten und aus Ausschreibungen/Angeboten. Zur Überprüfung der Plausibilität sind indirekt-Parameter verwendet worden mit deren Hilfe der Wärmebedarf abgeschätzt werden konnte. Die aufgeführten Daten basieren somit nur in geringem Umfang auf Angaben von Betreibern.

2 Maßnahmen zur Optimierung der Funktionalität und Energieeffizienz bei der Vergärung von Bio- und Grünabfällen

Die relevanten Maßnahmen umfassen die Segmente:

- Stoffstrommanagement
- Technik und Betrieb
- Gasverwertung
- Schwachstellenanalyse

2.1 Stoffstrommanagement

Bio- und Grünabfälle unterliegen sowohl quantitativen als auch qualitativen saisonalen Veränderungen.

Bei Bioabfällen ist insbesondere im Sommer und Herbst mit Anlieferungsspitzen zu rechnen, die einer Auslegung auf gleichbleibende Auslastung entgegenläuft. Aus küchenabfallreichen Bioabfällen kann deutlich mehr Gas generiert werden als aus Gartenabfällen. So konnten auf einigen Anlagen in der gartenabfallfreien Zeit - hauptsächlich Januar bis März - Gasausbeuten um den Faktor bis zu 2 über den Werten der Sommer-und Herbstmonate erzielt werden. Der Jahresgang bei den auf Vergärungsanlagen angelieferten Bioabfallmengen läuft dem qualitätsbedingten Jahresgang in der spez. Biogasproduktion ausgleichend entgegen. Eine gleichbleibende Auslastung der Fermenterkapazität orientiert an der Raumbelastung über das Jahr wird nicht erreicht (siehe Abbildung 1).

Neben der suboptimalen Fermenterauslastung können Minderleistungen in der Gasproduktion auch zu einer abnehmenden Auslastung der verwendeten BHKW mit der Folge eines sinkenden elektrischen Wirkungsgrades führen (siehe auch Kapitel 2.3). Ebenso wird der biologische Prozess durch Mengen- und Qualitätsschwankungen im Fermenterinput beeinträchtigt, was zu einer verminderten Gasproduktion und Prozess-stabilität führt.

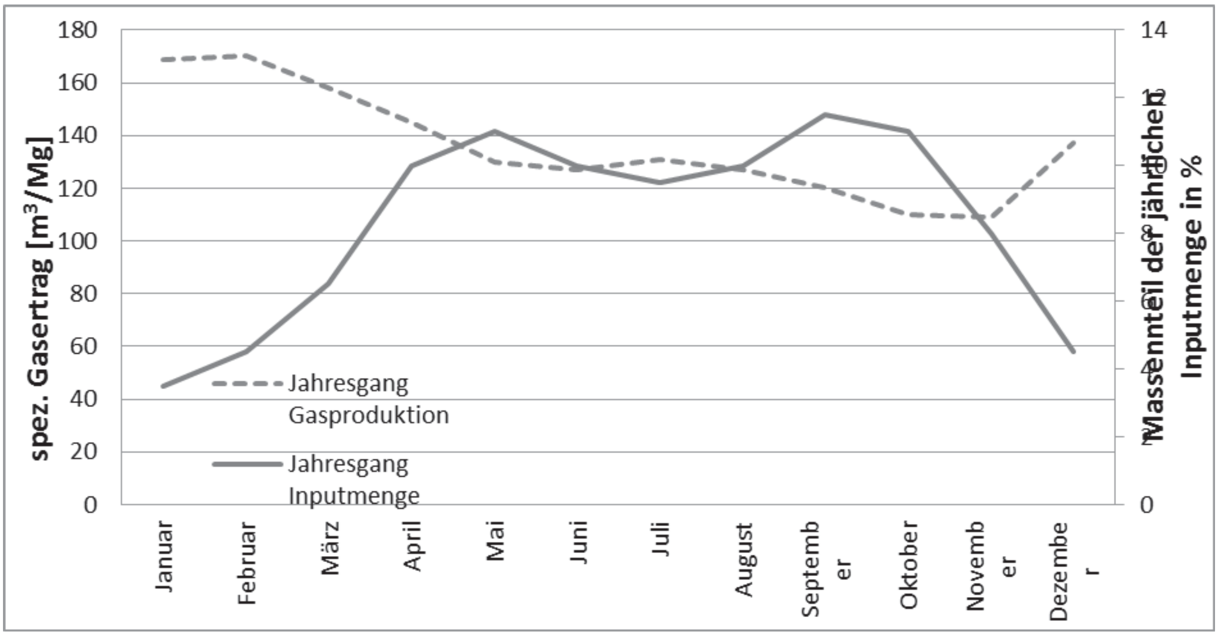

Abbildung 1: Exemplarische Darstellung der erfassten Bioabfallmengen und der korrespondierenden spezifischen Gaserträge im Jahresgang in Deutschland (eigene Daten und schriftliche Mitteilung Schulte, 2012)

Sehr ausgeprägt ist auch der Jahresgang beim Mengenanfall und bei der stofflichen Zusammensetzung der Grünabfälle. Falls auch geeignete Grünabfälle der Vergärung zugeführt werden, verstärken sich die oben aufgezeigten Probleme in der Fermenterauslastung und der Gasproduktion. Spätes Frühjahr und Sommer bilden den Zeitraum für den Anfall vergärbarer Grünabfälle, wie z.B. Grasschnitt, mit vergleichsweise hohem Gasbildungspotenzial. Der Herbst liefert große Mengen an Laub mit geringem Gasbildungspotenzial. Im Winter fallen kaum relevante Mengen vergärbarer Grünabfälle an.

Für eine effiziente Vergärung der Bio- und Grünabfälle ist eine Vergleichmäßigung über den Jahresverlauf notwendig. Insbesondere für die Wintermonate gilt es, Lösungen für eine verbesserte Auslastung der Anlage zu finden. Die Teilstromvergärung kann das Problem der suboptimalen Auslastung zwar lösen, allerdings nur bei Verzicht auf die Vergärung nicht unerheblicher Massenströme. Zwei Ansätze zur Lösung sind zu diskutieren, die temporäre Verwendung vergärbarer Abfallstoffe oder deren sachgerechte Zwischenlagerung über den Zeitraum mehrerer Monate.

Der temporäre Bezug geeigneter gewerblicher Abfälle gestaltet sich als sehr beschränkt realisierbar, da diese Abfälle in der Regel über das Jahr anfallen. Somit werden seitens der Produzenten Gesamtlösungen für die Verwertung bzw. Entsorgung angestrebt. Die stabile bzw. „konservierte“ Zwischenspeicherung dieser Abfälle könnte deren Verfügbarkeit zum Ausgleich von Mengen und Qualitätsschwankungen deutlich verbessern.

Die Lagerung über einen entsprechend langen Zeitraum darf jedoch zu keiner qualitativen Verschlechterung führen. Hier bietet sich als Verfahren die Silierung geeigneter Abfälle an. Bei richtiger Konservierung und Lagerung können Energieverluste vermieden und giftige Stoffwechselvorgänge, wie sie bei unsachgemäßer Zwischenlagerung entstehen, weitgehend unterbunden werden. Aus der Landwirtschaft sind verschiedene Lagerungs- und Konservierungsarten bekannt wie z.B. die biologische Silierung und die chemische Konservierung. Die Silierung ist ein Konservierungsverfahren, das durch Luftabschluss und natürlicher Ansäuerung konserviert. Bei chemischer Konservierung werden Säuren dem Lagergut zugemischt. Die Konservierung industrieller Reststoffe wie z.B. Biertreber, mit Hilfe von Konservierungssäuren entspricht dem aktuellen Stand der Technik. Unbehandelter Biertreber ist mit 2,5 Tagen nur sehr kurz lagerfähig und unterliegt danach erheblichen Energieverlusten. Unterschiedliche Säuremischungen erhöhen die Lagerungsfähigkeit und mindern die Bildung von inhibierend wirkenden Stoffwechselprodukten (siehe Abbildung 2).

Andere Reststoffe können durch Anpassen der Säuremischung und Dosierung stabilisiert werden, hierzu sind aber weitergehende Untersuchungen notwendig. Gewerbliche organische Abfallströme sind angesichts der relativ homogenen Eigenschaften eher für eine Konservierung und Lagerung geeignet als die deutlich inhomogeneren Bio- und Grünabfälle. Seit mehreren Jahren wird die Silierung der Feinfraktion von aufbereiteten Grünabfällen im ZAW Donau-Wald erfolgreich praktiziert. Hier wird eine kontinuierliche Trockenvergärungsanlage mit einem hohen Anteil an aufbereiteten Grünabfällen betrieben (Buchheit, 2012). Informationen über die Silierung von Bioabfällen liegen nicht vor.

Den zusätzlichen Kosten für die Lagerung und Konservierung stehen mögliche Gutschriften gegenüber, die aus einer verbesserten ganzjährigen Kapazitätsauslastung und einer höheren Energieausbeute resultieren.

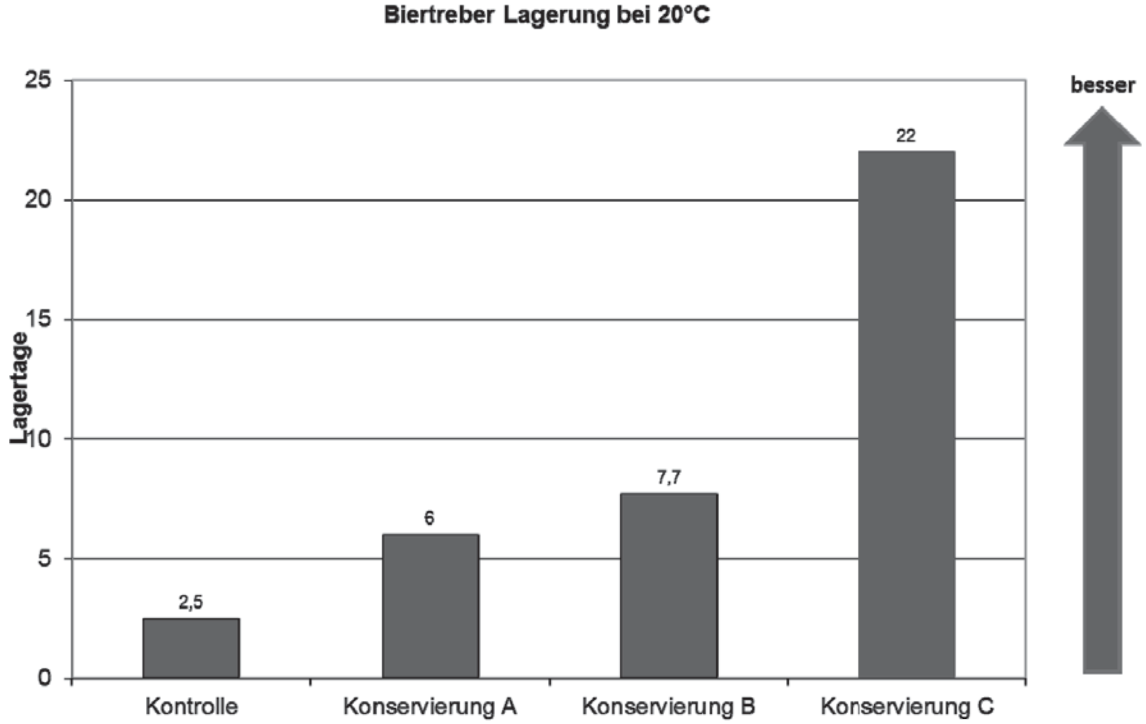

Abbildung 2: Steigerung der verderbfreien Lagerung durch Einsatz unterschiedlicher Konservierungsprodukte (SCHAUMANN BioEnergy)

2.2 Technik und Betrieb

2.2.1 Konfektionierung vor der Vergärung

Ziel der Aufbereitung der Bio- und Grünabfälle ist die Konfektionierung der Materialien für den anaeroben Abbau sowie die Abtrennung von prozess- und produktbeeinträchtigenden Komponenten. In den Anfängen der Vergärung von Feststoffen wie Bio- und Grünabfälle wurde eine weitgehende Zerkleinerung der Abfälle von bis auf < 40 mm vorgenommen, da hierdurch eine Verbesserung der Verfügbarkeit der organischen Materialien für die Mikroorganismen und dadurch ein schnellerer und effektiverer Abbau der Substrate erwartet wurde. Diese Art der Aufbereitung wurde in den vergangenen Jahren in der Form modifiziert, dass die Zerkleinerung nur noch auf ein für das eingesetzte Vergärungsverfahren erforderliches Maß mit Korngrößen < 60 bis 80 mm erfolgt. Ein Umbau bestehender Anlagen wurde in dieser Form bereits mehrfach vorgenommen, ohne dass von Anlagenbetreibern Einbußen in der Biogasproduktion festgestellt wurden.

Eine Vorbehandlung der Bio- und Grünabfälle wird bei den diskontinuierlichen Trockenvergärungsverfahren in der Regel nicht vorgenommen. Hiermit werden Investitions- und

Betriebskosten für die erforderlichen Aggregate eingespart. Eine zu weitgehende Zerkleinerung des Materials kann darüber hinaus dazu führen, dass die Perkolierbarkeit des Haufwerks herabgesetzt wird und dadurch die Gasproduktion verringert werden kann. Das Vermischen der Bio- und Grünabfälle mit dem Gärrest und das Beschicken der Fermenter erfolgt bei den diskontinuierlichen Trockenvergärungsverfahren vorwiegend per Radlader. Das Substrat ist folglich als vergleichsweise inhomogen zu klassifizieren und kann dadurch die Effizienz des Perkolationsprozesses einschränken. Auf einer diskontinuierlichen Trockenvergärungsanlage wurden im Rahmen von Optimierungsmaßnahmen zur Homogenisierung durchgeführt. Es kam ein konventioneller selbstfahrender Mietenumsetzer zum Einsatz. Schon die Homogenisierungswirkung eines „Umsetzvorganges“ führte zu einer deutlich höheren Biogasproduktion von 10 bis 15 %. Gleiche Homogenisierungswirkungen sind durch vorgeschaltete grobe Siebschnitte (Siebschnitt 100 bis 120 mm) zu erwarten. Trommelsiebe bewirken hierbei gegenüber Plansieben eine bessere Homogenisierungsleistung und üben zusätzlich Scherkräfte auf das Material aus.

Falls geeignete Grünabfälle der Vergärung zugeführt werden sollen, ist eine gezielte getrennte Erfassung, Anlieferung und Lagerung von Grünabfällen in vergärbare und kompostierbare bzw. energetisch verwertbare Chargen aufzubauen. Bei gemischt angelieferten Grünabfällen gemeinsam mit Baum- und Strauchschnitt ist eine separate Vorbehandlung vor der Vergärung erforderlich. Hier sind eine Zerkleinerung und Siebung sinnvoll, wobei sich das zur Kompostierung oder energetischen Verwertung geeignete Material im Überkorn um > 80 mm anreichert. Im Unterkorn reichert sich die für die Vergärung geeignete Fraktion an.

2.2.2 Beschickung der Fermenter

Eine Effizienzsteigerung bei der Vergärung kann durch eine gleichbleibende Beschickung der Vergärungseinheit erreicht werden. Neben einer kontinuierlichen Biogasproduktion wird hierdurch auch eine gleichbleibende Biogasqualität erreicht (siehe auch Kapitel 2.1). Die Beschickung der Vergärungseinheit nur tagsüber und an den Werktagen führt aufgrund der stoßweisen Beschickung zu Schwankungen in der Gaserzeugung. Insbesondere in den Nachtstunden und an den Wochenenden zeigt sich ein deutliches Abfallen der Gasproduktion. Darüber hinaus verändert sich die Biogasqualität gerade kurz nach dem Start der Beschickung (Abfall des Methangehaltes) und nach längerem Aussetzen der Beschickung (Anstieg des Methangehaltes). Abbildung 3 zeigt exemplarisch die Biogasproduktion einer nur an Werktagen und während des Tagesbetriebes beschickten Biogasanlage im Wochenverlauf.

Von verschiedenen Verfahrensanbietern und Anlagenbetreibern wird eine Zwischenspeicherung vor der Vergärung praktiziert um eine kontinuierlichen Beschickung sicherzustellen. Die Zwischenspeicherung ist in einigen Ausführungen kontinuierlicher Trockenverfahren mit einer aeroben Vorbehandlung über den Zeitraum von zwei bis drei Tagen kombiniert.

Der Wochengang bei der Biogasproduktion kann durch eine ausreichende Vorhaltung des Gasspeichervolumens kompensiert werden, sodass eine gleichmäßige Beschickung der BHKW gegeben ist.

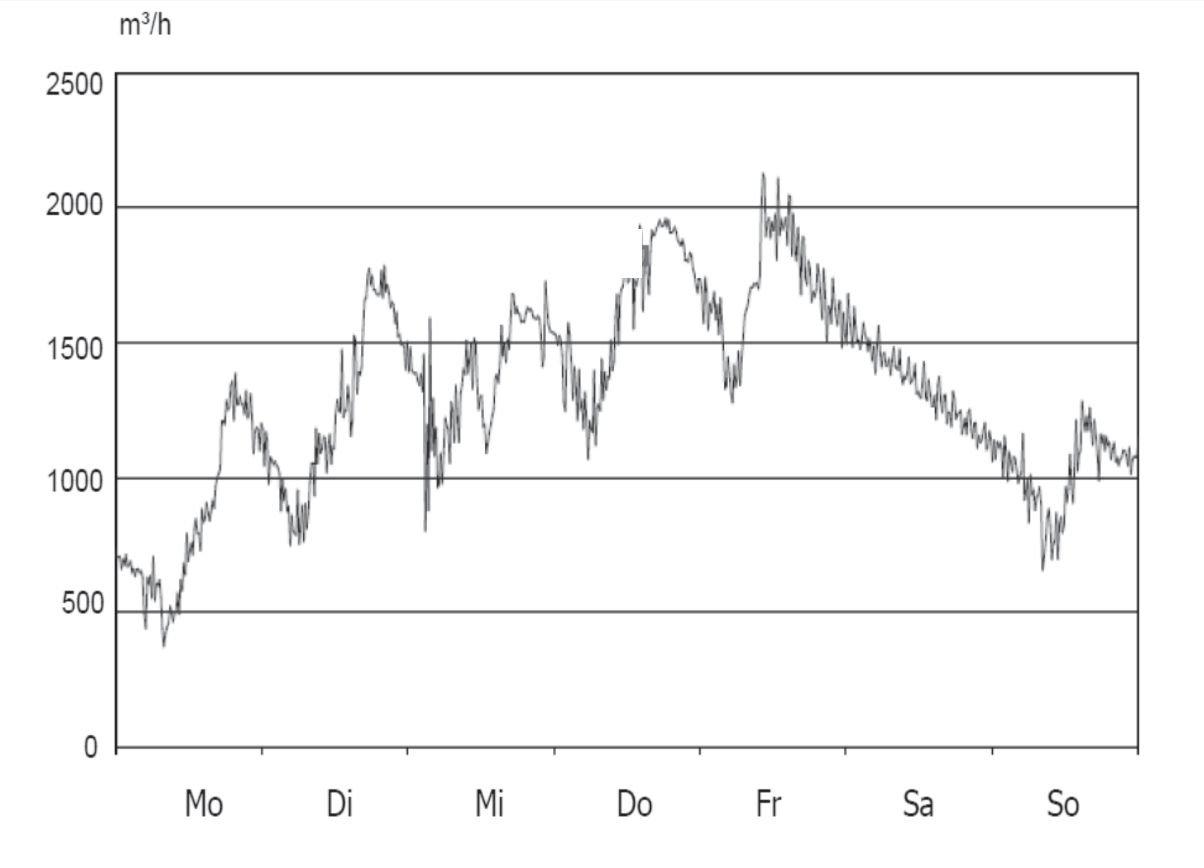

Abbildung 3: Typischer Wochenverlauf der Biogasproduktion einer quasi-kontinuierlich betriebenen Trockenvergärungsanlage (Frischen und Vielhaber, 2009)

2.2.3 Prozesstemperatur

Die thermophile Betriebsweise führt – bei den praktizierten Retensionszeiten - bei allen Verfahrens- und Prozessarten zu deutlich höheren Biogas- und entsprechend höheren Methanerträgen (siehe Teil 2 der Veröffentlichung). Diskontinuierliche trockene und auch nasse Verfahren werden zum überwiegenden Teil mesophil und kontinuierliche trockene Verfahren zum überwiegenden Teil thermophil betrieben. Erstgenannte bieten vor diesem Hintergrund ein entsprechendes Optimierungspotenzial. Tendenziell ist am Markt eine Zunahme thermophiler Prozessführungen zu beobachten. So ist es an mehreren Standorten bei den trockenen diskontinuierlichen Verfahren vorgesehen, auf thermophile Prozessführung umzustellen. Nach Rücksprachen mit entsprechenden Anlagenlieferanten ist auch bei den in Bau befindlichen Anlagen mehrheitlich ein thermophiler Prozess vorgesehen. Neben der Hygienisierung werden dadurch auch größere Gasausbeuten erwartet.

2.2.4 Entwässerung

Bei den Verfahren zur Bio- und Grünabfallvergärung fallen, im Gegensatz zu reinen Aerobverfahren, relevante Prozess- bzw. Abwassermengen an. Die Verwertung des Gärrestes bei der Bio- und Grünabfallvergärung besteht aus der direkten Ausbringung auf landwirtschaftliche Flächen und/oder der aeroben Nachbehandlung zur Erzeugung von Kompost. Falls eine aerobe Nachbehandlung vorgesehen ist, ist der Gärrest zu entwässern. Dieser energieaufwendige Verfahrensschritt ist bei allen kontinuierlichen Verfahren vorzusehen. Bei diskontinuierlichen trockenen Verfahren wird in der Regel auf die Entwässerung vor der Nachrotte verzichtet. Für die aerobe Nachbehandlung sind die Gärreste aus der Bio- und Grünabfallvergärung auf Wassergehalte um 60% zu entwässern, bei Zugabe von Strukturmaterialien können auch geringfügig höhere Wassergehalte akzeptiert werden. Abwassermengen von kontinuierlichen Bioabfallvergärungsanlagen liegen zwischen 200 und 500 l/Mg Input. Bei der diskontinuierlichen Trockenfermentation fällt Überschusswasser aus der Perkolation in einer Größenordnung von 20 bis 60 l/Mg des Materialinputs an (siehe Abbildung 4).

Exemplarisch wurde der Strombedarf der Entwässerung einer nassen und trockenen kontinuierlichen Vergärungsanlage mit einer Kapazität von 30.000 Mg/a kalkuliert. Der Energiebedarf nasser Verfahren liegt nach dieser Kalkulation zwischen 6 und 9 kWh/Mg. Kontinuierliche trockene Verfahren liegen in der gleichen Größenordnung, sofern eine Kombination aus Dekanter und Siebschneckenpresse aufgrund von Qualitätsanforderungen an das Ab- bzw. Überschusswasser erforderlich ist. Falls die Entwässerung einstufig ausschließlich mit Siebschneckenpressen erfolgt, wie dies zunehmend der Fall ist, liegt der Strombedarf bei 4 bis 7 kWh/Mg. (siehe Tabelle 1). Die Entwässerung der Gärreste mit der dazugehörigen Peripherie stellt mit ca. 30% des Gesamtstromverbrauches einen bedeutenden stromzehrenden Prozessbereich dar.

Ein Anlagenbetreiber setzte die Überschusswärme gezielt zur Verdunstung von überschüssigem Prozesswassers ein. Auf Grundlage der positiven Ergebnisse konnte auf dieser Anlage die Entwässerung weniger intensiv gefahren werden, mit der Folge geringerer Prozesswassermengen mit niedrigeren TS-Gehalten im zu verwertenden oder zu entsorgenden Prozesswasser. Positive Auswirkungen ergaben sich auch beim Verschleiß der Entwässerungsaggregate und beim Energieaufwand. Dieser Lösungsansatz resultierte aus Entsorgungsproblemen für überschüssiges Prozesswasser in dem Zeitraum, in dem die Ausbringung untersagt ist. Betriebswirtschaftliche Berechnungen ergaben einen deutlichen Kostenvorteil für diese Lösung.

Optimierungspotenzial im Bereich Entwässerung liegt u.a. in der

- Verringerung der notwendigen Entwässerungsintensität durch Nutzung von Überschusswärme zur Trocknung während der Rotte
- Intensivere Nutzung von Strukturmaterialien, sofern diese nicht anders nachhaltig verwertbar sind
- Hygienisierung der Gärreste ohne Aerobstufe und der direkten landwirtschaftlichen Applikation der Gärreste.

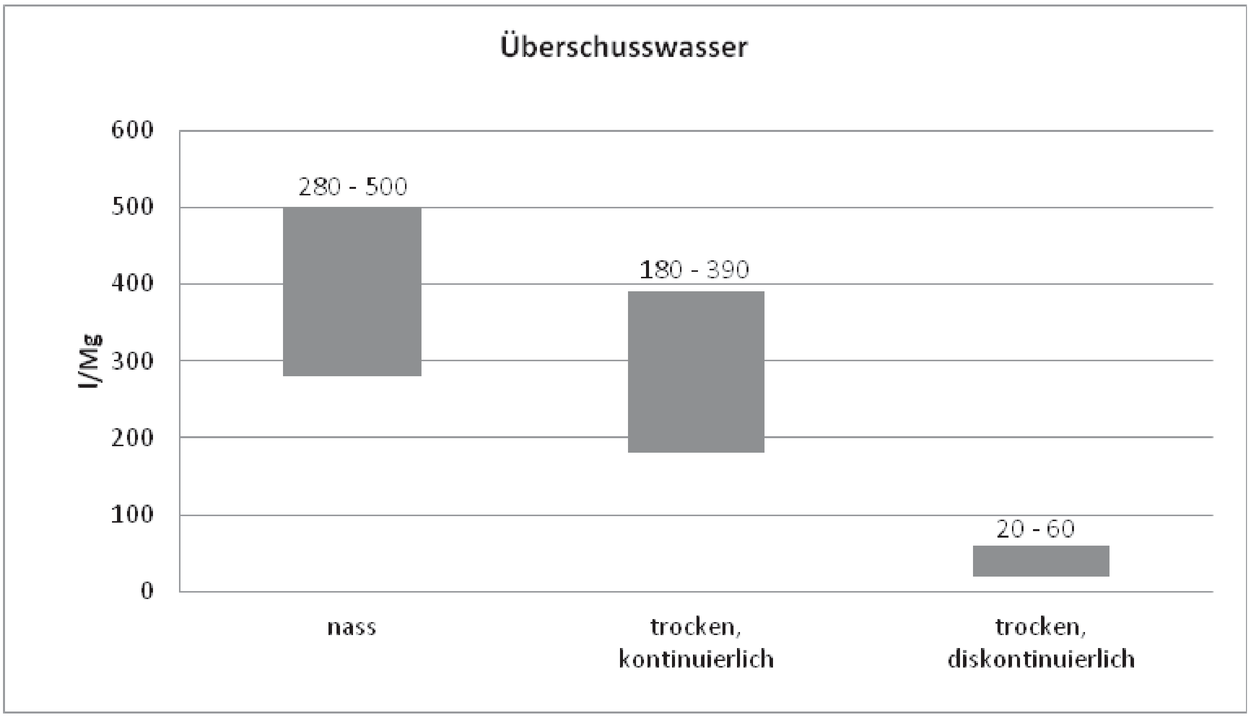

Abbildung 4: Überschusswasser bei der Vergärung von Bio- und Grünabfällen, differenziert nach Verfahrens- und Prozessarten

Tabelle 1: Vergleichende Abschätzung des Strombedarfs einer Entwässerungsstufe bei einer nassen und kontinuierlichen trockenen Vergärungsanlage mit einer Kapazität von 30.000 Mg/a

	Trockenverfahren	**Nassverfahren**
Anlagendurchsatz	30.000 Mg/a	
Gärrestmenge[1)]	34.500 Mg/a	84.100 Mg/a
Entwässerung[2)]		
-Prozesswasser	23.100 Mg/a	69.600 Mg/a
-Feststoff	11.400 Mg/a	14.500 Mg/a
Betriebszeiten		
-Siebschneckenpresse[3)]	3.300 Bh/a	-
-Dekanter4)	2.300 Bh/a	3.400 Bh/a
Strombedarf		
-Siebschneckenpresse	2 – 5 kWh/Mg	-
-Dekanter	2 – 4 kWh/Mg	4 – 7 kWh/Mg
-Peripherie[5)]	2 kWh/Mg	

1) unter Berücksichtigung von Anmaischwasser zur Einstellung des TS-Gehaltes im Reaktorzulauf

2) Verteilung, abhängig vom angestrebten TS-Gehalt im Feststoff (Annahme: Trockenverfahren 40%, Nassverfahren 35%)

3) unter Annahme einer durchschnittlichen Durchsatzleistung von 8 Mg/h

4) bei Vollstrombehandlung, Nassverfahren durchschnittliche Durchsatzleistung von ca. 25 m³/h

5) nur Zu- und abführpumpen und Behälterrührwerke

2.2.5 Elektromotoren

Bei den Elektromotoren, die in einer Vielzahl auf Vergärungsanlagen im Einsatz sind, hat es in der Vergangenheit eine Entwicklung zu einer höheren Effizienz gegeben, u.a. angetrieben durch Forderungen aus der EU. Die Verordnung (EG) Nr. 640/2009 zur Festlegung von Anforderungen an die umweltgerechte Gestaltung von Elektromotoren legt eine Mindesteffizienz für Elektromotoren fest. Die Effizienz kann bei einem Austausch oder Ersatz eines älteren Motors durch einen Elektromotor der Klasse

IE1 um etwa 6,4%

IE2 um etwa 7,3%

IE3 um etwa 8,6%.

verbessert werden (EnergieAgentur NRW, 2010; Volz, 2012). Neuanlagen müssen mit Elektromotoren mit diesen Effizienzklassen ausgestattet werden, bei Altanlagen ist der Austausch von Elektromotoren im Rahmen der Ersatzbeschaffung realisierbar. Weiterhin kann nach Volz (2012) bei einer regelmäßigen Wartung der Motoren durch eine Verringerung der mechanischen Verluste eine Stromeinsparung zwischen 3 und 10% erreicht werden.

2.2.6 Datenverfügbarkeit Energiebedarf

Auf keiner der betrachteten Anlagen sind detaillierte Daten zu Energieverbräuchen einzelner Teilbereiche oder Aggregate verfügbar. Eine Identifikation von Energieeinsparpotenzialen einzelner Verfahrenssegmente war somit nicht gegeben. Diese Information gilt jedoch als entscheidende Voraussetzung für Maßnahmen zur Steigerung der Energieeffizienz.

Als eine geeignete, vergleichsweise aufwandsarme, zerstörungsfreie Methode zur Generierung dieser Daten hat sich der sogenannte Zangenamperemeter bzw. die Rogowski-Klemme herauskristallisiert. Die analogen Signale werden mit Hilfe eines Analog/Digital-Wandlers digitalisiert. Gleichzeitig werden die einzelnen Datensätze des jeweiligen Aggregats codiert, sodass eine Rückverfolgung möglich ist. Diese Datenpakete werden über ein LAN/BUS-Netzwerk zu einem Knotenpunkt gesendet. Die Knotenpunkte fassen wichtige Baugruppen bzw. Anlagenteile zusammen. Sinnvoll ist es hierbei, benachbarte Aggregate zu Clustern zusammenzufassen und nur kurze Wegstrecken zu überbrücken. Meist gibt es auf den Anlagen für Teilbereiche, wie die Anlieferung, die Aufbereitung sowie die Konfektionierung, separate Schaltschränke. In diesen können die Leistungen der Aggregate sehr komfortabel abgegriffen werden. Aufgrund der Weitläufigkeit der Anlagen können die einzelnen Cluster bzw. Schaltschränke untereinander nur schwer mit Kabel also via LAN/BUS-System, verbunden werden. Stattdessen können sie mit einem W-LAN-System mit der Leitwarte verbunden werden. Hier laufen alle Informationen zusammen. Mit diesem modularen Verfahren lassen sich nicht nur Leistungen der Aggregate mitloggen, sie lassen sich auch mit weiteren verfahrens- und prozesstechnischen Steuerungsparametern korrelieren. Ein erhebliches Optimierungspotenzial wird z.B. bei Ventilatoren, Förderbändern und Aufbereitungsaggregaten identifiziert, die häufig im Leerlauf betrieben werden. Die WAGO Kontakttechnik GmbH & Co. KG, Minden hat sich bereit erklärt, ein entsprechendes Messsystem für den Anwendungsfall zu entwickeln und bereitzustellen. Mehrere Anlagenbetreiber und Anlagenlieferanten haben sich bereit erklärt, entsprechende Messkampagnen auf ihren Anlagenstandorten durchzuführen.

2.3 Gasverwertung

Auf 60 der 63 Anlagen sind BHKW im Einsatz, mindestens drei dieser Anlagen speisen zusätzlich Gas in ein Mikrogasnetz ein und versorgen damit BHKW in nahegelegenen Ortschaften mit vorhandenem Wärmenetz bzw. Wärmeabnehmer (siehe Tabelle 2). Die erzielten Wirkungsgrade$_{elektr}$ liegen im Bereich von 32 bis 42%, bei einem Mittel von 38%, die Wirkungsgrade$_{therm}$ liegen im Mittel bei 46%. Zwei Anlagen speisen ihr aufbereitetes Gas ins Erdgasnetz ein. Auf einer Anlage wird versuchsweise eine Brennstoffzelle mit Gas versorgt. 59 Anlagenbetreiber nutzen einen Teil der Wärme zur systemimmanenten Fermenter- und Substratheizung, um die mesophilen bzw. thermophilen Prozesstemperaturen einzustellen. Mindestens 17 Anlagenbetreiber trocknen ihre Gärreste bzw. nutzen die Wärme zur Prozesslufterwärmung für die Rottesteuerung (siehe auch Kapitel 2.2.4).

Die Effizienz der BHKW wurde in den vergangenen Jahren hinsichtlich des elektrischen Wirkungsgrades stetig verbessert (Schnattmann, 2011). Vornehmlich bei Aggregaten mit einer elektrischen Leistung von mehr als 500 kW liegt der elektrische Wirkungsgrad heute in der Regel über 40% (siehe Abbildung 5). Jedoch scheint sich die Entwicklung nicht in dieser Rasanz fortzusetzen. Dies erklärt auch, dass verschiedene BHKW-Lieferanten zu einer Steigerung der Anlageneffizienz an die BHKW-Module angepasste ORC-Module (Organic Rankine Cycle) für eine weitere Abwärmenutzung anbieten. Auch bei den verwendeten BHKW-Leistungsgrößen um 500 kWh sind Wirkungsgrade von 42% erzielbar. Optimierungen sind im Rahmen von Ersatzbeschaffungen realisierbar. Dabei ist jedoch zu beachten, dass thermische Wirkungsgrade moderner Aggregate sich zugunsten des elektrischen Wirkungsgrades reduziert haben, so dass insbesondere bei einem bestehenden Wärmekonzept hier die Auswirkungen kritisch geprüft werden müssen. Die korrespondierenden Wirkungsgrad$_{therm}$ liegen bei ca. 44%. Die Effizienzsteigerung der BHKW-Module hat höhere Anforderungen an die Biogasqualität zur Konsequenz. Insbesondere die Abtrennung von Schwefelverbindungen hat an Bedeutung gewonnen.

Neben der Wirkungsgradsteigerung der BHKW ist ebenso eine an die Aufgabenstellung angepasste Auslegung anzustreben. Die von den BHKW-Lieferanten angegebenen Wirkungsgrade wurden unter Prüfstandbedingungen ermittelt, so dass sie im praktischen Einsatz meist geringer sind. Weiterhin ist zu beachten, dass die Wirkungsgrade im Teillastbetrieb geringer als im Volllastbetrieb sind. Der Betrieb eines BHKW im Teillastbetrieb kann eine Reduzierung des elektrischen Wirkungsgrades von 2 bis zu 4%-Punkten nach sich ziehen (siehe Abbildung 6). Demgegenüber erhöht sich der thermische Wirkungsgrad der Module im Teillastbetrieb in einer ähnlichen Größenordnung, so dass der Gesamtwirkungsgrad nahezu konstant bleibt.

Tabelle 2. Art der Biogasverwertung und Wärmenutzung

Gasnutzung	**Anzahl Anlagen**
BHKW (elektr. Wirkungsgrade im Durchschnitt 38% (32 bis 42%)	61
BHKW plus Mikrogasleitung	3
Einspeisung Erdgasnetz	2
Brennstoffzelle	1
Wärmenutzung	**Anzahl Anlagen**
Fermenter- und Substratheizung	59
Trocknung Gärreste, Prozesslufterwärmung zur Rottesteuerung	17
Heizung Betriebsgebäude	10
Einspeisung Nahwärmenetz	4
Trocknung externer Produkte (Klärschlamm, Holz, Mais)	3
Heizung Gewächshäuser	1
Heizung Waschwasser für Reinigung Umleerbehälter	1

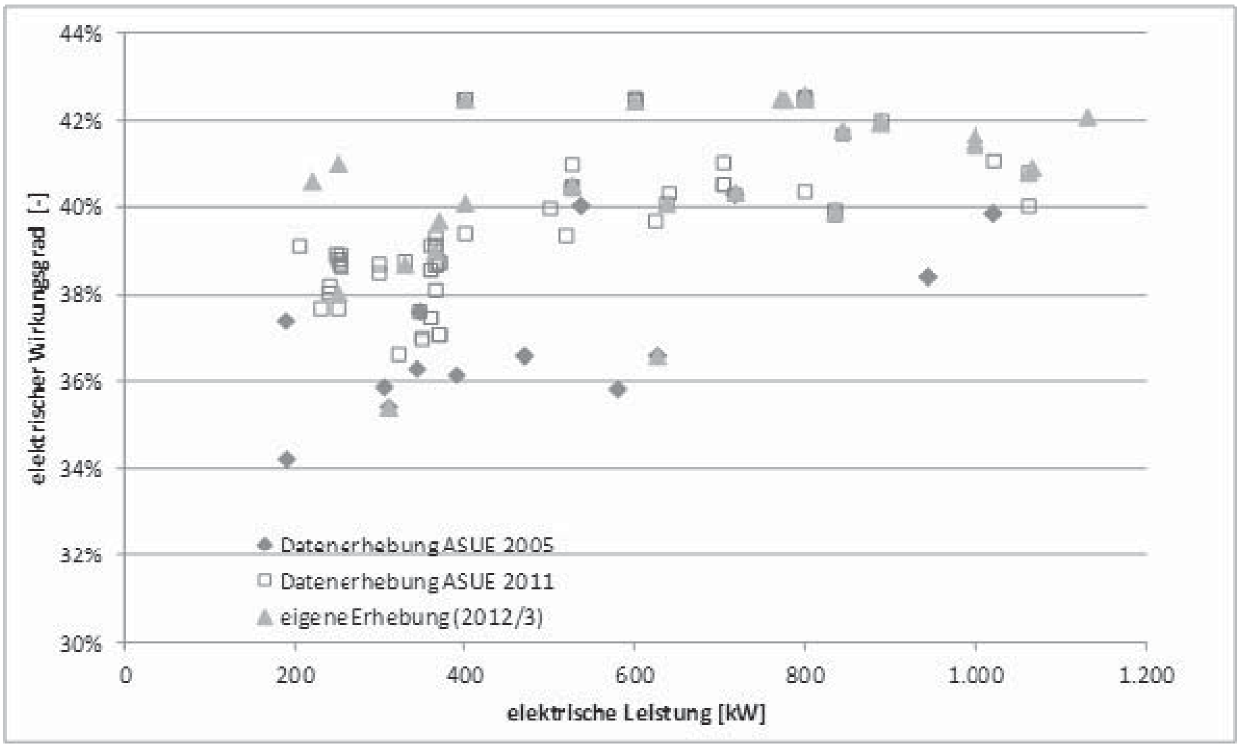

Abbildung 5: Entwicklung der elektrischen Wirkungsgrade verschiedener BHKW-Module

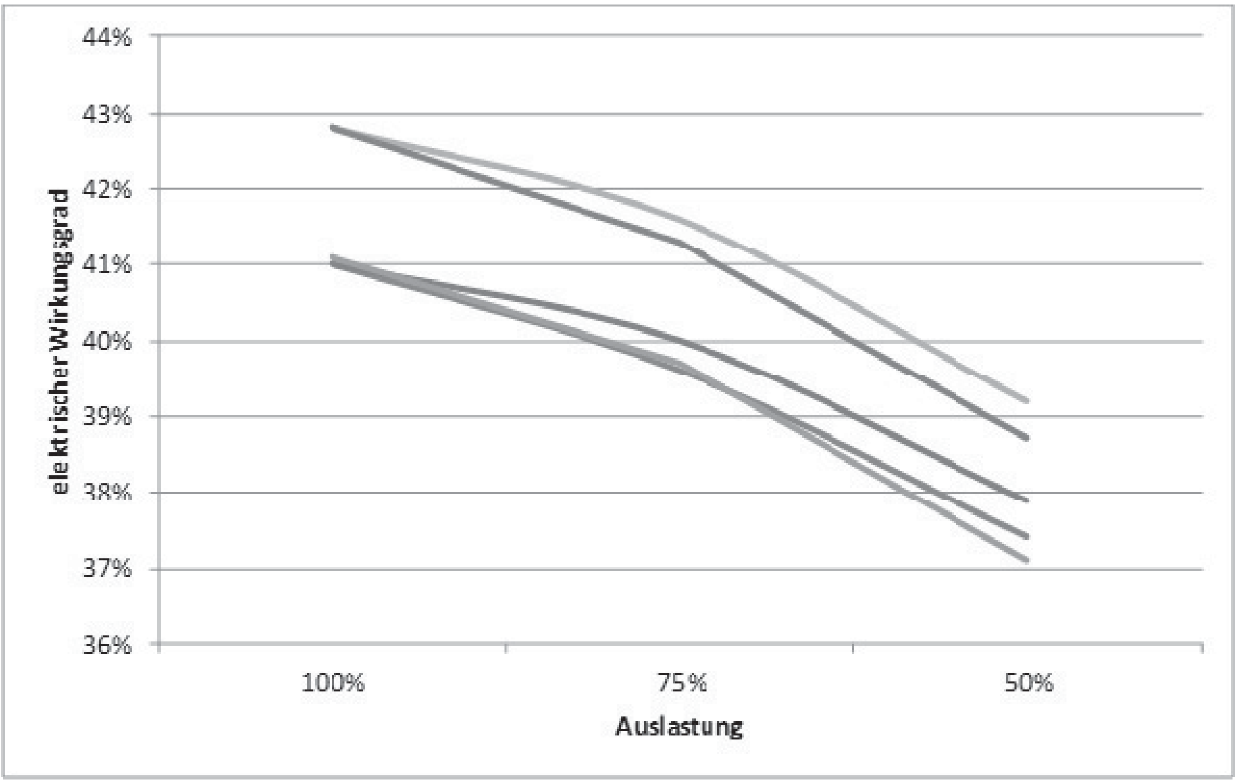

Abbildung 6: Elektrischer Wirkungsgrad in Abhängigkeit der BHKW-Auslastung von BHKW (exemplarische Darstellung)

2.4 Schwächen

Im Rahmen der Befragung und Begehung der Anlagen wurde gezielt nach Schwächen einzelner Behandlungsstufen und Aggregate sowie des Gesamtsystems gefragt. Die Auskunftsbereitschaft der Anlagenbetreiber war erwartungsgemäß sehr unterschiedlich. Gaben einige Befragte bereitwillig Auskunft zu Problemen in der Anlagentechnik oder auch resultierenden betriebswirtschaftlichen Schwierigkeiten, so hielt sich die Mehrzahl der Betreiber mit Angaben hierzu bedeckt. Die bei der Befragung und Begehung ermittelten Daten wurden ergänzt durch Befragung von Anlagenlieferanten und Ingenieurbüros sowie durch Auswertung diverser Rechtsstreits. Bei der Anlagentechnik sehen alle Befragten Optimierungspotenziale vornehmlich in den Bereichen Verschleiß und Wartungsaufwand sowie in der Durchsatzoptimierung bzw. Effizienzsteigerung der Anlage. Hinsichtlich der Reduktion von Verschleiß und Wartungsaufwand wurden besonders auf die Auswirkungen der Sedimentation und Inkrustation hingewiesen vornehmlich in den Prozessbereichen Fermenter und Entwässerung. Ebenfalls häufig genannt war der Themenkomplex Abrasion und Korrosion.

2.4.1 Sedimentation und Inkrustation

Von Kranert et al. (2002) wurde die mineralische Substanz von Bioabfällen diverser Einzugsgebiete differenziert nach den Kornfraktionen Schluff-, Sand- und Kiesanteil analysiert (siehe Tabelle 3). Die aufgeführten Mineralstofffraktionen werden vornehmlich über Anhaftungen an Pflanzenresten sowie über „Fege- bzw. Kehrgut" eingetragen. Sedimentationsrelevante Komponenten sind zusätzlich diverse Mineralien und Metalle aus der Störstofffraktion (siehe Tabelle 4).

Tabelle 3: Mineralstoffanteil ausgewählter Bioabfälle differenziert nach Korngrößen (Kranert et al., 2002)

	Mineralanteil (Angaben in % TS)			
	Kies	Sand	Schluff	Gesamt
Herbst	<1-9	8-20	7-13	19-35
Winter	1-13	4-14	4-6	12-30
Frühling	1-6	9-23	11-30	23-59
Sommer	1-3	7-27	3-20	12-40
Mittelwert	3,5 (2-6)	14 (10-21)	11 (7-14)	28,5 (22-36)

Tabelle 4: Störstoffanteil im Bioabfall und Zusammensetzung der Störstoffe bezogen auf 100% (Fricke et al., 2003)

Störstoffart	Mittelwert	Schwankungsbereich
Mittlerer Störstoffgehalt im Bioabfall, davon	1,8% in der FS	1-12% in der FS
- Anteil Kunststoffe	57%	44-88%
- Anteil Glas	9%	5-32%
- Anteil Metall	6%	4-15%
- Anteil Sonstiges	28%	12-58%

Sedimentationsprobleme treten bei nassen und trockenen kontinuierlichen Vergärungsverfahren gleichermaßen auf. Kombiniert ist die Sedimentation in vielen Fällen mit einer Inkrustation, die zu einer intensiven Verfestigung des Sediments führt. Die betrieblichen Auswirkungen können wie folgt zusammengefasst werden:

- **Sedimentation/Inkrustation**
  - Ablagerungen von Sedimenten in Behältern bewirken eine Reduktion des Faulvolumens. In konkreten Fällen wurden Verringerungen bis zu 25% festgestellt.
  - Ablagerungen in Verbindung mit Inkrustationen können die mechanischen Einrichtungen im Fermenter, wie z.B. Rührwerke und Räumvorrichtungen durch erhöhte mechanische Beanspruchungen beeinträchtigen bzw. durch Blockade außer Funktion setzen.
  - In liegenden Fermentern mit Pfropfstromtechnologie können der Materialtransport beeinträchtigt und somit sogenannte Kurzschlüsse im Materialstrom begünstigt werden. Bei stehenden Fermentern können Inkrustationen und Verstopfungen im Auslauf auftreten.
  - Verstopfung von Rohrleitungen, diversen Ausläufen, Schiebern, Ventilen etc.
  - Die Verblockung von Festbetten unterbindet die Durchströmung im Fermenter. Die Funktion des Festbetts wird eingeschränkt.

- **Verschleißerscheinungen**
  - Übermäßige Verschleißerscheinungen bis hin zur Zerstörung, verursacht durch Abrasionen, treten hauptsächlich an Zerkleinerern, Pumpen und mechanischen Entwässerungseinrichtungen auf.
  - Korrosive Erscheinungen werden durch Abrasionen begünstigt.

Die aufgeführten Probleme können massive betriebliche und ökonomische Konsequenzen nach sich ziehen. Dies sind Minderleistungen der Fermenter bis hin zu Anlagenhavarien. Fermenter müssen runtergefahren, geöffnet, entleert/saniert und wieder hochgefahren werden. Bei fehlender Redundanz ist mit Ausfallzeiten von mehreren Monaten zu rechnen. Vermehrte Anlagenstillstände werden durch notwendige Reparaturen verursacht. Weitere Folgen sind verkürzte Standzeiten bei den genannten Aggregaten und Bauteilen mit den entsprechenden Auswirkungen auf Abschreibungszeiträume und Kalkulationsansätze für Wartung, Reparatur und Unterhalt (RWU). Die Energieeffizienz wird durch Einschränkungen in der Verfügbarkeit der Anlage beeinträchtigt.

Lösungsansätze

Die Minimierung der Fraktionen Mineralien und Metalle vor dem Fermenterzulauf gilt als wesentlicher Lösungsansatz für nasse und trockene Verfahren gleichermaßen.

Trockene Verfahren:

- Effiziente Fe-, Ne- und Schwerstoff- Scheidung vor dem Eintrag in den Fermenter.
- Sicherstellung eines engen Viskositätsfensters im Gärgut. Zur Minimierung von Sedimentationsprozessen steht im Rahmen der Prozesssteuerung nur ein enger nutzbarer Viskositätsbereich zur Verfügung, der einerseits einem effektiven Förder- und Durchmischungsvorgang nicht entgegen steht, aber dennoch ein zu starkes Absinken von Schwerstoffen verhindert. Dieser Bereich ist spezifisch für die jeweilige Anlage und das zu verarbeitende Substrat zu ermitteln.
- Zur Verringerung potenzieller Sedimentationszonen ist bereits bei der Wahl der Fermentergeometrie darauf zu achten, mögliche Todzonen zu vermeiden und – insbesondere bei stehenden Fermentern – Winkel so zu wählen, dass ein selbstgängiger Sedimentaustrag begünstigt wird. Insbesondere im Austragsbereich ist auf einen möglichst unbehinderten Substrataustrag zu achten, um Sedimente aus dem Fermenter abführen zu können und Verstopfungen zu vermeiden.
- In Abhängigkeit von der Fermentergeometrie sind nach Möglichkeit geeignete Spül- und Räumvorrichtungen vorzusehen. Räumvorrichtungen, wie Schubbö-

den, müssen über geeignete, d.h. vor allem abrasions- und korrosionsresistente Untergründe verfügen, mit ausreichenden Niederhaltern ausgestattet sein und stabil geführt werden. Ein Anlagenlieferant hat mittlerweile vollständig auf den Einbau von Räumvorrichtungen (Kratzboden) verzichtet. Zur Lösung von Sedimenten können Systeme zur Gas- und Flüssigkeitseinpressung vorgesehen werden.

- Vor dem Hintergrund ggf. notwendiger Fermenteröffnungen und -räumungen wird empfohlen, Fermenter redundant auszulegen. Hierdurch kann ein Totalausfall der Vergärungsstufe weitestgehend unterbunden werden. Darüber hinaus steht geeignetes Inokulum für die Wiederinbetriebnahme des in Revision befindlichen Fermenters zur Verfügung als Voraussetzung für eine Verkürzung der „Hochfahr-Zeit“. Insbesondere bei kleineren Anlagen stehen diesem Lösungsansatz wirtschaftliche Aspekte entgegen.

- Die Wartung der im Fermenter installierten Systeme ist in der Regel mit der Öffnung und Entleerung des Fermenters verbunden, daher sind außen liegende Antriebe von Vorteil.

- Es wird empfohlen, geeignete Überwachungssysteme zur Messung von Ablagerungen und Inkrustationen zu installieren. Akustische und infrarotbasierte Methoden sind in der Erprobung, nach Kenntnisstand aber noch nicht zuverlässig einsetzbar.

- Im Gewährleistungskatalog sollte die revisionsfreie bzw. öffnungsfreie Fermenterstandzeit festgelegt und ggf. erforderliche Revisionen kostenseitig definiert werden.

Nasse Verfahren:

Detaillierte Kenntnisse zum oben genannten Problembereich liegen den Autoren aus dem Betrieb von Nassfermentern mit und ohne integriertem Festbett vor. Die Kenntnis für Festbettfermenter stammt von Restabfallbehandlungsverfahren:

- Viele der oben genannten Lösungsansätze gelten in gleicher oder in modifizierter Form auch für nasse Verfahren und werden an dieser Stelle nicht wiederholt.

- Bei Festbettfermentern ist der Feststoffgehalt im Fermenterzulauf auf < 1% in der FS zu begrenzen. Hierdurch können die oben beschriebenen Probleme der Festbettverstopfung weitgehend unterbunden werden. Inkrustationen sind hierdurch zwar nicht zu verhindern, ein wesentlicher Teil der Grundmatrix wird aber entzogen. Die Aufwendungen für Schlammräumung und -austrag werden bei diesen geringen Feststoffgehalten reduziert. Auch der Schwimmdeckenbildung wird entgegengewirkt.

- Die alleinige Schwerstoffscheidung im Stofflöser/Pulper wird als nicht ausreichend beurteilt, um Sedimentationsproblemen entgegenzuwirken. Gute Trennergebnisse können in der Regel mit Dekanterzentrifugen erzielt werden. Für die Abtrennung körniger Inhaltsstoffe sind prinzipiell Sandscheider (Sandwäscher) geeignet. Sie sind jedoch nicht in der Lage, Feinstsande sowie Faserstoffe effizient abzuscheiden, wie dies für Festbettfermenter notwendig ist. Für Nassfermenter ohne Festbett kommt ein Sandscheider häufig nach dem Pulper zum Einsatz. Schwingsiebe mit Feinstsiebbezügen sind geeignet, entsprechende faserige Stoffe bis auf ein Mindestmaß zu eliminieren. Schwierig ist die Leistungsfähigkeit derartiger Aggregate auf die Eliminationsleistung von Feinsanden zu beurteilen.

2.4.2 Korrosion und Abrasion

Korrosionserscheinungen, insbesondere an metallischen Materialien, treten hauptsächlich bei Aggregaten der Anlagenperipherie zur Vergärung auf. Der Schwerpunkt ist dem Nachrottebereich von Gärresten zugeordnet. Als Folge derartiger Korrosionsschädigungen treten erhöhte Instandhaltungs- und Sanierungsaufwendungen, verkürzte Standzeiten sowie Beeinträchtigungen des Verfahrensprozesses mit den entsprechenden Auswirkungen auf die Betriebskosten und Verarbeitungsleistungen auf (Fricke et al., 2009). Kompost- und Vergärungsanlagen bieten ideale Milieubedingungen für Korrosionsprozesse.

Lösungsansätze:

- Verwendung höherwertiger geeigneter bzw. höherwertigerer Bau- und Werkstoffe, wie Edelstahlsorten bei mechanisch beanspruchten Metallen, speziell bei Erosions- und Reibkorrosion, allerdings wurden auch Korrosionen an V2A und V4A-Stählen beobachtet, z.B. Lochfraß.

- Ersetzen metallischer Rohrleitungen durch Kunststoff- oder Mineralstoffprodukte, in einem Fall erfolgte auf Grund massiver Korrosionserscheinungen ein Austausch von $AlMg_3$-legierten Rohleitungen (Saugbelüftung) durch Kunststoffprodukte.

- Korrosionsschutz durch geeignete Beschichtungen. Positive Erfahrungen liegen vor mit dreilagiger Beschichtung nach Sandstrahlung à 80µm: 2K-EP-ZP-GB; Grundschicht: Epoxidharz (EP) – Zinkstaub; Zwischenschicht: EP mit Fe-Glimmer; Deckschicht: Polyurethanlack.

- Verbesserte Abschottung korrosiver Prozessbereiche von den übrigen Anlagenbereichen (u.a. Feuchtigkeit, Staub) durch bauliche und verfahrenstechnische Konzeptionen. Soweit möglich, Verlegung sensibler Funktionseinheiten in weniger korrosive Anlagenbereiche.
- Ein Teil der Schäden ist an Stellen aufgetreten, die bei der Montage beschädigt und nachfolgend nicht wieder ausreichend beschichtet wurden. Diese nie ganz vermeidbaren Schwachstellen müssen durch Kontrollen lokalisiert und frühzeitig ausgebessert werden.
- Intensive Reinigung der Werkstoffe von Biofilmbelägen.
- Um die beim biologischen Prozess entstehende Feuchte und Wärme besser aus dem Prozess abführen zu können, Abstrahlverluste in angrenzende Bauwerke (z.B. Tunnelvorhallen) zu minimieren sowie das feuchte Klima aus den Hallen ableiten zu können, sind ausreichende Luftwechselraten erforderlich.
- Elektro- und Steuerschränke isolieren und im Überdruck fahren.
- Intensives Monitoring zur Werkstoffprüfungen mit unmittelbaren Maßnahmen zum Korrosionsschutz bei korrosionsbetroffenen Stellen oder bei beschädigten Beschichtungen.
- Einplanung von Verschleißteilen bei besonders beanspruchten Bau- und Werkstoffen.

Im Hinblick auf den Ausbau der Kapazitäten von Vergärungs- und Kompostierungsanlagen und den Sanierungsbedarf an vorhandenen Anlagen müssen Lösungsansätze für die Reduzierung der Korrosion an Bau- und Werkstoffen infolge der vorherrschenden Wirkmechanismen entwickelt und Methoden zur Sanierung konzipiert werden. Vor allem fehlen Lösungsansätze mit präventivem Schutzcharakter, die sowohl bei Sanierungsmaßnahmen – insbesondere aber auch bei Neubauten – zum Tragen kommen können.

3 Abschätzung zusätzlich erschließbarer Energieausbeuten durch die Vergärung von Bio- und Grünabfällen

Um die Entwicklungspotenziale der Biogasproduktion aus Bio- und Grünabfall in Deutschland aufzuzeigen, wird im folgenden Kapitel ein Szenarium entwickelt, das mögliche Jahresproduktionsmengen für Biogas, Biomethan sowie nutzbare elektrische und thermische Energie abschätzt. Das Szenarium basiert im Wesentlichen auf drei Wirkfeldern:

- Optimierung der Energieerzeugung bestehender und in Bau befindlicher Vergärungsanlagen;
- Überführung der derzeit schon erfassten Bio- und Grünabfallmengen in die Vergärung sofern sie hierfür qualitativ geeignet sind;
- Erschließung zusätzlich erfassbare Bio- und Grünabfallmengen durch flächendeckende Implementierung der Bioabfallerfassung.

Unsicherheiten bestehen bei der Mengenprognose über die zu vergärenden Grünabfälle und die erzeugbare Biogasmenge. Ob die prognostizierten 50% tatsächlich für die Vergärung verfügbar gemacht werden können ist fraglich. Problematisch ist vor allem, dass ein Teil dieser Abfälle auf reinen Grünabfallkompostanlagen verarbeitet werden, für die im Vergleich zu Bioabfallkompostanlagen deutlich niedrigere Betriebskosten zu entrichten sind. Auch die Vermarktung reiner Grünabfallkomposte gestaltet sich aufgrund deren Hochwertigkeit einfacher und ertragsreicher.

Auch eine exakte Bestimmung des Gasbildungspotenzials der vergärbaren Grünabfälle ist auf Basis der verfügbaren Datenbasis mit Unsicherheiten behaftet. Für die Prognose für kontinuierliche Verfahren 73m^3 und für diskontinuierliche Verfahren 64m^3 Biogas pro Mg Grünabfall angesetzt. Es wird angenommen, dass zukünftig bei Neubauten 50% mit kontinuierlichen Verfahren und 50% mit diskontinuierlichen Verfahren errichtet werden.

Auf Basis der beschriebenen Optionen zur Optimierung der Energieausbeute sind die beschriebenen Optimierungsansätze quantifiziert worden. Als Kalkulationsgrundlage wurden u.a. Leistungsdaten aus dem oberen Drittel der erhobenen Daten angesetzt Die detaillierte Herleitung der prognostizierten Leistungsdaten ist dem Abschlussbericht zu entnehmen (BMU, 2013). Aus den einzelnen Optimierungsansätzen resultiert eine Steigerungsquote bei der Stromausbeute von ca. 1,4 und bei der Wärmeausbeute von 1,2.

Der größte Zugewinn an netto Energieausbeute lässt sich durch die Vergärung von derzeitig schon erfassten aber der Kompostierung zugeführten Bio- und Grünabfälle erzielen (siehe Abbildung 7 und Abbildung 8). Ein Zugewinn an Stromausbeute (netto) mit jährlich 1.094GWh und Wärmeausbeute (netto) mit jährlich 989 GWh lässt sich durch Erschließung zusätzlich erfassbarer Bio- und Grünabfallmengen bei flächendeckender Implementierung des Systems Biotonne erzielen. Das Erweiterungspotenzial durch flächendeckende Sammlung der Bioabfälle beträgt jährlich 532GWh Stromausbeute und 481GWh Wärmeausbeute jeweils Nettoerträge.

Das Gesamtpotenzial zusätzlich erschließbarer Energien (Nettoausbeute) durch die Vergärung von Bio- und Grünabfällen liegt bei 1.772GWh Strom und 1.556GWh Wärmeausbeute.

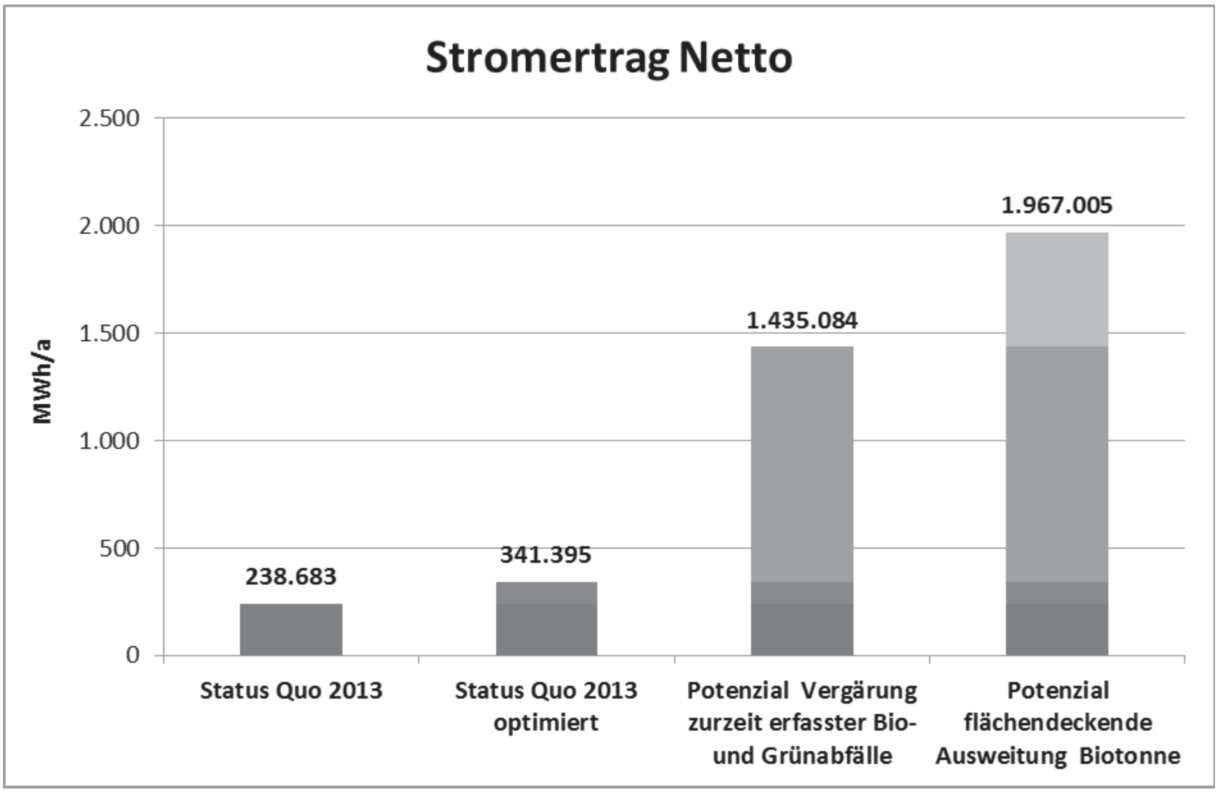

Abbildung 7: Netto-Stromausbeuten bei der Vergärung von Bio- und Grünabfällen bei unterschiedlichen Ausbaustufen

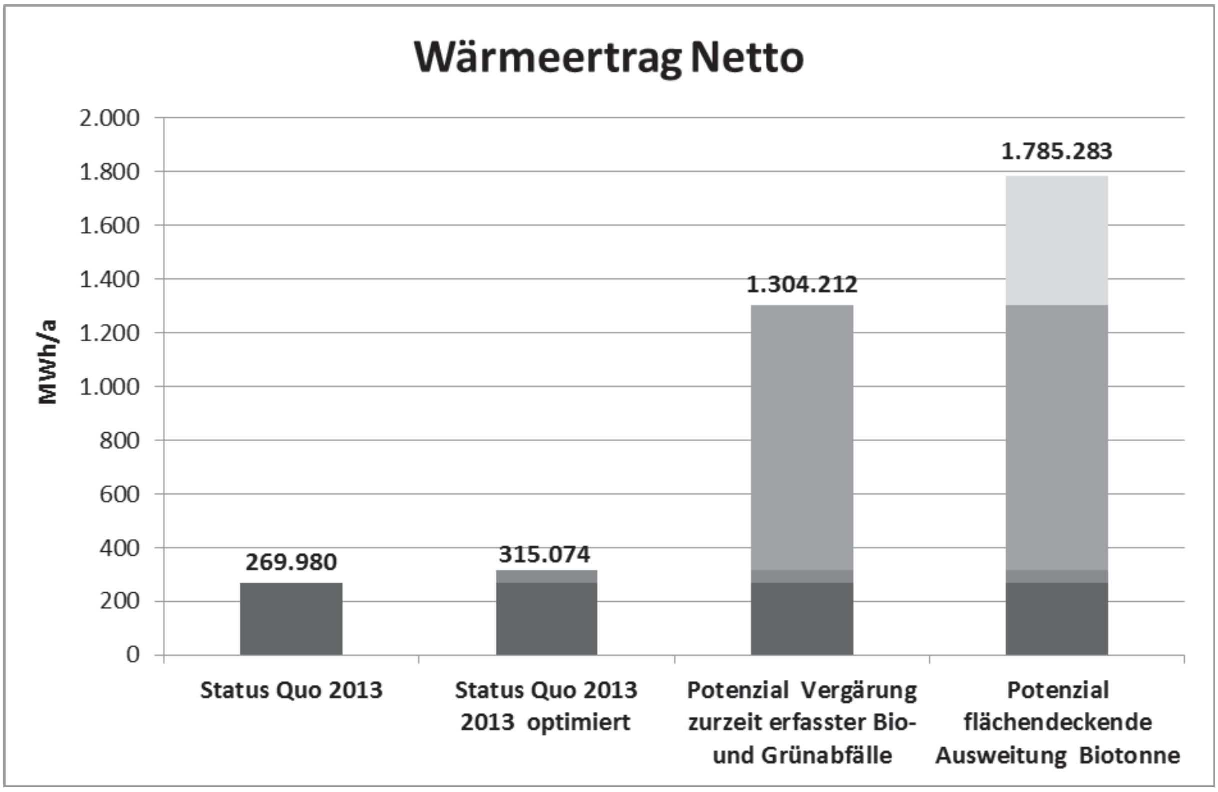

Abbildung 8: Netto-Wärmeausbeuten bei der Vergärung von Bio- und Grünabfällen bei unterschiedlichen Ausbaustufen

4 Zusammenfassung

Die Vergärung nimmt bei weitem nicht den Stellenwert ein, der ihr durch die ökologischen Vorteile zugesprochen werden müsste. Dies belegt auch das hohe Ausbau- und Entwicklungspotenzial bei der Vergärung von Bio- und Grünabfällen. Dieses erstreckt sich über die Segmente Stoffstrommanagement, Technik und Betrieb.

Hervorzuheben im Segment Stoffstrommanagement sind die Zuführung bereits erfasster Bio- und Grünabfälle in die Vergärung, sofern diese hierfür geeignet sind. Gleiches gilt für die flächendeckende Erfassung von Bioabfällen. Ausgeprägte Jahresgänge bei den Mengen und Qualitäten der zu vergärenden Abfälle beeinträchtigen massiv die Effizienz der Anlagen. Lösungsansätze liegen in der Bereitstellung von Inputmaterialien, die geeignet sind, Mengen- und Qualitätsschwankungen auszugleichen. Eine Schlüsselfunktion wird in der Entwicklung von Methoden zur energiekonservierenden Lagerung gesehen. Falls geeignete Grünabfälle der Vergärung zugeführt werden sollen, ist eine gezielte getrennte Erfassung, Anlieferung und Lagerung von Grünabfällen in vergärbare und kompostierbare bzw. energetisch verwertbare Chargen aufzubauen.

Die technischen Optimierungen sind vielschichtig. Bei kontinuierlichen trockenen Verfahren ist zu prüfen, ob die installierte intensive Zerkleinerung erforderlich ist. Hier ergibt sich ggf. ein Ansatz zur Verringerung des Energiebedarfs. Bei diskontinuierlichen Verfahren kann eine bessere Homogenisierung zu höheren Gaserträgen führen. Die Abtrennung sedimentierbarer Komponenten reduziert die Gefahr der Sedimentbildung im Reaktor und vermindert Abrasionen bzw. den Verschleiß in nachgeschalteten Aggregaten.

Die thermophile Betriebsweise führt bei allen Verfahren zu deutlich höheren Biogas- und Methanerträgen. Diskontinuierliche trockene und auch nasse Verfahren werden zum überwiegenden Teil mesophil betrieben und bergen daher Optimierungspotenzial. Die Entwicklung der BHKW-Technologie hat zu verbesserten elektrischen Wirkungsgraden geführt. Diese Entwicklung ist bei Neuanlagen und im Rahmen von Ersatzbeschaffungen nutzbar. Die zur Verfügung stehenden Optionen zur Gasverwertung werden nur sehr eingeschränkt genutzt. Besonders bei der Nutzung der Wärme besteht Optimierungspotenzial.

Die Entwässerung gilt als einer der größten Energiezehrer. Durch Nutzung von Überschusswärme zur Steuerung des nachgeschalteten Aerobprozesses kann die Nachrotte mit höheren Wassergehalten gefahren werden, mit der Folge geringerer Prozesswassermengen. Positive Auswirkungen sind auch beim Verschleiß der Entwässerungsaggregate und beim Energiebedarf zu erwarten. Die Hygienisierung des Gärgutes vor oder während des Anaerobprozesses bietet die Möglichkeit der direkten Ausbringung zumindest in der Vegetationszeit. Diese Verwertungsoption bietet ein hohes Optimierungspotenzial zur Steigerung der Energieeffizienz.

Bei den Elektromotoren, die in einer Vielzahl auf Vergärungsanlagen im Einsatz sind, hat es in der Vergangenheit eine Entwicklung zu einer höheren Effizienz gegeben. Neuanlagen müssen mit Elektromotoren mit diesen Effizienzklassen ausgestattet werden, bei Altanlagen ist der Austausch von Elektromotoren im Rahmen der Ersatzbeschaffung realisierbar.

Betriebliche Optimierungen liegen u.a. in der Vergleichmäßigung der Beschickung auch in den Nachtstunden und am Wochenende. Dem Lagermanagement ist hierbei größere Beachtung zu schenken. Weiterhin führt eine sachgerechte Wartung der eingesetzten Aggregate zu einer Verlängerung der Standzeiten und zu Einsparungen im Energiebedarf. So kann z.B. bei einer regelmäßigen Wartung der Motoren durch eine Verringerung der mechanischen Verluste eine Stromeinsparung zwischen 3 und 10 % erreicht werden.

Zur Sicherung einer hohen Verfügbarkeit der Anlage sind die aufgezeigten Maßnahmen zur Unterbindung von Sedimentationen im Fermenter zu beachten. Mess- und Überwachungssysteme sind zu installieren.

Als problematisch ist zu beurteilen, dass keine der betrachteten Vergärungsanlagen über Daten zu spezifischen Energieverbräuchen - differenziert nach Prozessabschnitten - verfügt. Hier besteht dringender Handlungsbedarf, da eine Optimierung der Energieverbräuche nur auf Basis von entsprechenden Detailkenntnissen möglich ist. Methoden zur aufwandsarmen Messung entsprechender Energieverbräuche sind verfügbar.

Das Gesamtpotenzial zusätzlich erschließbarer Energiemengen (Nettoausbeute) durch die Vergärung von Bio- und Grünabfällen wird mit 1.772 GWh Strom und 1.556 GWh Wärmeausbeute prognostiziert. Die größten Potenziale liegen im Ausbau der Vergärungskapazität für schon erfasste Bio- und Grünabfälle sowie der Vergärung der zusätzlich erfassbaren Bioabfälle durch flächendeckende Einführung der Biotonne.

Ob es tatsächlich zu einer flächendeckenden Implementierung der Bioabfallerfassung kommt wie im KrWG vorgeschrieben, ist fraglich. Die fehlende Definition der „Flächendeckung“ eröffnet das „Aussitzen“ der Forderung durch Einführung von „Alibi-Biotonnen“. Hier wird dringender Regelungsbedarf gesehen.

Unsicherheiten bestehen bei der Mengenprognose über die zu vergärenden Grünabfälle. Ob die prognostizierten 50% tatsächlich für die Vergärung verfügbar gemacht werden können ist fraglich. Problematisch ist vor allem, dass ein Teil dieser Abfälle auf reinen Grünabfallkompostanlagen verarbeitet werden, für die im Vergleich zur Vergärungsanlagen deutlich niedrigere Betriebskosten zu entrichten sind. Auch die Vermarktung reiner Grünabfallkomposte gestaltet sich aufgrund deren Hochwertigkeit einfacher und ertragsreicher.

Ob die Vergärung zukünftig den Stellenwert in der deutschen Abfallwirtschaft einnehmen wird, die ihr durch die ökologischen Vorteile zugesprochen werden müsste, ist abzuwarten. Das KrWG enthält in § 8 Abs. 2 und in § 11 Abs. 2 zahlreiche Verordnungsermächtigungen, die es u. a. ermöglichen, die Anforderungen an die Hochwertigkeit der Verwertung zu regeln. Nach § 8 Abs. 2 Satz 2 KrWG kann insbesondere bestimmt werden, dass die Verwertung des Abfalls entsprechend seiner Art, Beschaffenheit, Menge und Inhaltsstoffe durch mehrfache, hintereinander geschaltete stoffliche und anschließende energetische Verwertungsmaßnahmen (Kaskadennutzung) zu erfolgen hat. Es wird empfohlen, dass das BMUB von seinen Regelungsmöglichkeiten Gebrauch macht, und die Anforderungen an eine hochwertige Verwertung des Bioabfalls durch Rechtsverordnung konkretisiert.

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Peripheral fermentation of organic waste – Insights and data from practice

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Abstract

The fermentation of organic waste is a valuable source for alternative energy and nutrients in form of fertiliser.

To increase the treatment of organic waste quantities, peripheral digestion plants can have a significant contribution. Although small scale digestion units have higher investment costs based on the waste quantities processed, a specialisation on suitable wastes and an efficient use of alternative energy and fertiliser can guarantee an economic and ecological success.

Keywords

Peripheral fermentation technology, solid waste, dry fermentation,

1 Introduction

Anaerobic degradation is a very cost-effective method for treating organic wastes because the formed biogas can be used for heat and electricity production and the digestate can be recycled to agriculture as a secondary fertilizer. Various process types are applied and state of the art which differ in material, reaction conditions and in the form of the used reactor systems. The introduction of anaerobic digestion has shown that organic wastes are a valuable source for energy and nutrients. Anaerobic waste treatment is done today in biogas plants on middle farm scale as well as on large industrial scale with the best beneficial and economic outcome. Through the development of new anaerobic treatment technologies based on small scale the recycling rate of organic waste should be increased.

2 Small scale dry fermentation technology

2.1 Technology MobiGas

The organic waste treatment technology consists of 1 control module, up to 10 process modules and bio filter equipment. All modules are designed as a container system to increase modularity and transportability, which allows regional treatment of organic waste and the possibility of active reaction to changing waste quantities (e.g. the tested prototype consisted of 1 control module, 3 process modules and 1 bio filter module). The modules are manufactured in compliance to be transported with normal trucks. In addition the process modules are connected to the control module with an exhaust air line and a control cable via Plug&Play, which are the only fix installed components of the technology on site.

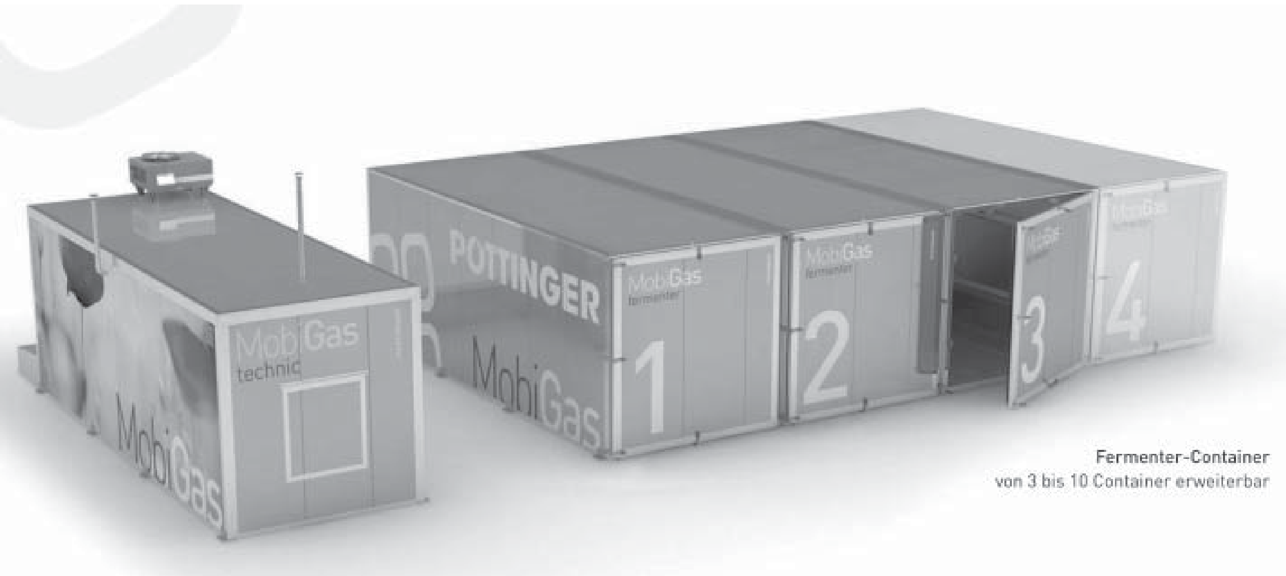

Figure 1 MobiGas technology: 1 control module and 3 process modules

<u>Control module</u>

The control module equipped with visualisation and remote control is mainly responsible for monitoring the process flow of the individual process modules and provides information about the operating condition of the system. It is divided into two areas, an engineering room and biogas storage. The engineering room contains:

- Control cabinet with visualised remote control
- Exhaust air and gas distribution valves and pipes with technical equipment

- Gas measurement equipment
- Power generation

Process module

The organic waste material is processed in the process modules, which contain all basic system elements for processing: percolate storage and pumps, blower, ventilation pipes and floor heating system. The process modules equipped with heat insulation clad with metal plating, possess a fill capacity of 58m³/module. The process modules are designed to treat all kinds of organic waste.

3 Treatment process

In the process solid state material like organic waste, heavy fraction of municipal solid waste (MSW), bio waste and residual materials out of food industry is treated to produce humus to particular national conditions and energy. The process proceeds under controlled and closed conditions in 3 consecutive phases:

- the first phase (duration 1-3 days) works under aerobic condition after filling up the process module with input material and closing it gas-proof. The substrate in the process module is aerated until a defined level of temperature because of microbial self-heating is reached. The generated exhaust air charged with odour and dust emissions is purified using bio filter equipment.

- the second phase (4-6 weeks) starts with the addition of percolation water, which is responsible for the required water content in the substrate and the faster beginning of the anaerobic activity. The biogas production starts during few hours after the second phase was started. The biogas is used to generate energy in form of electrical and thermal power by diverse power generation technologies. End of the anaerobic phase starts with the forced ventilation of the substrate.

- the third phase (1-5 days) of the process works under aerobic condition again. The system measures the concentration of oxygen and the temperature level in the process module to secure that the process is working according to default for the quality of the end product; aims of this phase can be the sanitation or the dehumidification of the substrate. The generated exhaust air charged with odour and dust emissions is again purified using bio filter equipment.

4 Implementation and Operation

4.1 Implementation

For the implementation of the technology, infrastructure including hard surface for the container, manipulation surface, connecting pipes and lines and drainage has to be established. On the following pictures the infrastructure works e.g. construction of the container and manipulation surface, are shown.

Figure 2 Construction of infrastructure; container & manipulation surface

After checking the installation surface and mounting the container fixings, the delivery of the containers has to be made. The containers, control & process modules, are unloaded and set up. Subsequently the installation of the supply channel for the pipes & lines connecting the modules each other is started.

After installing the pipes and lines a pressure test of gas & heating pipes is done and a functionality test of the modules including control unit is made.

Figure 3 Implementation of MobiGas technology in composting plant

4.2 Operation

The technology is developed to treat all kind of solid organic waste, like organic, waste, heavy fraction of municipal solid waste, bio waste and residuals out of agro and food industry. Before treatment of such wastes, it is necessary to prepare the input material regarding the following topics:

1) Preheating the fresh input material during cold period
the temperature of the input material is very important for starting the digestion process. Therefore it is necessary to preheat the fresh input material during cold periods to speed up the process. A very simple method is to prepare the input material in a pile using the natural self-heating process from the material e.g. compost pile.

2) Mixing the input material with digestate and structure material - to inject the bio waste with methane- producing bacterium
To guarantee an ideal biogas production it is important to find an ideal mixture with input material, structure material and digestate.

Figure 4 Implementation of MobiGas technology in composting plant

5 Monitoring Data

For the monitoring and controlling of the digestion process several relevant parameters as pH value, FOS/TAC, temperature of the input material, biogas production and CH_4 content are measured. The measurement of the parameter pH and FOS/TAC is done by the leachate of the input material, the temperature is taken from the input material and the biogas production and Ch4 content is done by the biogas stream.

<u>pH value</u>

The pH value is a relevant parameter to check t the development and quality of the bio-process. In the following figure the comparison between optimal and real pH value is visible.

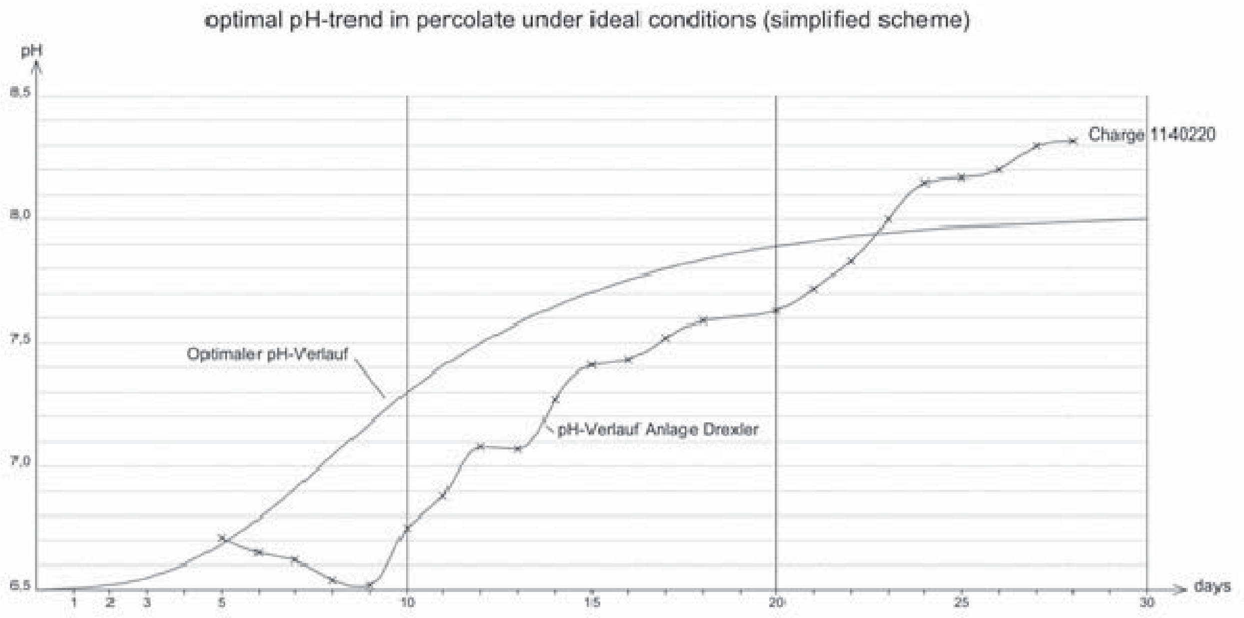

Figure 5 Comparison between optimal and actual shape of the pH curve

<u>FOS/TAC</u>

The determination of organic acids (FOS) and total inorganic carbon (TAC) is a simple way to monitor the fermentation process and the maturity level. Furthermore the parameter informs about the composition of the next batch of input material.

In the following figure the curve profile of 4 charges is shown.

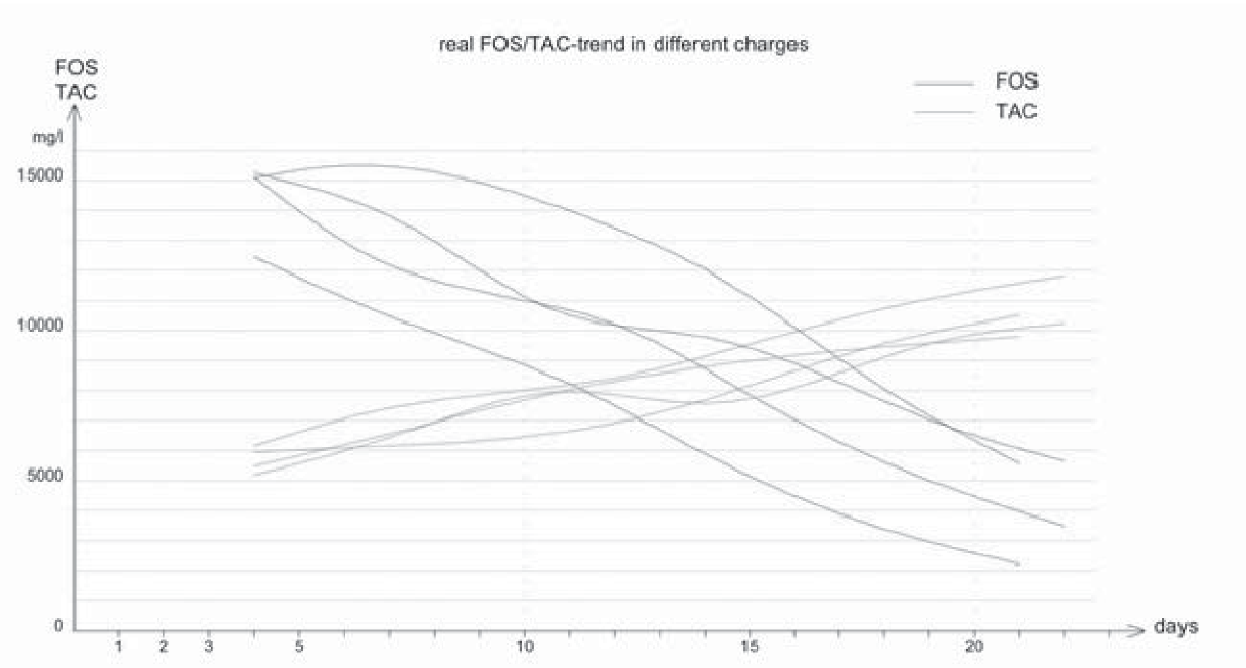

Figure 6 Curve profile of FOS/TAC of 4 different charges

<u>Temperature</u>

The digestion process takes place optimal around 38 to 42 °C of the input material. The temperature of the input material is measured in 3 measuring points and the curve profile is shown in the following figure.

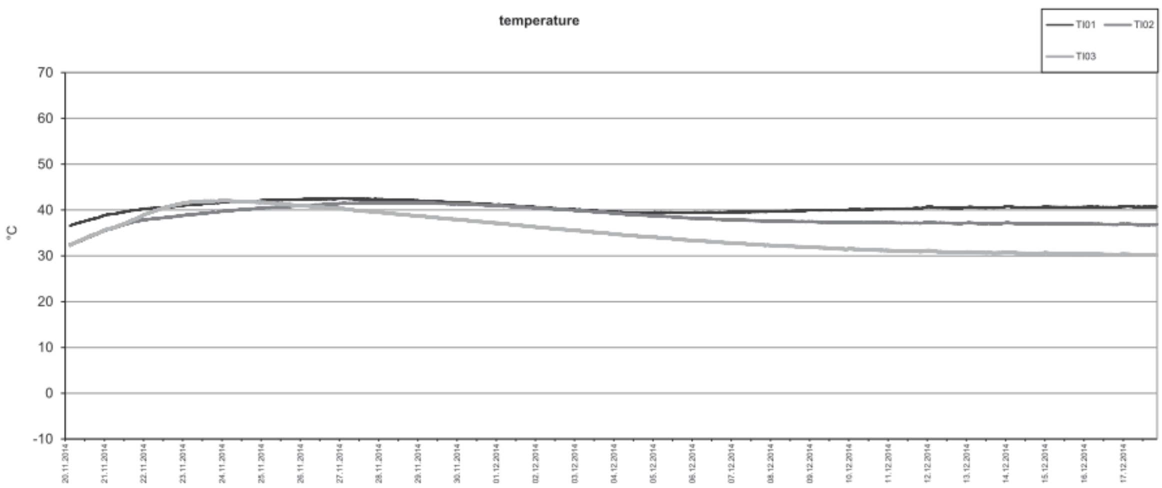

Figure 7 Curve profile of temperature measurement points

Biogas production

The biogas production rate provides information about the energy content of the input material and is used as an indicator for the point of time of the next material change.

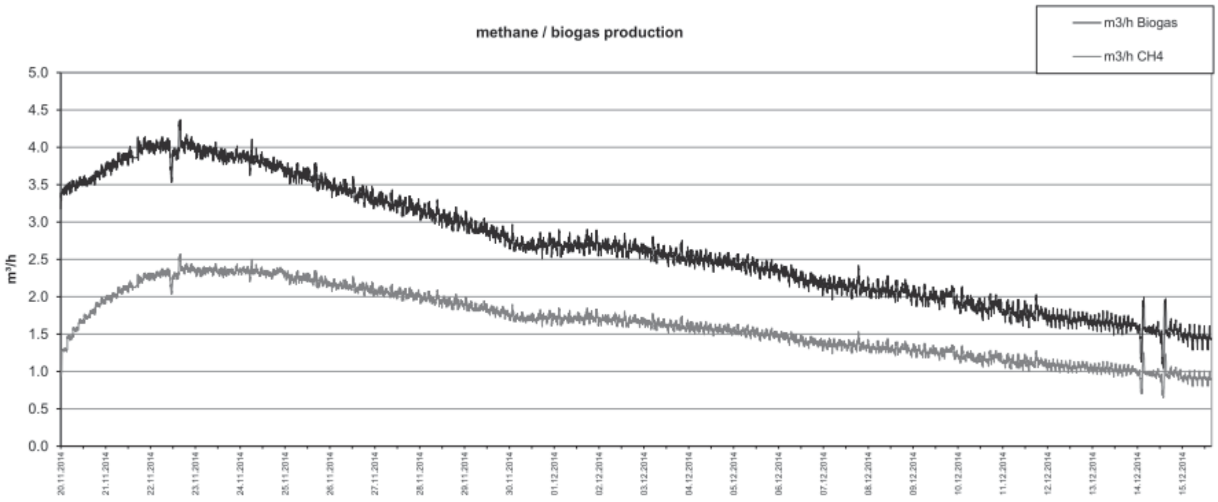

Figure 8 Biogas and CH_4 production rate

CH$_4$ content

The CH_4 content in the biogas is an indicator for the activity of the biogas production microorganisms and provides relevant information at the starting phase of the digestion process.

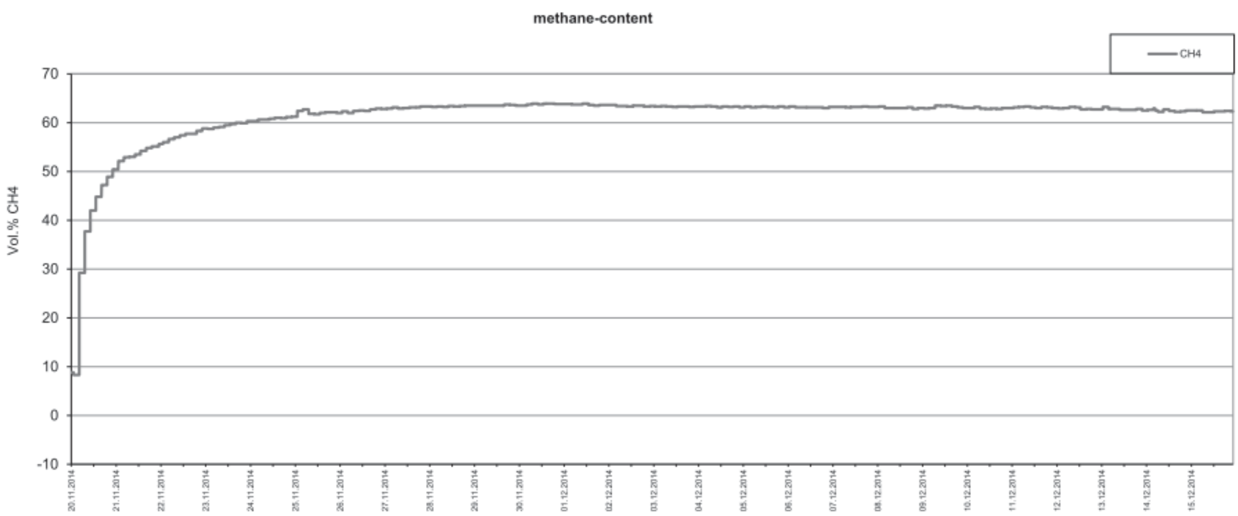

Figure 9 CH_4 content in biogas

6 Data from practice

The data from practice provides the illustration of differences between dissimilar input materials e.g. separate collected bio waste and horse manure.
In the following graphics the most relevant parameters (amount of biogas production and CH_4 content) for an economic system operating are shown.

6.1 Data - treatment of bio waste

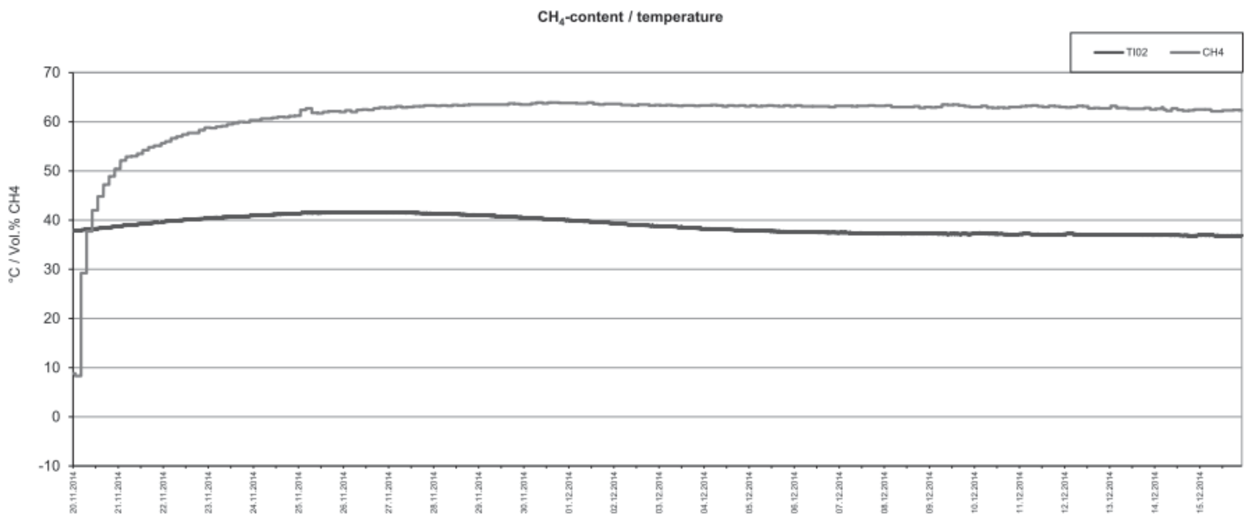

Figure 10 CH_4 content in biogas and temperature of input material

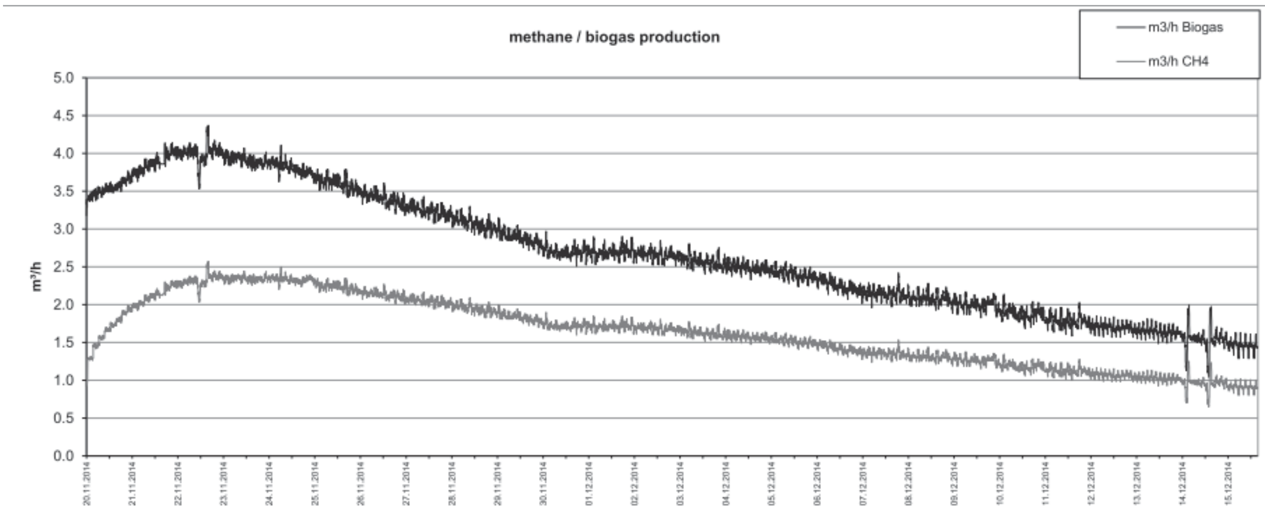

Figure 11 Biogas and CH_4 production rate

6.2 Data - treatment of horse manure

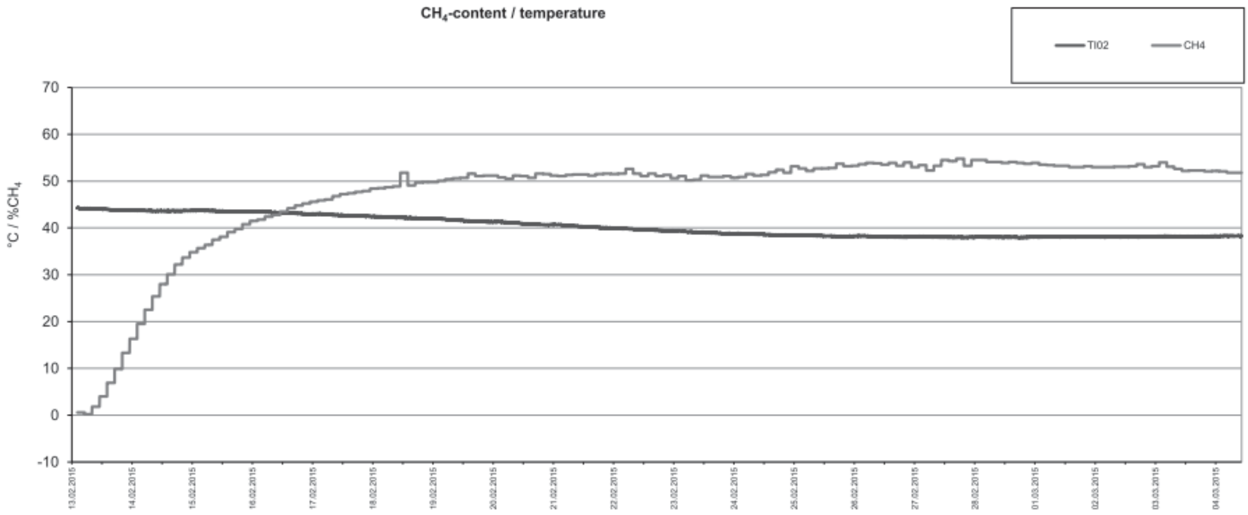

Figure 12 CH_4 content in biogas and temperature of input material

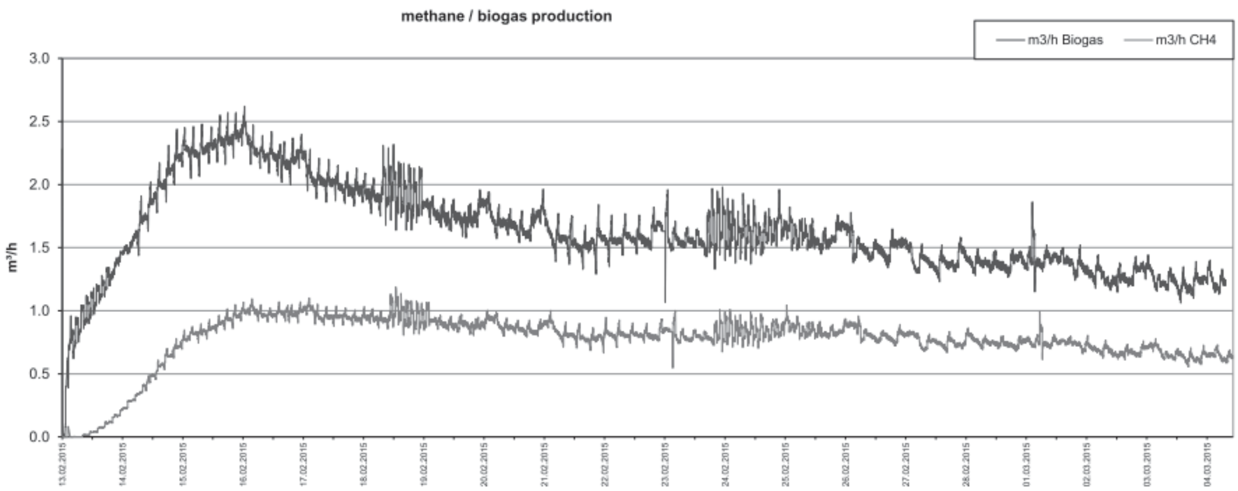

Figure 13 Biogas and CH_4 production rate

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Development of a rotating fermentation reactor for biogas production from organic waste

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Abstract

To maximize biogas yields, adequate substrate mixing during anaerobic digestion (AD) is of particular importance. In dry AD this may be hampered by high solid matter contents causing a pronounced wear of mixing tools and triggering costly maintenance interruptions. This study aims at the development of a rotating drum fermenter (RDF) to overcome these problems. As a first step towards the development of a full-scale RDF for dry AD of biowaste, particular attention was given to the mixing performance. Therefore, a lab-scale RDF was constructed from acrylic glass to allow visual inspection of the radial mixing process. To reflect the heterogeneous properties of biowaste, several model materials were selected and characterized. Mixtures of these materials were soaked with water and a polymeric suspension was added to achieve desired viscosity. The slump test was applied to estimate the yield stress of the mixtures. The mixing behaviour was investigated for granular materials as a typical substrate for solid state fermentation and a viscous three-component substrate consisting of granular and bulky material and a polymeric suspension. To quantify the state of mixing via image analysis a dyed-tracer technique was applied. The radial mixing performance of the RDF was satisfactory even at high filling levels of up to 80 % and could be further improved by a single baffle mounted on the inner wall of the RDF. The necessary number of rotations to reach a well-mixed state for viscous substrates strongly depends on the rheological characteristics of the substrate.

Keywords

Anaerobic digestion, biowaste, rotating drum fermenter, mixing, slump test

1 Introduction

Anaerobic digestion (AD) is a proven technology for energy recovery from biowaste. AD processes are classified by critical operating parameters such as continuity (batch-feed versus continuous-feed), operating temperature (psychrophilic, mesophilic and thermophilic), reactor design (plug-flow, complete-mix, and covered lagoons), and solid content (wet, semi-dry, and dry) (LI ET AL. 2011). Solid AD is differentiated by the total solid (TS) content of the feedstock and can be subdivided into dry AD (TS > 20%) and semi-dry AD (15% < TS < 20%). Compared to wet AD (TS < 15%) advantages of this technology include: improved cost effectiveness by higher throughputs, lower operation costs and more compact reactor design for equivalent loading rate, reduced water demand, more simple phase-separation for the digestate, and less pretreatment requirements (BENBELKACEM ET AL. 2013).

Biowaste is a highly degradable substrate (MATA-ALVAREZ ET AL. 2014) but is also complex and heterogeneous in terms of structure, composition and size. Thus, one major challenge is related to the physical characteristics of the feed: on account of low water content, its “apparent viscosity’’ is high and technical equipment is required for transporting the fresh feed and mixing it with the partially digested waste in the reactor (GARCIA-BERNET ET AL. 2011). To maximize biogas yields, adequate substrate mixing is of particular importance. Depending on the system configuration, different strategies have been adopted including mixing by gas, paddles or external pumping devices (GARCIA-BERNET ET AL. 2011). In dry AD this may be hampered by high solid matter contents causing a pronounced wear of mixing tools thereby triggering costly maintenance interruptions. Indeed, paddle mixers are the most critical component of plug-flow fermenters for dry AD of biowaste (GÖRISCH AND HELM 2007).

The above-named problems may be circumvented by digestion in a rotating drum. Rotating drums are known to provide relatively gentle and uniform mixing by the tumbling motion of the solid medium and have been used as bioreactors for solid-state fermentation since the 1930s (MITCHELL ET AL. 2006). Current industrial-scale applications include the continuous aerobic composting of municipal biowaste. However, until now only little attention has been paid to the performance of dry AD in rotary drum fermenters (RDF). A series of studies utilizing a lab-scale RDF system (volume = 3.7 L) were performed by JIANG ET AL. (2002, 2005). The main focus of their work was given to the description and the microbiological process management (e.g. the effect of hydraulic retention time and stirring media on acidogenesis). Less attention was paid to the mixing efficiency of the RDF.

This study aims at the development of a rotating drum fermenter to overcome suboptimal gas yields due to insufficient homogenization of the substrate. As a first step towards the development of a full-scale RDF for dry AD of biowaste, particular attention was given to the effect of baffles configuration, filling degree, and material characteristics.

2 Material and Methods

2.1 Identification and Characterisation of Model Materials

To reflect the heterogeneous properties of biowaste, several model materials were selected and characterized (cf. Table 1). Granular materials like wheat grains, mustard seeds and maize kernels were selected to reflect particular components like vegetables, fruits and food wastes. Straw, wood shavings, hemp bedding and cotton litter was selected as bulking material. The selection criteria were colourability and water uptake behaviour. Pre-soaking was necessary to mimic the typical moisture content of biowaste and to avoid changes of the material properties during the mixing experiments.

Table 1 Characteristics of model materials (native and soaked). Values given for TS, L_{max} and BD are based on 6, 100 and 10 determinations, respectively.

	TS native (%)	TS soaked (%)	L_{max} native (mm)	BD native (kg/L)	BD soaked (kg/L)
Mustard seed	92	30	2.1 ± 0.2	0.74	0.85
Wheat grain	88	64	6.3 ± 0.5	0.76	0.78
Maize kernel	92	63	11.2 ± 1.7	0.76	0.74
Wood shavings	92	27	11.5 ± 5.3	0.11	0.39
Straw	90	22	14.3 ± 7.7	0.12	0.39
Hemp bedding	88	19	10.8 ± 3.0	0.10	0.39
Cotton litter	88	18	4.2 ± 0.5	0.15	0.83

TS: Total solid content, L_{max}: Characteristic maximum length ± standard deviation, BD: bulk density

The slump of the model substrate was used as a rheometrical test to estimate the yield stress of the model substrate which dominates rheological behavior of biomass slurries such as pretreated corn stover (STICKEL ET AL. 2009). It was also successfully employed by other researchers to characterize anaerobic digestates (BAUDEZ ET AL. 2004; GARCIA-BERNET ET AL. 2011). The experimental set-up for yield stress measurements was adopted from (BAUDEZ ET AL. 2004).

2.2 Lab-scale RDF

To study the radial (two dimensional) mixing process, a lab-scale RDF (diameter 0.5 m, length 0.3 m, volume 50 L) was manufactured from acrylic glass. This allowed for the visual inspection (see Figure 1) of the substrate. The turning motion was achieved by an electric motor attached to a transmission chain mounted on a quill shaft. The latter may also serve as the feed inlet during transient mixing experiments if required. A rectangular area of the front end was used to quantify the temporal development of the mixing performance by image analysis. Therefore, part of the substrate was coloured with a dye.

To study the effect of baffles on the dynamics of the mixing process one evenly spaced straight baffle with a length of 0.2 m (80% of the RDF radius) was fixed normal to the drum wall. The baffle length was chosen based on results by SCHUTYSER ET AL. (2001)

who found that small baffles (< 50% of the RDF radius) hardly influenced the mixing of granular substrates.

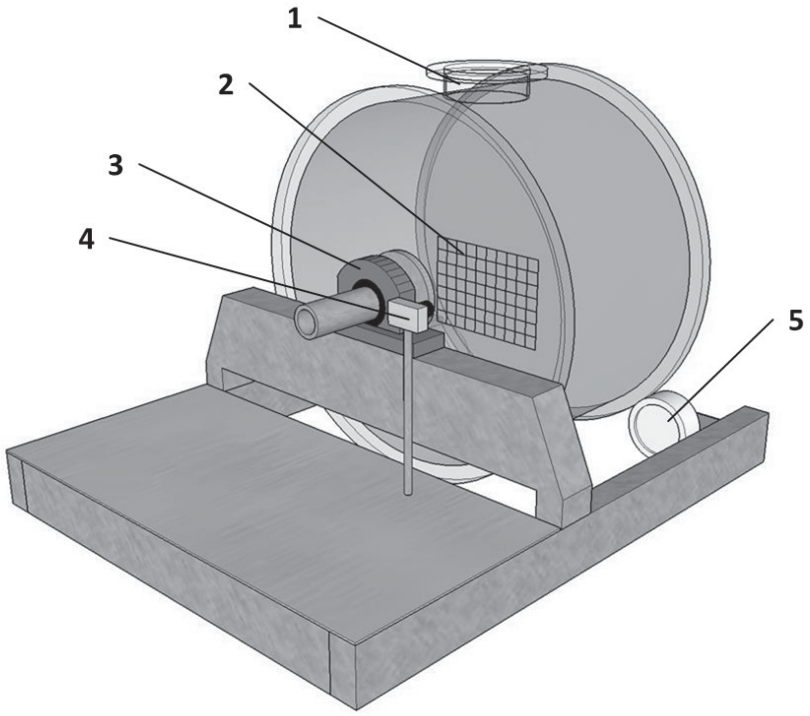


Figure 1 Schematic of the lab-scale RDF. 1: Filler pipe, 2: Area for image acquisition, 3: Mount, 4: Web-cam, 5: Roller.

2.3 Substrate pre-treatment

Concrete mixers were used both for pre-soaking the materials and the dyeing of aliquots with methylene blue (Merck, Germany). To trace the mixing process the native (uncoloured) and dyed model substrates were filled into the reactor as two distinct horizontal layers of uniform volume.

Two types of model substrates were studied. The first consisted of dyed and native (both pre-soaked) wheat grains as a typical substrate for solid state fermentation (MITCHELL ET AL. 2006; SCHUTYSER ET AL. 2001). The equilibrium moisture content of the wheat grains after pre-soaking for 16 h was about 35 % (65% TS).

The second type of model substrate involved dyed and native viscous mixtures of granular and bulky material. A polymeric suspension was added to achieve desired viscosity based on the yield stress (slump-test) of a real anaerobic digestate (KOMPOGAS dry AD, Fulda). The suspension contained semolina and wheat bran as fines and 0.05% xanthan with a TS content of 13%. The procedure of substrate preparation is outlined in Figure 2.

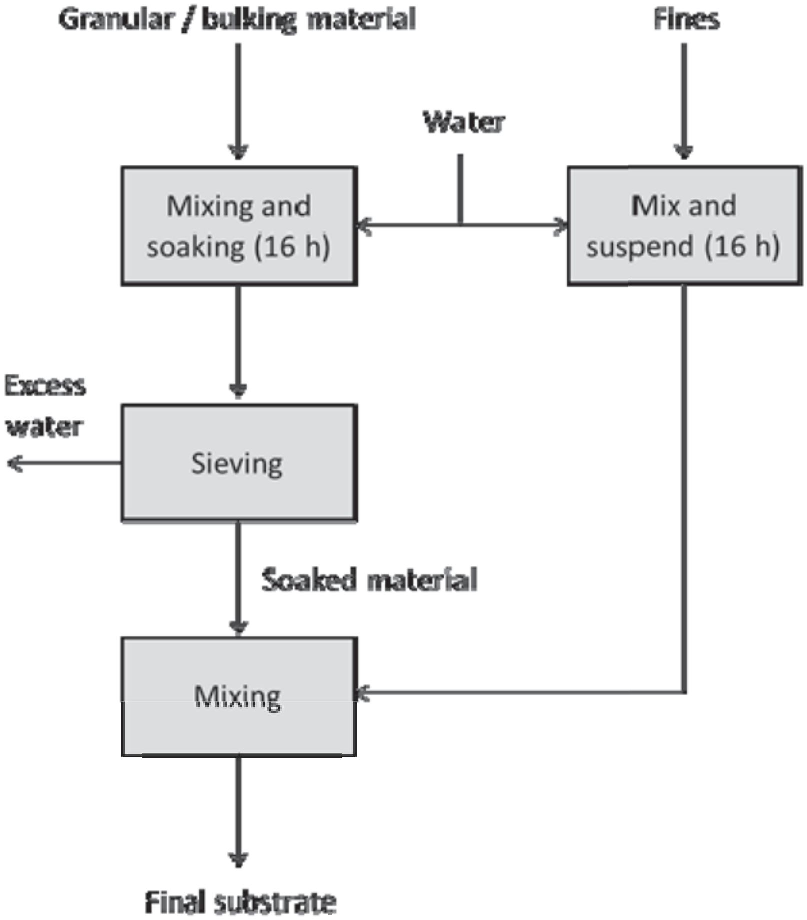


Figure 2 Substrate pre-treatment scheme.

2.4 Experimental

The mixing experiments were conducted at a rotation rate of 0.5 rpm. This is slow enough to provide a discontinuous motion (avalanching) of granular materials where each avalanche ceases completely before the next begins. This defines slow rotation since the timescale of turning is separated from the timescale of particle motion (METCALFE AND SHATTUCK 1996).

Typically, mixing in rotating drums having filling degrees larger than 0.5 is characterized by a successive breakdown of an unmixed zone (core). If breakdown is too slow incomplete mixing may result which leads to an uneven distribution of residence times during axial transport and thereby may hamper the AD process. To account for this effect the core size was also quantified by analysis of individual pictures against a calibrated scale.

2.5 Quantitative Image Analysis

To provide an objective proxy for the mixing efficiency the entropy of mixing was determined by image analysis. A detailed description of the method is given in (SCHUTYSER ET AL. 2001, 2002). The following modifications were made to the image processing: (i) Non-invasive image acquisition through the front end (see Fig. 1) avoided the need to "freeze" the system by a binder solution and slicing the whole bed into different axial sections prior to image acquisition. (ii) Instead of analysing the whole cross-sectional area of the RDF front end, image analysis was performed within a 15 cm x 10.5 cm rectangle section which was subdivided into 70 uniform cells (1.5 cm x 1.5 cm). (iii) Since the image section was always completely filled with substrate the entropy of mixing could be calculated without accounting for the actual number of particles in each cell. Image acquisition was done in intervals of 1/8 to 1 revolutions. The frequency of acquisition was adopted to the mixing progress (high resolution at the beginning, lower resolution towards the end of experiments). Image analysis was performed on the scale of individual pixels with a fuzzy-C-means-algorithm (MATLAB®) involving analysis of hue limiting values and superimposition of HSV-channels. The pixel numbers were used to calculate the ratio of native and colored particles in each cell. The mixing was assessed by dividing the sum of this ratio by the entropy of a randomly mixed system (SCHUTYSER ET AL. 2001). For image acquisition a webcam (Logitech c920 HD PC Camera) was used with an image resolution of 1,920 x 1,080 pixels. During image acquisition the drum was stopped. As stated by SCHUTYSER ET AL. (2001) good lightning and the use of appropriate dyes for the model material are critical for image quality and processing.

3 Results and Discussion

3.1 Mixing behaviour of granular substrate (wheat, TS > 35%)

Figure 3 shows the temporal evolution of the entropy of mixing for the granular substrate at different filling levels without the use of baffles. Two flow regions, typical for granular flow in rotating drums, were observed: the flowing layer region (active layer) and the "fixed bed" region (passive layer) (CHOU ET AL. 2010). For granular substrates we observed that the motion followed a slumping mode, i.e. after exceeding a critical value of the dynamic angle of repose the material slid down the passive layer in an avalanche manner and came to rest. For all filling degrees tested, a satisfactory degree of mixing was approximated during 15 revolutions of the RDF. The entropy time-course is characterized by a steep initial slope followed by an asymptotic approximation of values between 0.7 and 0.9. This corroborates findings by SCHUTYSER ET AL. (2001, 2002) and indicates that the non-invasive procedure of image analysis was adequate. The results obtained from the rectangular target area suggest that mixing performance was slightly faster and mixing was more complete at lower filling degrees.

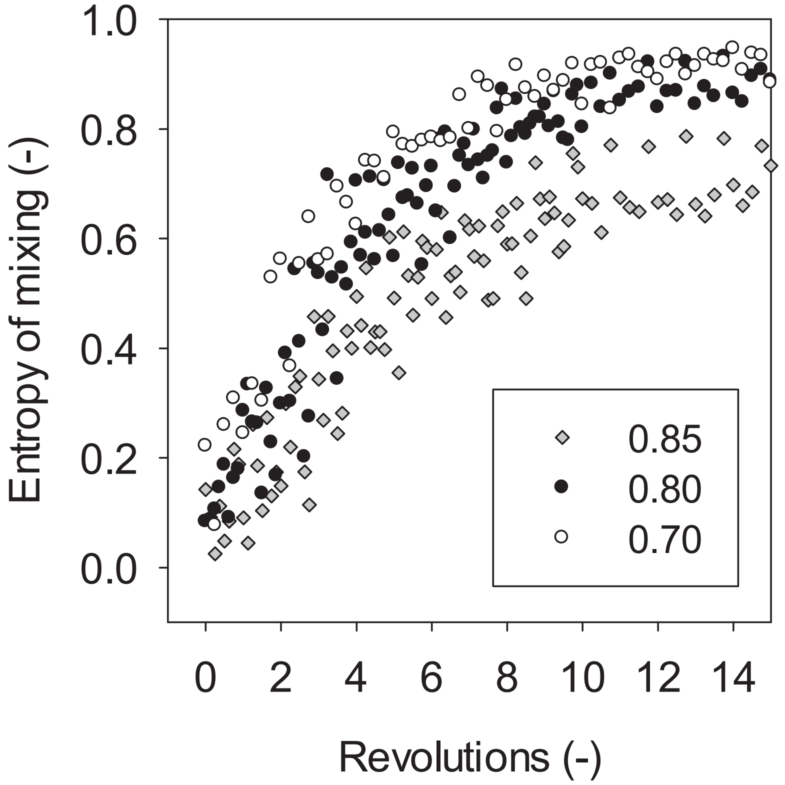


Figure 3 The entropy of mixing versus number of revolutions in a RDF at different filling degrees and without baffles.

In all experiments with granular substrates and no baffles an unmixed core of varying radium was conserved. This was independent from the filling degrees tested. Core size and speed of breakdown, however, were related to the operating conditions. Figure 4 depicts the breakdown of the core at a filling degree of 0.8 (dry and pre-soaked). As shown, part of the lower entropy of mixing obtained at this filling degree is due to the conservation of an unmixed core. Apparently, the core size and speed of breakdown depend on the moisture of the substrate and its consequence for the substrate motion (rolling vs. slumping mode). The residual core approached after 30 and 40 revolutions has a radius of 5 cm (wet substrate) and 8 cm (dry substrate). To overcome this imperfect mixing the use of baffles has been successfully demonstrated in a series of applications (SCHUTYSER ET AL. 2002).

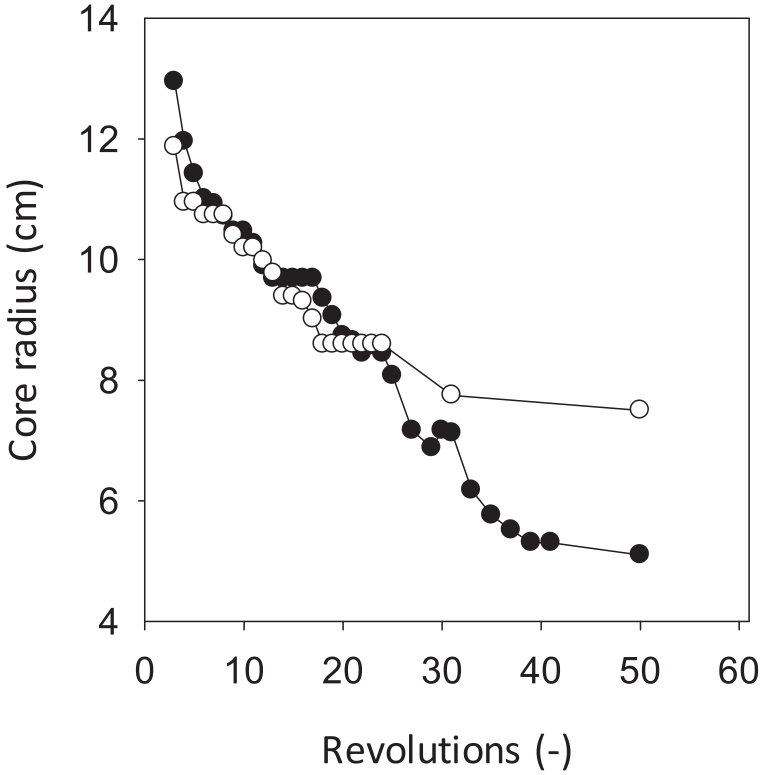


Figure 4 Core radius versus revolutions of the RDF. Comparison of dry (white circle) and soaked (black circle) granular material (filling degree: 0.80).

Figure 5 shows the perimeters of the unmixed zones obtained in presence and absence of a 0.2 m baffle mounted on the inner wall of the RDF. The baffle caused a distortion of the circular core observed in the experiments without baffles. As expected the breakdown of the unmixed zone was much faster. Also, we observed that the unmixed zone moved away from the centre of the RDF towards the back of the baffle. Since the baffle increases the angle of repose, part of the substrate is forced to “fall” through the centre region of the granular bed. This imposes an additional motion on the substrate: In addition to the avalanches of the active zone the motion takes place as a hopper flow causing a faster mixing of the material.

It is also noteworthy that mixing performance could be improved with only one single baffle. The most commonly reported design for rotating drum fermenters is to mount four baffles opposite to each other. However, a smaller number may be economically more favorable by reducing the specific power consumption {Wang 2013 #4076}.

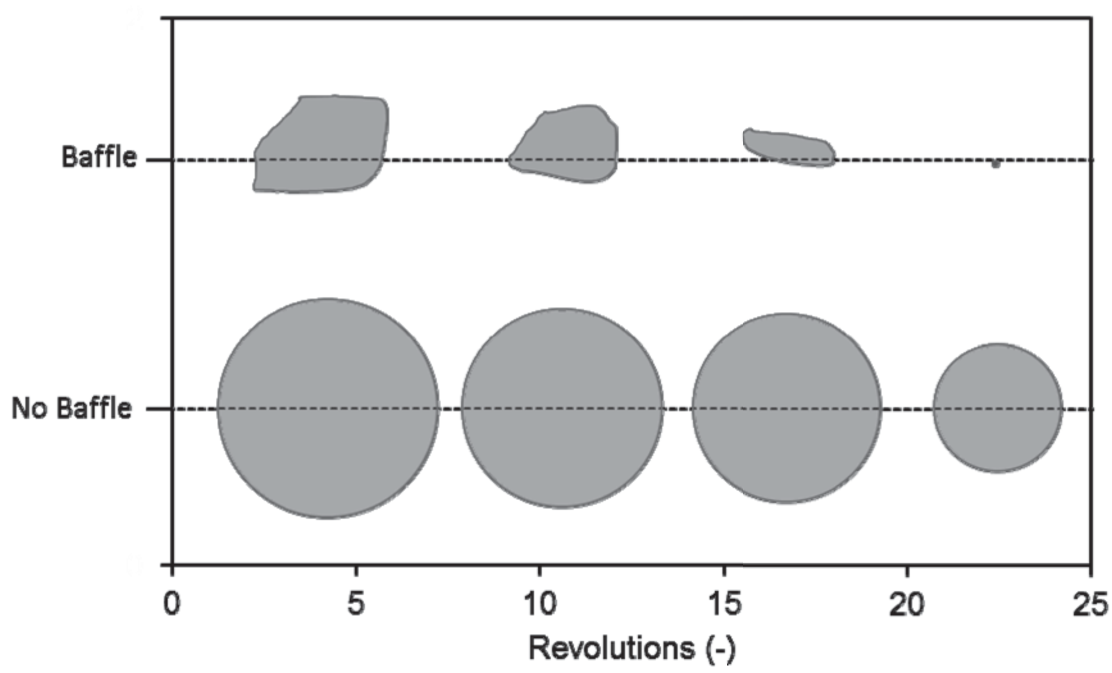


Figure 5 Perimeters of the unmixed radial zones recorded after 4, 11, 17 and 23 revolutions of the RDF with baffle (length: 0.2 m) and without baffle. Fill level: 0.80.

3.2 Mixing behaviour of viscous substrate (25% < TS < 35%)

To more realistically mimic the rheology of real biowaste substrates during AD, viscous substrates were also included in the mixing experiments. The composition of the tested substrates is given in Table 2. While the measured TS changed only moderately in the individual mixtures the yield stress showed strong variations. This indicates that TS does not adequately predict the rheological properties.

Table 2 Characteristics of Substrate 1 - 4 prepared according to Figure 2.

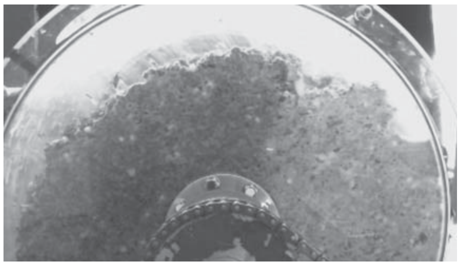
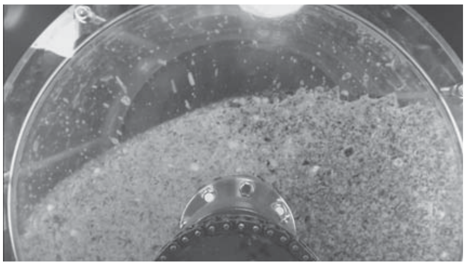
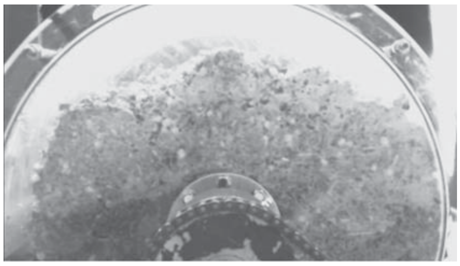
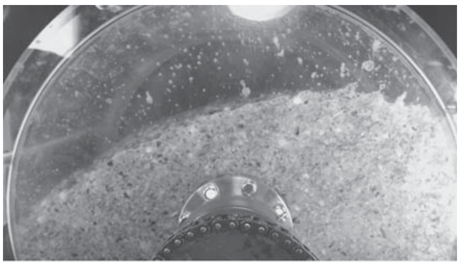
	Substrate 1	Substrate 2	Substrate 3	Substrate 4
Fraction (wt-%)				
Granular material	46	51	47	33
Bulking material	13	14	17	28
Suspension (13% TS)	41	35	35	39
TS content of mixture (%)	33	31	36	29
Yield stress (Pa)	74	172	>300	>500

Obviously, however, the yield stress is strongly related to the fraction of bulky material present in the mixture. Substrate 2 most closely resembles real digestates for which a yield stress around 200 Pa was observed. Test runs with substrate 2 and 3 were conducted in the presence of a baffle (0.2 m). The mixing behaviour of substrate 1 and 4 was studied in the absence of baffles.

Overall, compared to granular mixtures a more continuous flow pattern was observed for substrates with a yield stress below 300 Pa, i.e. no intermittent avalanching took place. In addition the thickness of the active zone was markedly enlarged. This suggests a faster mixing progress since the unmixed zone is less stable. However, in the absence of baffles mixing time was substantially increased. For substrate 4 (not shown) mixing as judged by the distribution of blue and native layers was unsatisfactory even after 60 revolutions.

Figure 6 depicts the radial mixing progress for substrates 1 and 3. Substrate 3 showed better degree of mixing already after 20 revolutions although having a higher yield stress.

Table 3 Comparison of the radial mixing progress for substrate 1 and 5 at 3, 20 and 40 revolutions of the RDF (fill level: 0.80).

Revolutions	Substrate 1 (no baffle)	Substrate 3 (baffle)
3		
20		
40		

4 Conclusion

The radial mixing performance for granular materials (TS >35%) of the RDF found in our experiments was satisfactory even at high filling levels of up to 80 % and could be further improved by a single baffle mounted on the inner wall of the RDF.

To more realistically mimic the rheology of real biowaste substrates during AD, various granular and bulky materials were mixed and blended with a polymeric suspension. The slump test was successfully applied as a rheometrical test to estimate the yield stress for those heterogeneous substrates. The observed flow dynamics were strongly influenced by yield stress and particle size distribution of the substrate. The necessary number of rotations to reach a well-mixed state was substantially increased in the absence of baffles.

Ongoing research is devoted to the relationship between the rheological characteristics and the resulting radial and axial mixing behaviour of viscous and heterogeneous substrates. Future work will also consider attempts to apply the quantitative image analysis (entropy of mixing) on such substrates.

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First year biomethane plant of BSR in Berlin: From biowaste to biofuel

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Abstract

Generation of biomethane from biowaste is thought to be a very interesting and climate friendly option for substitution of fossil fuels. However comprehensive data considering all relevant aspects of plant operation and subsequent processes with reference to emissions, energy efficiency and climate protection are rare.

To close this gap an extensive program with data collection and measuring for 1 year was conducted by BSR in Berlin to get a detailed description of the recently installed Biogas West process and to evaluate the greenhouse gas balance of this process.

The resulting key figures and balances give a reliable insight in what is fact today about generation of biofuel from biowaste by anaerobic digestion according to best practice and high emission reduction standards.

Keywords

Biowaste, anaerobic digestion, AD, biogas, gas upgrading, biomethane, biofuel, mass balance, energy balance, energy efficiency, emission factor, methane, nitrous oxide, greenhouse gas balance

1 Introduction

Since 2013 the public cleansing service of the City of Berlin „Berliner Stadtreinigungsbetriebe AöR“ (BSR) operates a plant for anaerobic digestion (AD) of 60,000 t/y separately collected biowaste (plant “Biogas West”). Biogas is upgraded to biomethane, which is utilized as motor fuel for the waste collection vehicles of BSR. For that purpose it is injected into the public gas grid and discharged at BSR depots. Today biofuel from biowaste drives about 150 gas powered waste collection vehicles in Berlin.

Ever since first conceptual considerations the plant concept of Biogas West was oriented to operate with very low emissions. Therefore, during design of Biogas West, emission data from existing AD-plants available at that time and the identified sources of emissions as well as potentials for optimization were consequently considered. These include for example

- Exhaustive digestion of biowaste using a continuous dry fermentation system
- Minimization of methane emissions from solid digestate by immediate aerobisation

- Reduction of methane emissions from process water by short retention times and small volumes of process water stores
- biogas capture during storage of liquid digestate (logistic stores) using closed stores with headspace connected to the biogas system
- enclosure of all emitting processes with capture and treatment of exhaust air via biofilters
- Removal of ammonia from exhaust air by acid scrubbing
- biogas upgrading by an amine scrubbing system with minimal methane loss.

Figure 1 BSR Biogas West

Within the scope of permit procedure in 2011 an estimation of greenhouse gas balance for the plant Biogas West was conducted by iba GmbH, Hanover. In 2014, based on operation data from the first year of regular plant operation, basic data and results of the greenhouse gas balance were critically reviewed and evaluated.

The evaluation process, also executed by iba GmbH, covered an extensive program of data acquisition from operation, measurements and laboratory analytics at Biogas West. Also included was the determination of emissions of subsequent digestate treatment (e. g. external compost production from solid digestate, external storage of liquid digestate). By data collection over a period of 12 month and hence considering seasonal variations a significant data basis for the evaluation was obtained.

In the following plant concept, characteristic operation data and results of the greenhouse gas balance of BSR Biogas West are presented.

2 Project time flow

The biomethane plant Biogas West was erected by order of BSR on an old industrial area in the urban space of Berlin (Berlin-Ruhleben). Planning and consulting for the project started at end of 2007 (contractor for consulting: Consortium of iba GmbH, Hanover and Grontmij GmbH, Berlin/Cologne). The contract for construction and start-up was awarded in September 2009 to a consortium of STRABAG Umweltanlagen GmbH, Dresden and STRABAG AG, Berlin as general contractor.

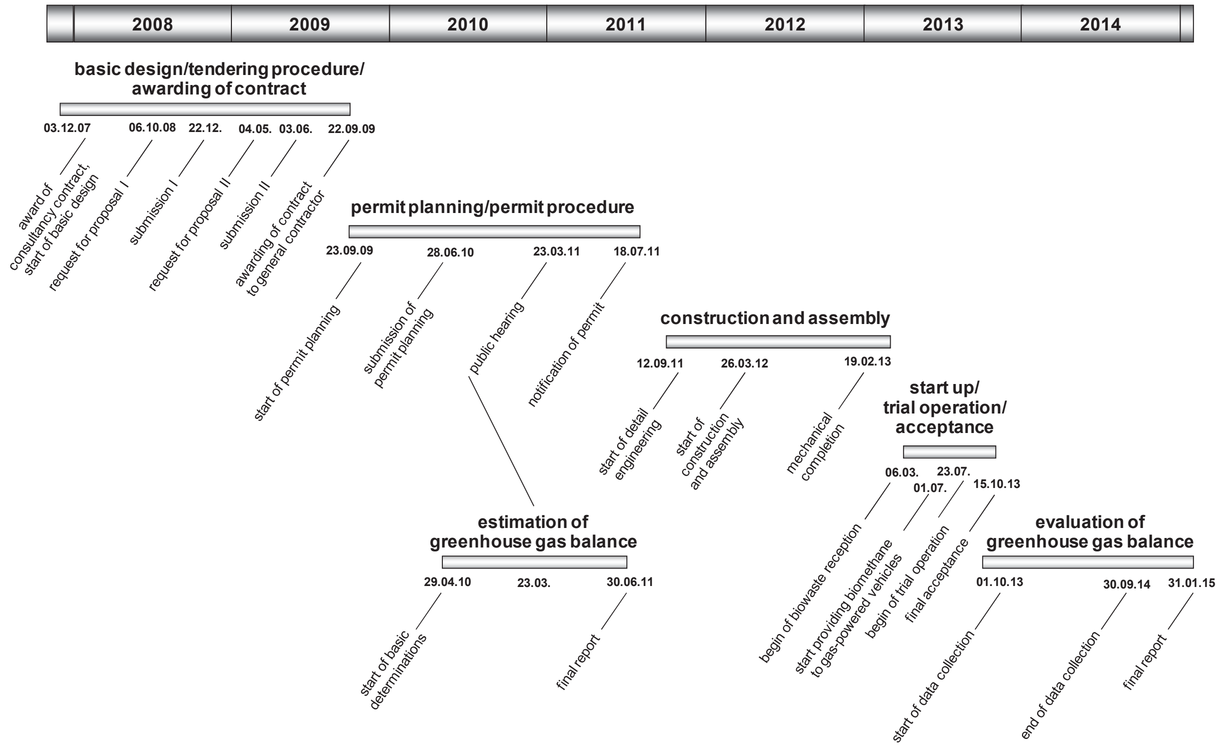

Figure 2 schematic time flow of project BSR Biogas West

Due to a special focus on reduction of emissions and to find out, if the Biogas West process could be a favorable and climate-friendly way of biowaste utilization, permit planning and the permit procedure for the plant Biogas West lasted longer than usual (about 22 month). In particular permit application was complemented by an estimation of greenhouse gas balance for Biogas West based on design specifications for operation and on expected values for emissions. Finally all questions in this context could be answered satisfactorily and notification of permit was handed out by the approving authority in July 2011.

In September 2011 detail engineering and preparation of the panel started. Panel preparation proved to be laborious and time-consuming due to undestroyed parts of old industrial buildings in the ground. Construction phase began in March 2012 and from then on construction and assembly (11 month), start-up (4 month), trial operations (3 month) and transfer to regular operation could proceed according to the time schedule until final acceptance at October, 15th 2013.

To fulfill a distinct condition of the permit, concurrent to the beginning of regular plant operation in October 2013 data collection started for evaluation of the greenhouse gas balance. The period for balancing ended one year later at September, 30th 2014. The final evaluation report was presented in January 2015.

3 Process concept

Biowaste from the city of Berlin is separately collected and transported by collection vehicles to the plant Biogas West. In the plant the biowaste is mechanically treated (MT) by screening (70 mm) and metal separation. The fine fraction from screening (< 70 mm) is buffered in a store before feeding to digestion. The coarse fraction (> 70 mm, biomass and impurities) is used externally for energy recovery (thermal utilization). Operation time of MT is about 8 hours at 6 days a week.

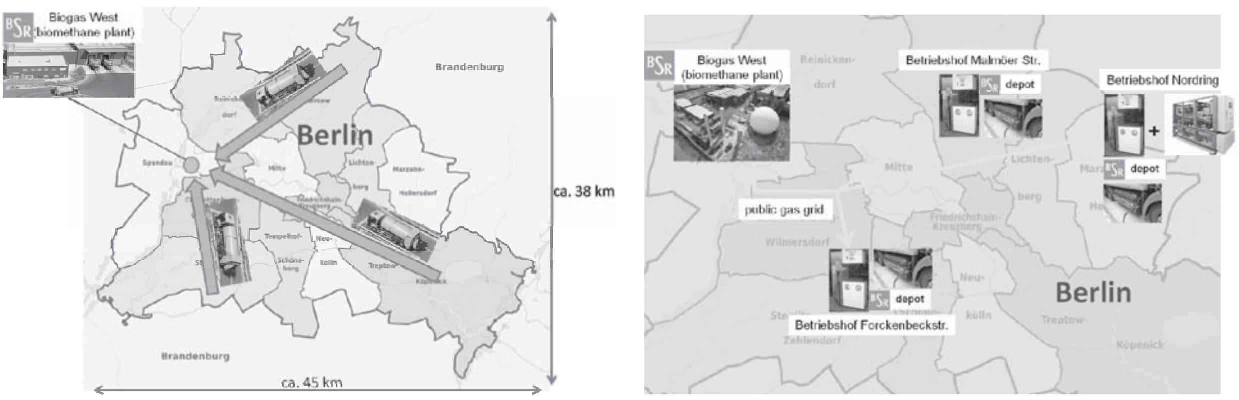

Figure 3 biowaste collection and biomethane utilization by BSR in Berlin

From the buffer store the fine fraction is fed to two horizontal plug-flow digesters. Operation time of feeding is 24 hours at 7 days a week (continuous feeding). The digestion process runs thermophilic (ca. 55 °C) with a dry matter (DM) content in the reactors of ca. 25 % (dry AD) and a retention time of approx. 3 weeks. The thermophilic process effects sanitation of the digestate according to the German biowaste directive.

Biogas from the digestion process is desulphurized and cooled to remove humidity before it is transferred (via gas holder) to the gas upgrading system. Via amine scrubbing carbon dioxide (CO_2) is separated generating biomethane from the biogas. The biomethane is compressed and conveyed to the station for gas injection to the public grid. The station for injection was newly erected, adjacent to the entrance area of Biogas West, by the grid operating company (NBB). After quality check and adding of LPG (if necessary) injection of biomethane to the public grid is carried out.

As byproducts of the digestion process solid and liquid digestate are produced via dewatering of the digester output. Liquid digestate is partially recirculated to the reactor input for use as inoculate. Quantities not needed for inoculation are pumped to two buffer stores (logistic stores) before loading and carriage to external digestate stores.

The logistic stores at Biogas West cover a capacity of ca. four days. The head space of the closed and anoxic vessels is connected to the biogas system via a gas transfer line. Hence instead of emitting to the environment residual biogas produced in the logistic stores is collected and upgraded to biomethane together with the biogas from the digesters.

Liquid digestate output of Biogas West is recycled as fertilizer in agriculture. For this purpose long time stores were erected at customers' sites in the surrounding countryside (Brandenburg). Liquid digestate is transported there by tank vehicles. Stores are open at top with the surface of the digestate covered by plastic floating bodies for odour reduction (except one store, where floating bodies are not used).

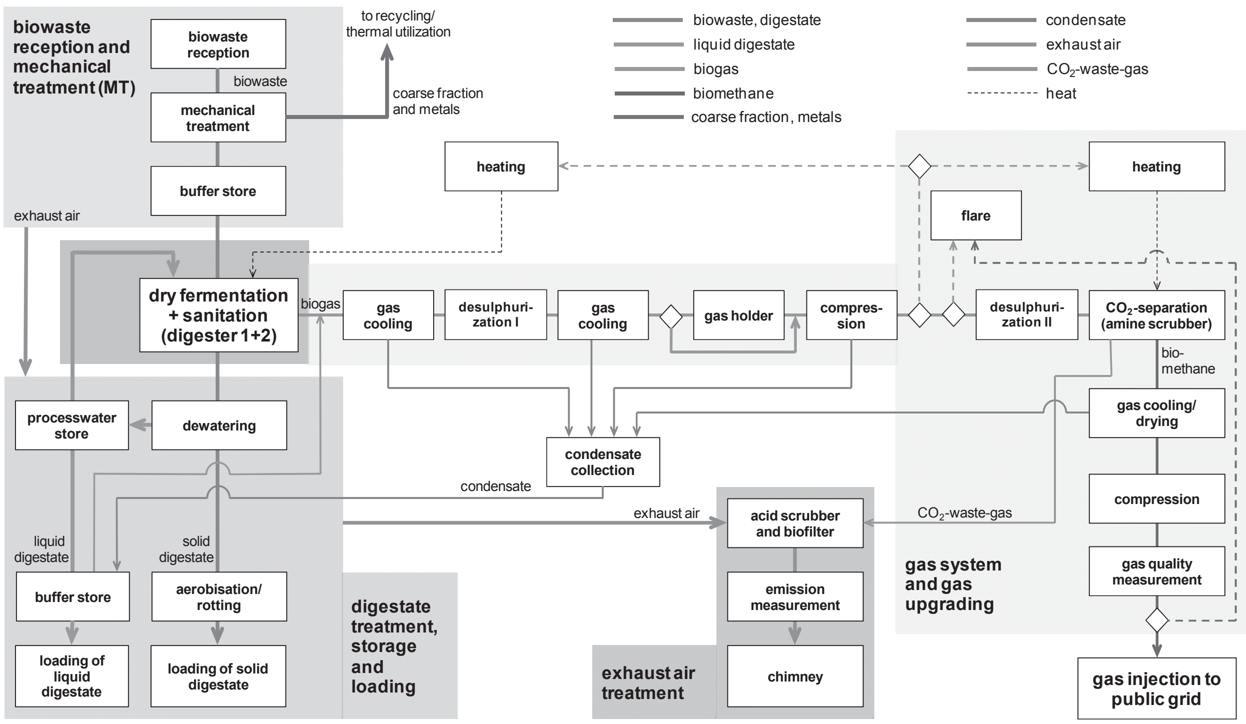

Figure 4 process flow chart of plant Biogas West

Solid digestate is intensively aerated and maturated for one week in a closed hall at Biogas West (aerobisation). By the aerobisation process residual fermentation activity is stopped and residual biogas is removed from pores in the digestate. Aerobic degradation also is promoted in the digestate during aerobisation. Thereby and by additional heating of the injected air a reduction of moisture in the solid digestate can be achieved. Afterwards the treated solid digestate is carried by trucks to composting plants in Brandenburg for compost production (open windrow composting).

At Biogas West handling of biowaste and digestate occurs in closed buildings with exhaust air capture. All streams of exhaust air are collected and ammonia is removed by acid scrubbing. Subsequent the exhaust air is treated in biofilters for reduction of organic load and odour. Finally the exhaust air is discharged to the environment via a chimney. At the chimney an access for sampling and a continuous measurement for total organic carbon (TOC) are installed for monitoring of emissions.

The process equipment is completed by two heating stations (heating of digesters and heating of thermal oil for regeneration of amine), a system for condensate collection, safety installations (e. g. flare) and the process control system incl. visualization.

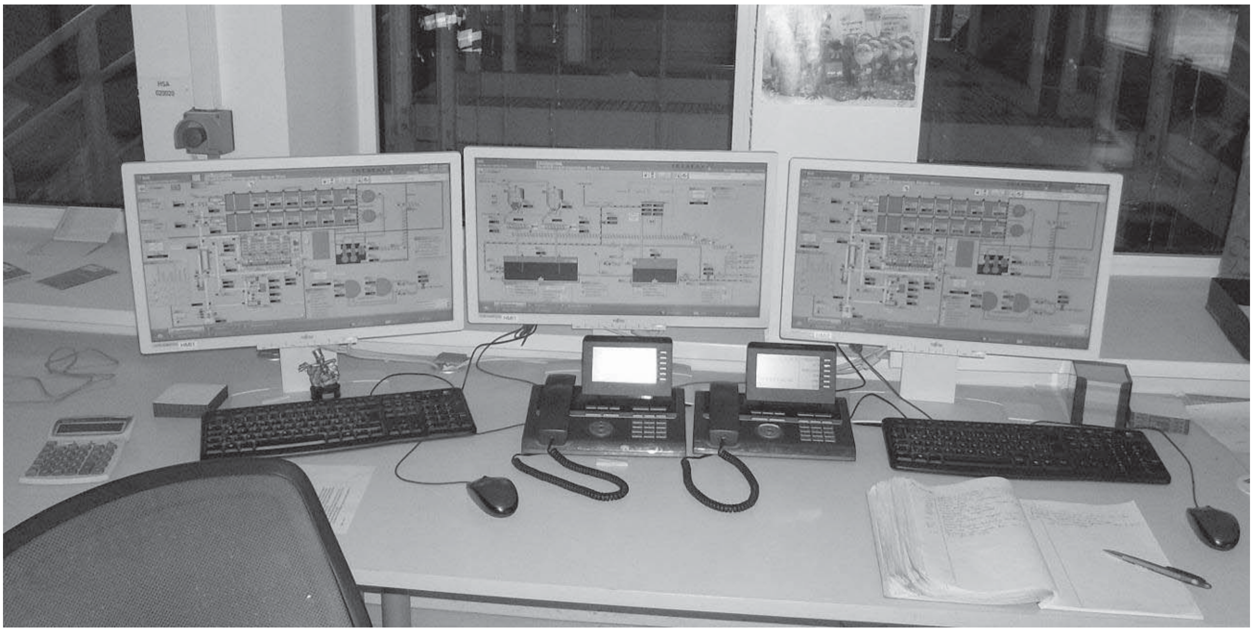

Figure 5 Process visualization at the control room of Biogas West

4 Biowaste throughput and mass balance

Main basis of mass balance of Biogas West are daily data from vehicle weighing at entry and exit. For the first year of regular operation (= balancing period) the collected and delivered biowaste summed up to 55,529 t/y. That was 92.5 % of design value (60,000 t/y). Collected amounts of biowaste not constantly reached the design level in particular in the first half of the balancing period.

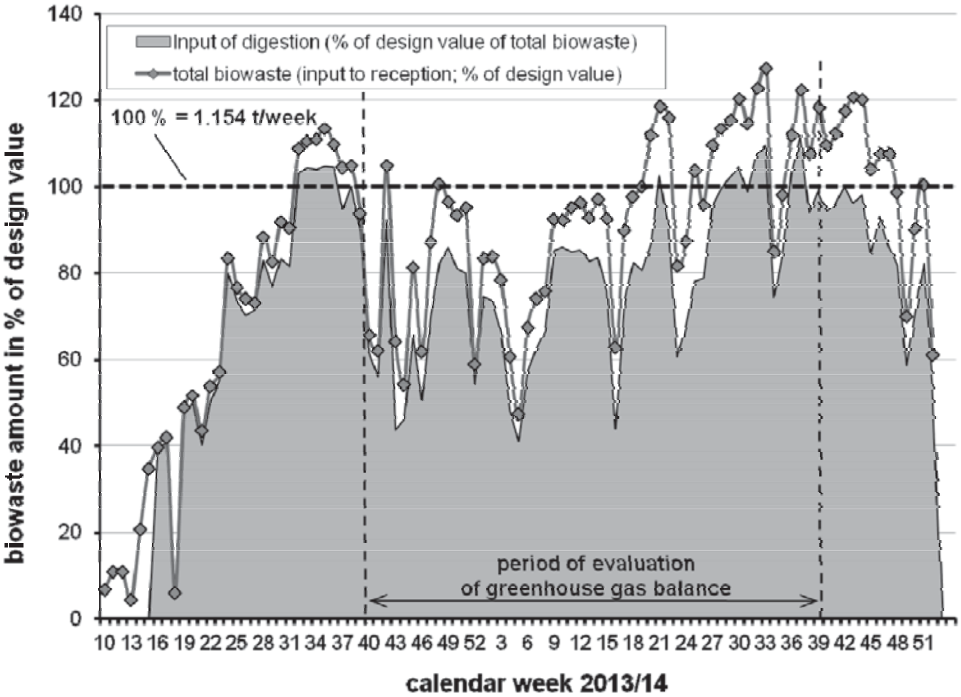

Figure 6 development of input quantities

Comparison of input quantities of reception (or input MT respectively) and input quantities of digestion (fine fraction < 70 mm) shows a relative high difference mostly caused by the separated coarse fraction (> 70 mm) from MT. A coarse fraction is produced to separate coarse materials including plastics and other impurities from the biowaste before feeding to anaerobic digestion. The coarse fraction amounted to about 15 % of input biowaste during balancing period. Fe-metals also separated by MT are only of small relevance in mass balancing (0.1 %).

Corresponding to the portion of coarse fraction from MT input quantity of digestion summed up to approx. 84 % of total input of biowaste.

Total digestate output came up to 85 % of biowaste input throughout the balancing period (52 % liquid + 33 % solid). This includes condensate and other streams of process water added to the liquid digestate.

Biogas (before upgrading) contributed about 10 % to the mass balance, whereas biomethane to injection accounted for 3 %. Overall biogas and biomethane yields were moderately lower than expected due to temporarily low collection quantities of biowaste, relative high amounts of coarse fraction and a moderate specific biogas yield.

For further enhancement of capacity utilization of the digestion process an increase in total biowaste input to the plant Biogas West is intended by BSR. For this purpose an add-on to the operation permit was applied by BSR and recently authorized by the approving agency, covering an uprating of the total plant throughput to 75,000 t/y.

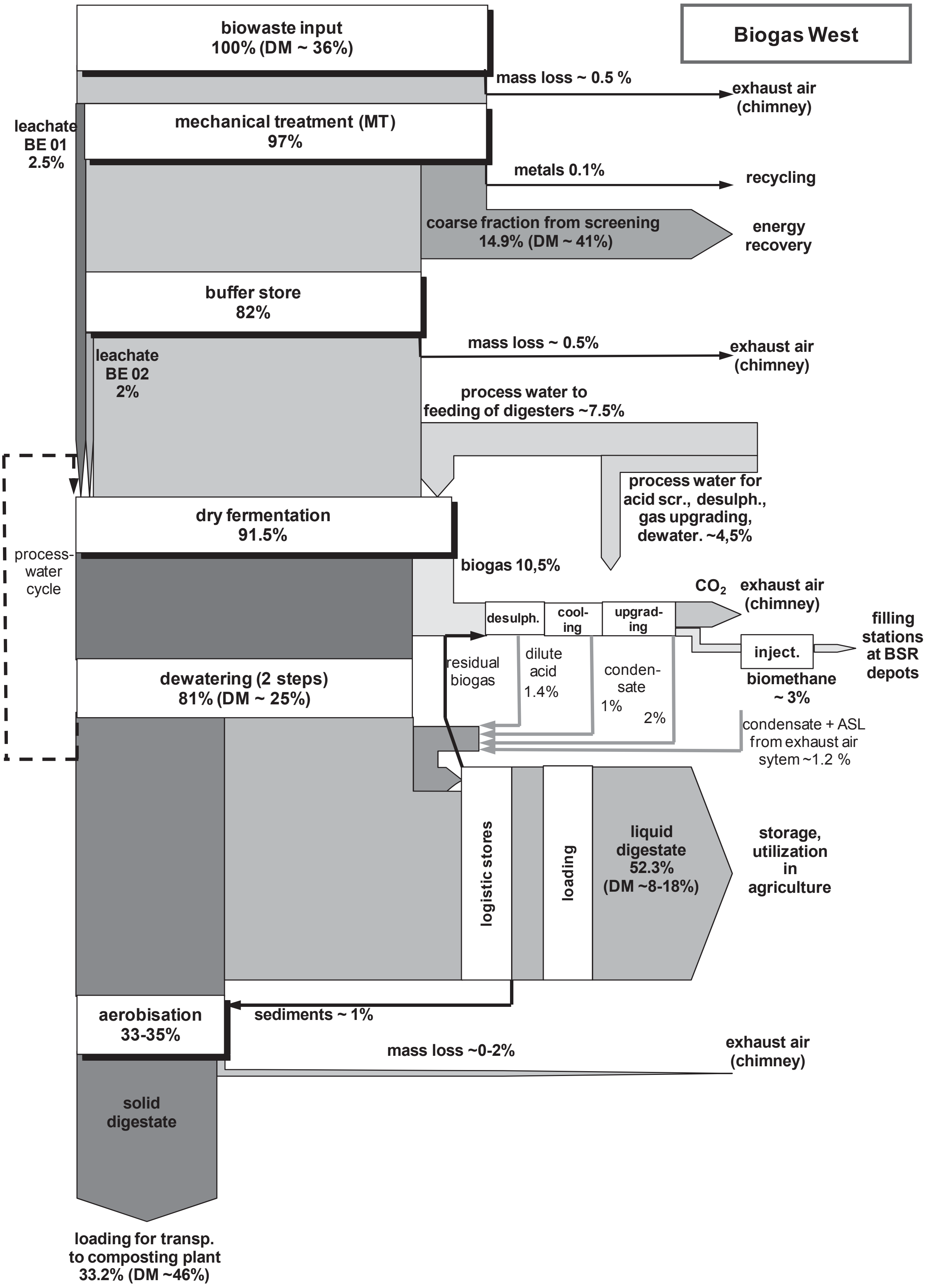

Figure 7 mass balance 2014

5 Utilization of coarse fraction (> 70 mm) from MT

The coarse fraction from MT was subject to a special program for composition analysis (four sorting campaigns throughout the balancing year). The striking result was a portion of about 90 % biogenic organics (≈ green waste) and only 9 % of plastics (incl. small amounts of sanitary products) as mean composition of the coarse fraction.

The portion of non biogenic compounds in the coarse fraction amounts to ca. 1.4 % with reference to total biowaste. This seems to be not too high, although separation is necessary to secure a high quality of digestate. A potential for optimization of separation technics for plastics/impurities is indicated to lower the portion of biogenic organics in the coarse fraction in favor of enhancing input-quantities to digestion.

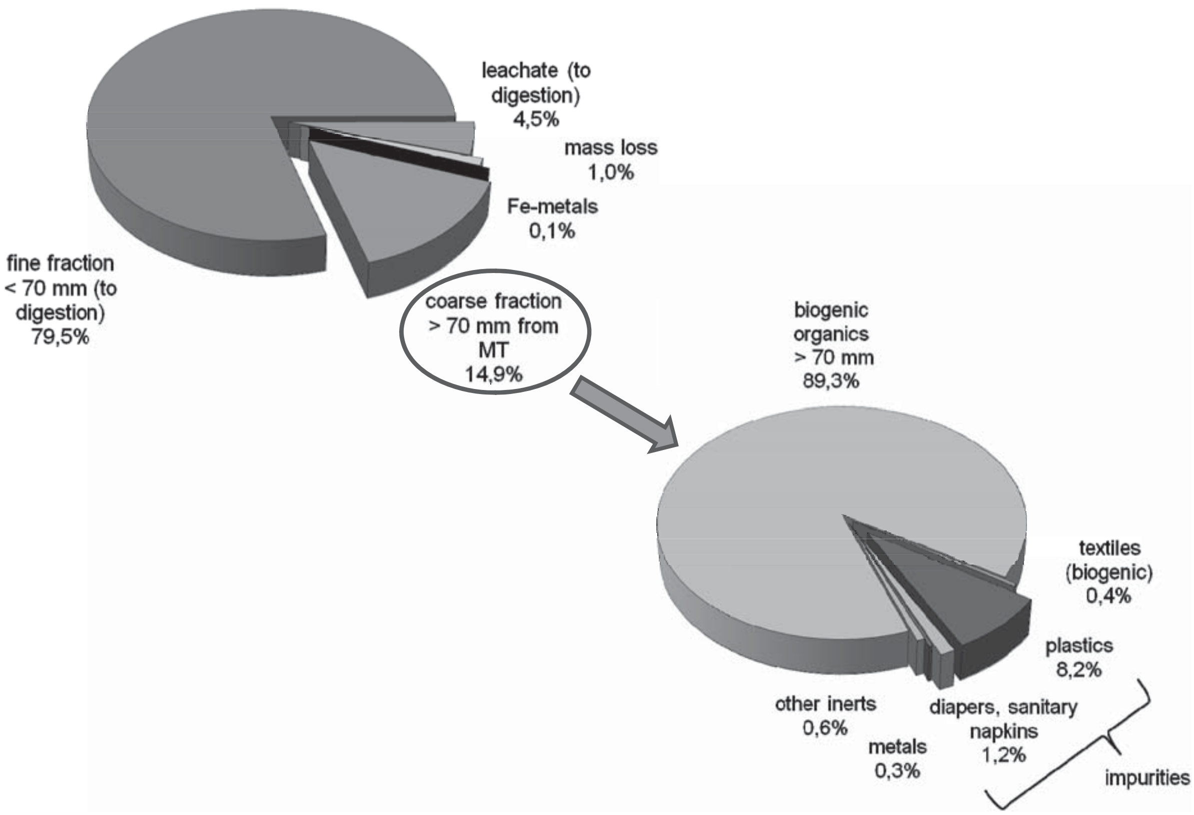

Figure 8 quantity and quality of coarse fraction (> 70 mm) from MT

The coarse fraction from Biogas West is subject to thermal utilization. The lower heating value (H_i) of this fraction was analyzed to ca. 5,100 kJ/kg. From laboratory analysis the content of fossil carbon was estimated to approx. 3.4 kg C_{foss}/t biowaste.

These data in combination with data of energy efficiency of the WtE-plant (MHKW Ruhleben) were used in the greenhouse gas balance to calculate carbon credits and debits for thermal utilization of the coarse fraction. As result net carbon credits from this fraction significantly contribute to the greenhouse gas balance.

6 Biogas balance

Biogas data are continuously drawn from different measuring points in the biogas system of Biogas West. Raw biogas sums up to about 4.7 Mio. m^3/y with an average methane content of ca. 55 % throughout the balancing period.

The raw biogas produced in the fermenters is mainly broken down to biomethane (about 50 vol.-%) and waste gas (CO_2; 36 vol.-%) by upgrading. Before gas upgrading about 10 vol.-% are separated by gas cleaning and cooling (humidity/condensate and trace gases). Only small amounts of biogas and biomethane were burned by a flare or internally used for heating.

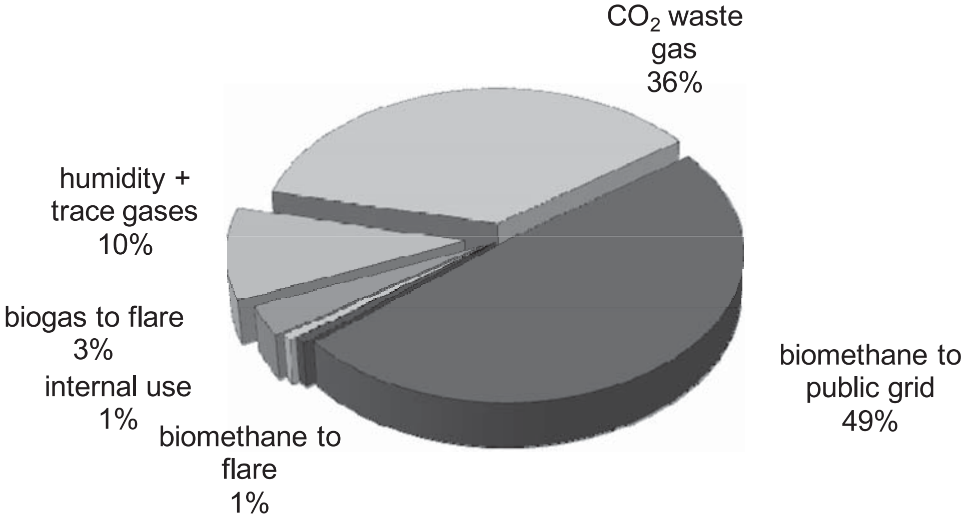

Figure 9 biogas balance 2014

The specific biogas yield throughout the balancing period was determined to 91 Nm^3 Biogas / t input digestion as average value. Due to seasonal variations in biowaste quality a fluctuation margin of ca. 60 – 160 Nm^3/t was observed.

An exhaustive digestion was proven by comparison of the biogas yield from the process with biogas yields from laboratory analysis of digester input and digestate. Digestate shows a very low level of residual biogas yield for all spot checks. Methane yields of ongoing sampling and laboratory analysis of digester input were always even lower compared to the real methane production from digesters.

It has to be determined that biowaste quality has changed to a lower biogas yield since it was checked as basis for plant design (in 2007).

During the balancing period about 2.3 Mio Nm^3/y were generated by the gas upgrading facility and injected into the public grid. The installed gas upgrading system works very stable with a very low methane loss (about 0.1 % of biomethane) and a very high average methane content of about 97-98 % in biomethane.

Output of biomethane (biofuel) amounts to ca. 180,000 Nm^3/month (2.1 Mio Nm^3/y). Waste collection vehicles are supplied by filling stations at three BSR depots. About 150 vehicles are continuously powered by biofuel from biowaste. This ensures a low-emitting collection of MSW and biowaste in the city of Berlin.

The energy content of biofuel represents a very important source of carbon credits in the greenhouse gas balance.

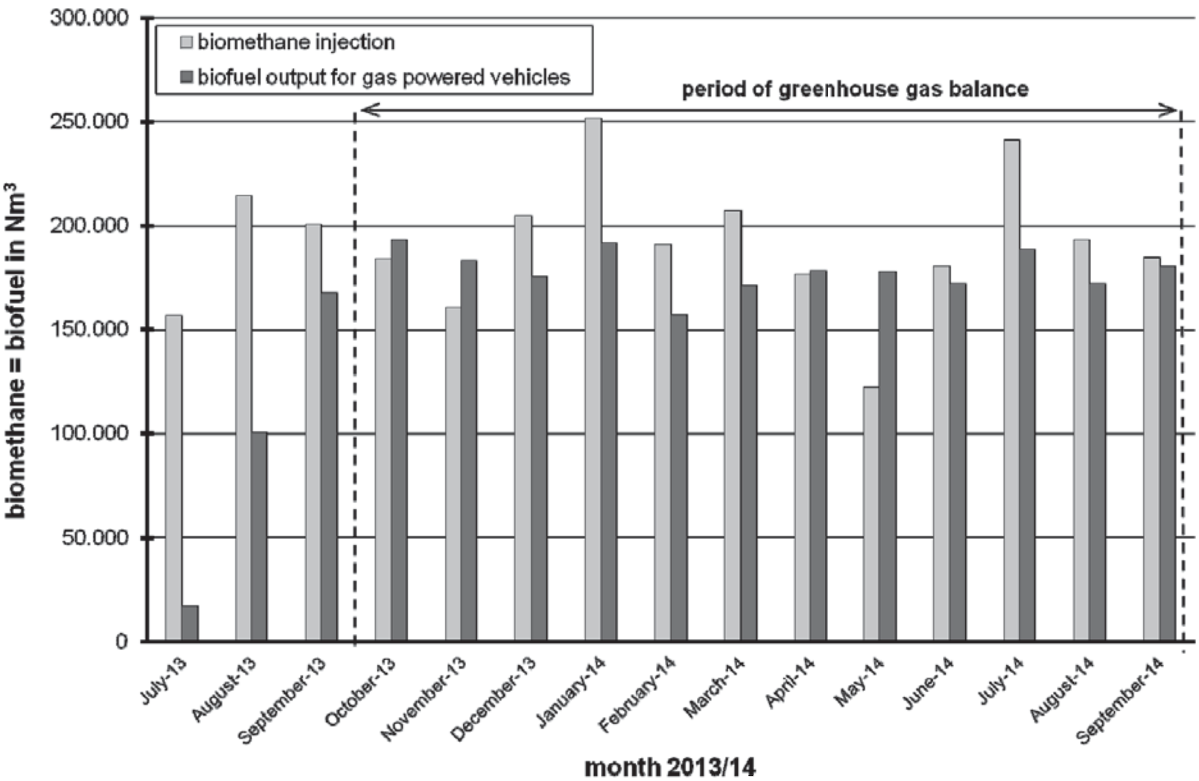

Figure 10 development of biomethane injection and biofuel output

7 Energy balance

For energy balancing of the Biogas West process the following parameters were examined:

- energy input with biowaste
- energy consumption of plant Biogas West (power, heat, diesel)

- energy consumption of gas injection, transport and compression at filling station
- energy consumption by transport of output (metals, digestate, coarse fraction)
- energy consumption of external treatment and application of digestate
- energy output via biomethane
- net energy output from thermal utilization of coarse fraction
- energy output via digestate

Energy consumption of the plant Biogas West was found to be much lower than design values (ca. -40 to -50 %). This means a relevant decrease in carbon debits compared to previous estimations.

For heating purposes at Biogas West natural gas (CNG) from the public grid was used most of the time, with a view to maximizing biomethane injection for use as biofuel. CNG consumption corresponded to ca. 22 % of biomethane produced throughout the balancing period.

Table 1 energy consumption of plant Biogas West

Energy carrier	**Design specification**	**Operation data**	**Difference**	**Specific consumption**
Power	3.674.683 kWh/y	2.094.436 kWh/y	-43%	38 kWh/t
Natural gas	8.150.886 kWh/y	4.843.080 kWh/y	-38%	91 kWh/t
Biogas	0	183.246 kWh/y		
Motor fuel (for wheelloaders)	44.000 l/y	22.072 l/y	-50%	0,4 l/t

Energy content in biowaste input was determined to ca. 750 kWh/t biowaste. More than half of the energy input with biowaste leaves the plant Biogas West in form of biomethane (54 %). This is converted into diesel equivalents with an efficiency factor of ca. 87 % by use in BSR waste collection vehicles.

About 32 % of energy input with biowaste leaves the plant Biogas West within the solid digestate. After composting about 21 % of energy are left in the compost. Liquid digestate features a negative heating value due to a high content of water and a low portion of organic dry matter.

The biomass-rich coarse fraction from mechanical treatment of biowaste contains about 28 % of energy input. This fraction as well as another coarse fraction from post-treatment of compost is subject to thermal utilization with a joint energy output (power + heat) of approx. 20 % of energy input with biowaste.

The combined energy output in form of the energy sources biofuel, heat and power amounts to about 67 % of energy input with biowaste. Compared to this, energy input in form of power, CNG and diesel for the overall process sums up to ca. 24 % of energy input with biowaste.

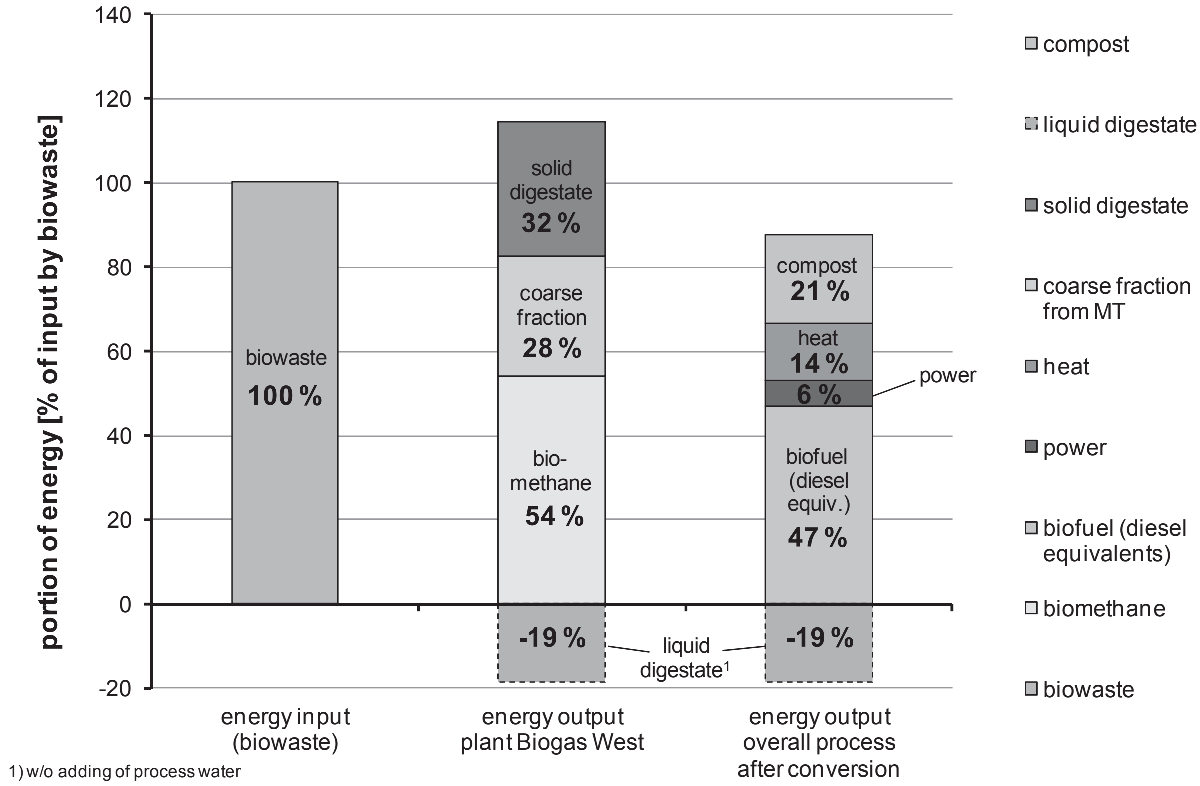

Figure 11 energy balance 2014 (here: energy output from biowaste)

Future optimization measures by BSR will focus on enhancement of biogas yield to increase biomethane output and/or substitute CNG by biogas. This presumably will further improve energy efficiency of the Biogas West process and hence will have positive effects on greenhouse gas balance too.

8 Emissions

The notification of permit for Biogas West includes detailed requirements concerning emission control und supervision. Amongst others a limit value for total organic carbon in exhaust air (TOC < 200 mg C/Nm^3 yearly average) was defined for the first time regarding biowaste treatment plants in Germany. For that purpose the permit requirements stipulate a continuous measurement and recording of the TOC content emitted through the chimney of Biogas West.

To determine the content of greenhouse gases in exhaust air of plant Biogas West emission data from continuous measuring and data from additional sampling and analyzing of exhaust air were collected throughout the balancing period. Thereby the portion and load of methane in TOC and significant data on development of nitrous oxide (N_2O) content and load in exhaust air were obtained.

Corresponding to previous assumptions (greenhouse gas balance 2011) average methane-C portion in TOC was found to be 80 % in exhaust air.

As main result the effective TOC-emission via chimney of plant Biogas West amounted to 80 mg C/Nm^3 as yearly average, which is 60 % lower than permit limit. The TOC-load at chimney sums up to 25 t/y, corresponding to an emission factor of 453 g C/t biowaste throughout the balancing period. The emission factor for nitrous oxide in 2014 represents 13.7 g N_2O /t biowaste, which is about 55 % less than estimated during permit planning in 2011.

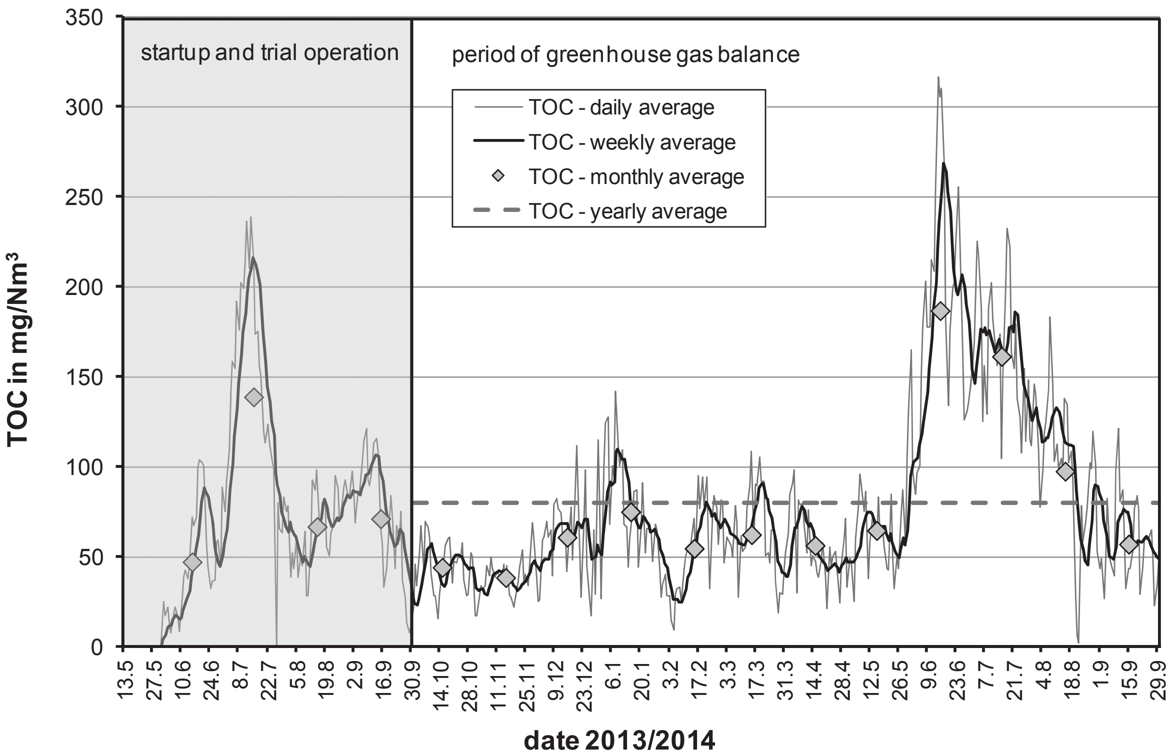

Figure 12 development of TOC emissions at plant Biogas West (chimney)

Looking at shorter data sections (daily/weekly/monthly average) it is found that, due to operational and seasonal effects, TOC-content in exhaust air considerably fluctuates throughout a year. Even TOC-peaks of much more than 200 mg C/Nm^3 were recorded for short times. By this it becomes clear that long evaluation periods are required, if emission limits for biological processes are defined and supervised.

Due to effective measures and equipment for emission reduction fugitive emissions only occur to a very small extent at Biogas West. For overall emission balancing 5 % of emissions at chimney were added in calculation across the board as fugitive emissions.

Concurrent to data collection at plant Biogas West an extensive measuring program to determine greenhouse gas emissions (methane and nitrous oxide) from compost production with solid digestate and from long term storage of liquid digestate at external sites was conducted.

Figure 13 liquid digestate store (left, here: Milower Land, Brandenburg) and open windrow composting of solid digestate (right, here: Trappenfelde, Brandenburg)

The measuring programm included e. g.

- Emissions of transport of digestate from Biogas West to external sites
- Emissions of filling liquid digestate into stores
- Emissions of liquid digestate storage at rest
- Emissions of liquid digestate while agitation
- Dynamics of liquid digestate quantities in external stores
- Energy consumption by liquid digestate transport and storage (see energy balance)
- Emissions of composting of solid digestate
- Dynamics of solid digestate quantities at composting plants
- Energy consumption of composting (see energy balance)

To record seasonal fluctuations four measuring campaigns were conducted throughout the balancing period of one year.

Results are given in the following for the overall process including emissions of plant Biogas West. It can be stated that just as for plant Biogas West emissions of composting and of long term storage of liquid digestate were much lower compared to expected values from permit planning. In total the emission factor for TOC sums up to 934 g C/t biowaste in 2014. For nitrous oxide an overall emission factor of 18 g N_2O /t biowaste was determined.

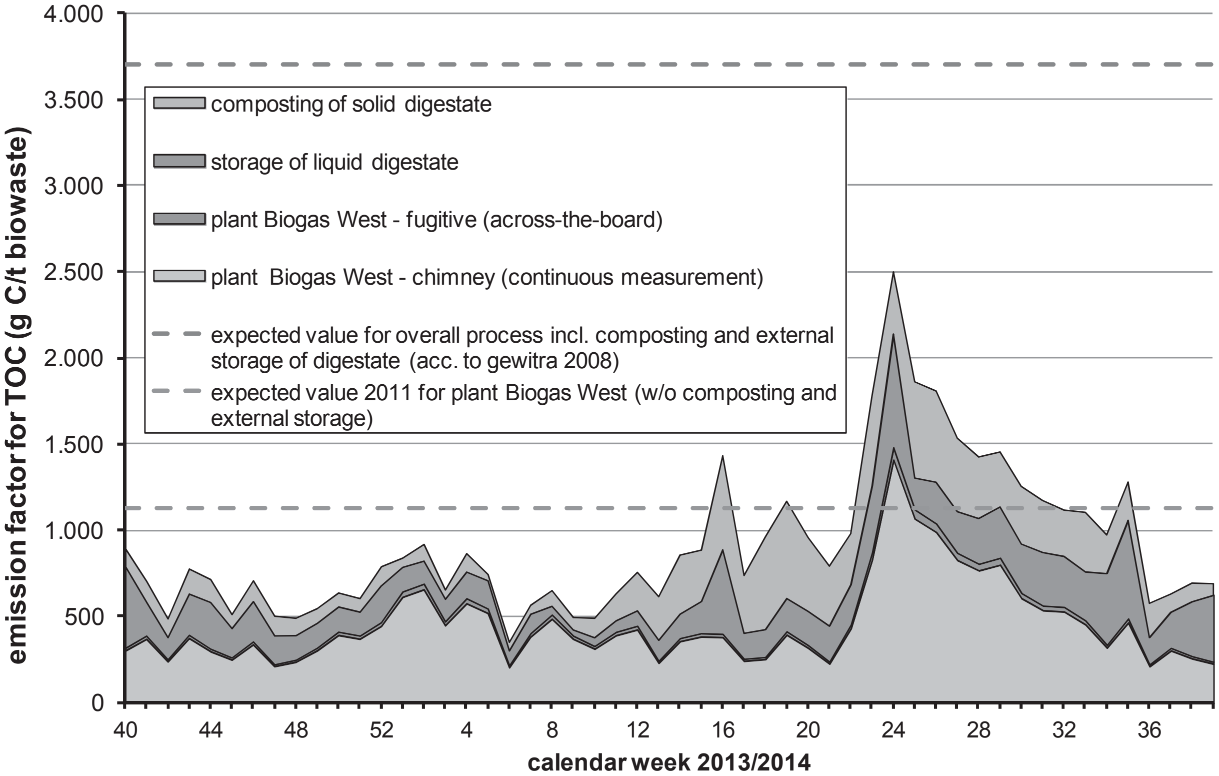

Figure 14 development of TOC emission factor of BSR Biogas West (overall process) during balancing period

The presented emission factors for Biogas West can be compared to current investigations for utilization of biowaste in Germany (gewitra, 2014). This comparison shows, that overall emissions of the BSR Biogas West process are about 80 % lower for TOC and about 75 % lower for N_2O than average values estimated in the cited study for german AD plants with subsequent open windrow rotting. Differences to expected values from permit planning of Biogas West are in the same range.

Due to an elaborate plant conception and efficient treatment of biowaste and digestate at Biogas West emissions from the biogas plant and from subsequent treatment, storage and application processes of digestate are by far lower compared to standard processes.

As consequence carbon debits based on emissions of Biogas West and of subsequent treatment steps turn out to be significantly lower compared to previous estimations.

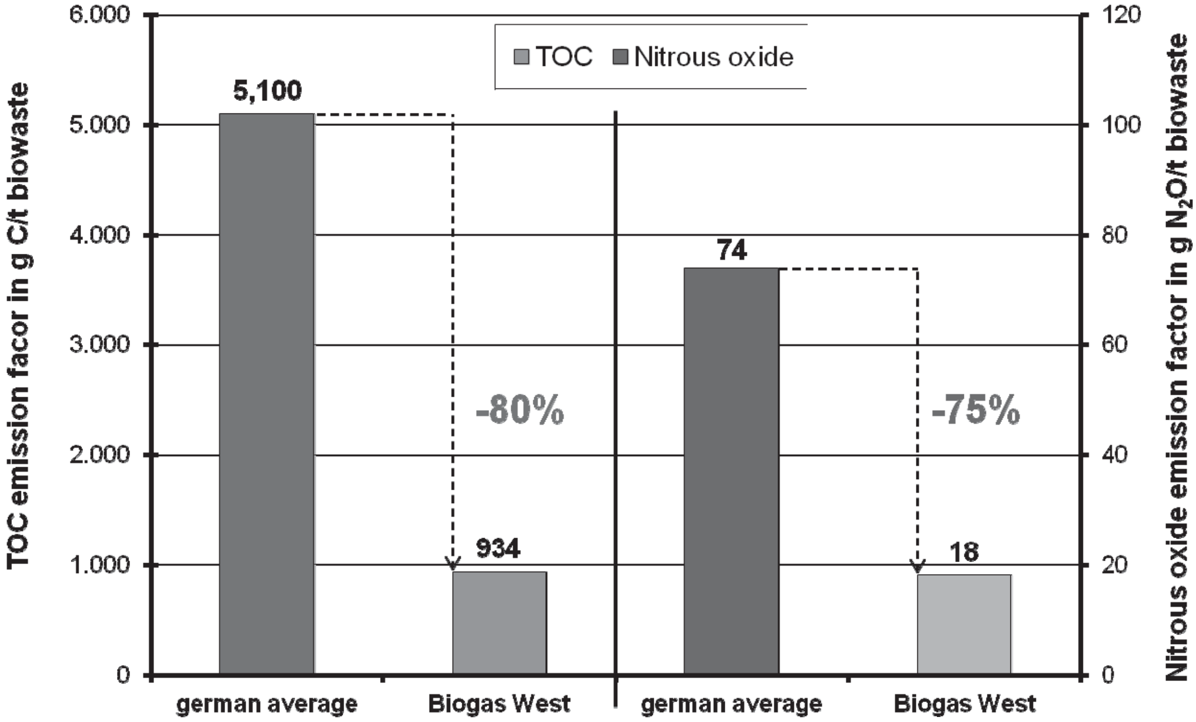

Figure 15 Emissions of BSR Biogas West (overall process) compared to average values from german biowaste digestion plants incl.post-rotting (acc. to gewitra, 2014)

9 Greenhouse gas balance

Greenhouse gas balancing for BSR Biogas West includes all relevant parameters concerning the plant Biogas West as well as subsequent processes of treatment and utilization of material and energy output from Biogas West. Depending on the environmental effects carbon credits or debits are caused by the following processes:

Carbon debits

- Energy consumption of all involved plants
- Methane and nitrous oxide emissions from the biogas/biomethane plant, from the composting plants and from the liquid digestate stores
- Emissions form thermal utilization of the coarse fraction from MT
- Emissions of transport of digestate and other output streams
- Emissions of application of digestate/compost

Carbon credits

- Biomethane injected to the public grid or substituted amount of diesel fuel respectively
- Benefit from digestate and compost utilization in agriculture/horticulture (fertilizer, humus value/substitution of peat, additional benefits according to current studies)
- Metals recycling
- Energy output from thermal utilization of the coarse fraction from MT

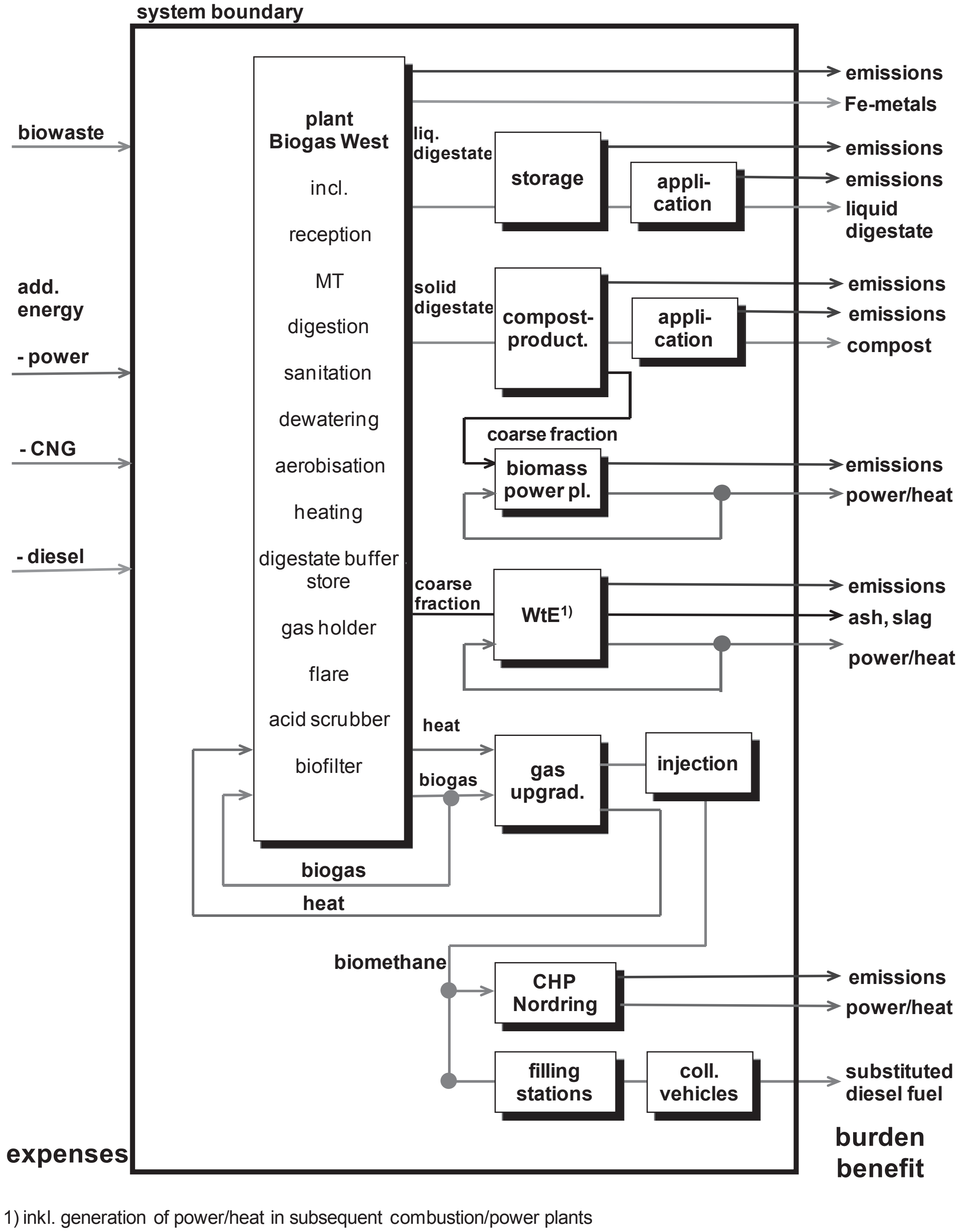

Figure 16 system boundaries for greenhouse gas balance of biowaste-AD with biogas-upgrading, biomethane injection and use as biofuel

Carbon credits and debits were calculated using sums and extrapolations of balance values of the individual parameters and translation to CO_2-equivalents with valid greenhouse gas factors for Berlin.

System boundary for the use of biomethane is combustion in the motors of BSR waste collection vehicles. As carbon credit the saving of emissions from the substituted amount of diesel fuel is counted.

For evaluation of credits and debits from digestate and compost utilization composition of overall compost/digestate output from Biogas West was compared to data from current studies for greenhouse gas balancing of biowaste composting or digestion in Germany (UBA, 2012 und IFEU/ICU, 2013). As result relevant ingredients (organic carbon and nutrients) of the digestate from Biogas West do not differ to a noteworthy extent from assumptions drawn in the mentioned studies. Because of this, carbon credits and debits for digestate and compost utilization were put on the same level with the results of IFEU/ICU, 2013.

The following data compilation shows, that carbon credits are mainly provided by biomethane, energy recovery from the coarse fraction from MT and utilization of compost/digestate in agriculture/horticulture. As most relevant part of this the credits derived from energetic output (biomethane and coarse fraction) sum up to about 60 % of overall carbon credits.

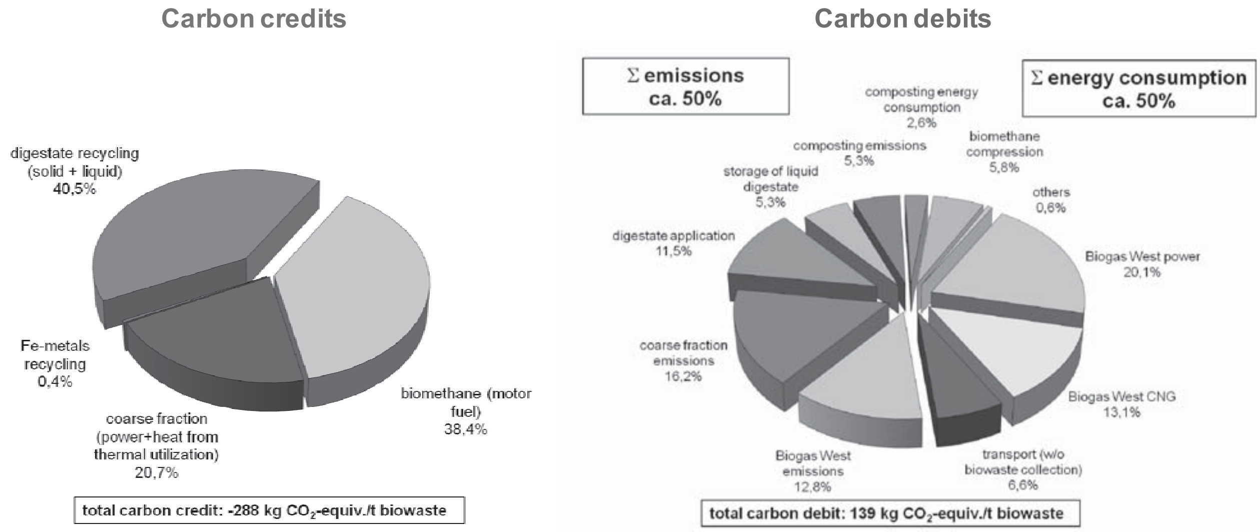

Figure 17 breakdown of carbon credits (left) and carbon debits (right)

Compared to carbon credits carbon debits divide into much more relevant processes. Most important are power and CNG consumptions of the plant Biogas West, which combined with methane and nitrous oxide emissions from the plant contribute to nearly 50 % of all debits.

All subsequent processes correspondingly sum up to little more than 50 % of carbon debits. Great portions of the latter are provided by emissions from incineration of the coarse fraction and from emissions of digestate and compost application. In contrast debits from composting and long term storage of liquid digestate are of minor importance. A breakdown of ca. 50:50 is also found, when carbon debits caused by emissions and energy consumptions are compared.

In particular overall methane and nitrous oxide emissions and energy consumption of the plant Biogas West contribute to a much lower extent to carbon debits than expected from previous estimations and current studies.

Expressed in numbers overall carbon debits of +139 kg CO_2-equiv./t biowaste are faced by a sum of credits of -288 kg CO_2-equiv./t biowaste. This results in a joint greenhouse gas balance of -149 kg CO_2-equiv./t biowaste for Biogas West in 2014, which is based on operation data from the first complete year of regular operation.

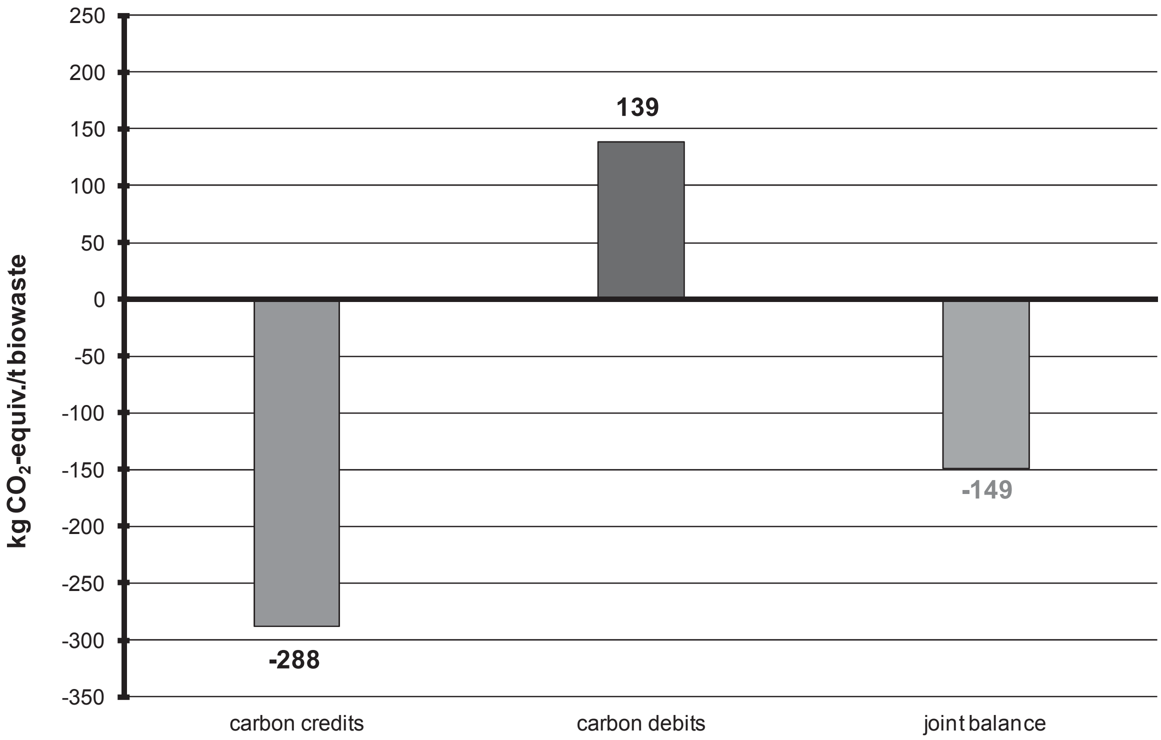

Figure 18 greenhouse gas balance (overall process w/o biowaste collection)

Assuming a throughput of 60,000 t/y, this means a relief of ca. 9,000 t CO_2-equiv. per year. The relief is even slightly higher than the comparable value from previous estimations (greenhouse gas balance 2011).

To identify the net relief of CO_2-equivalents the balance value of Biogas West has to be compared to the greenhouse gas balance of the former way of biowaste treatment in Berlin, which was open windrow composting.

The reference value of composting is derived from IFEU/ICU, 2013 with exclusion of biowaste collection. According to IFEU/ICU, 2013, composting of the biowaste of Berlin provided only a small greenhouse gas relief of -15 kg CO_2-equiv./t biowaste. Hence compared to composting the present state of biowaste treatment by AD in Biogas West yields a surplus in climate protection of -134 kg CO_2-equiv./t biowaste. This means a relief of ca. 8,000 t CO_2-equiv. per year compared to composting.

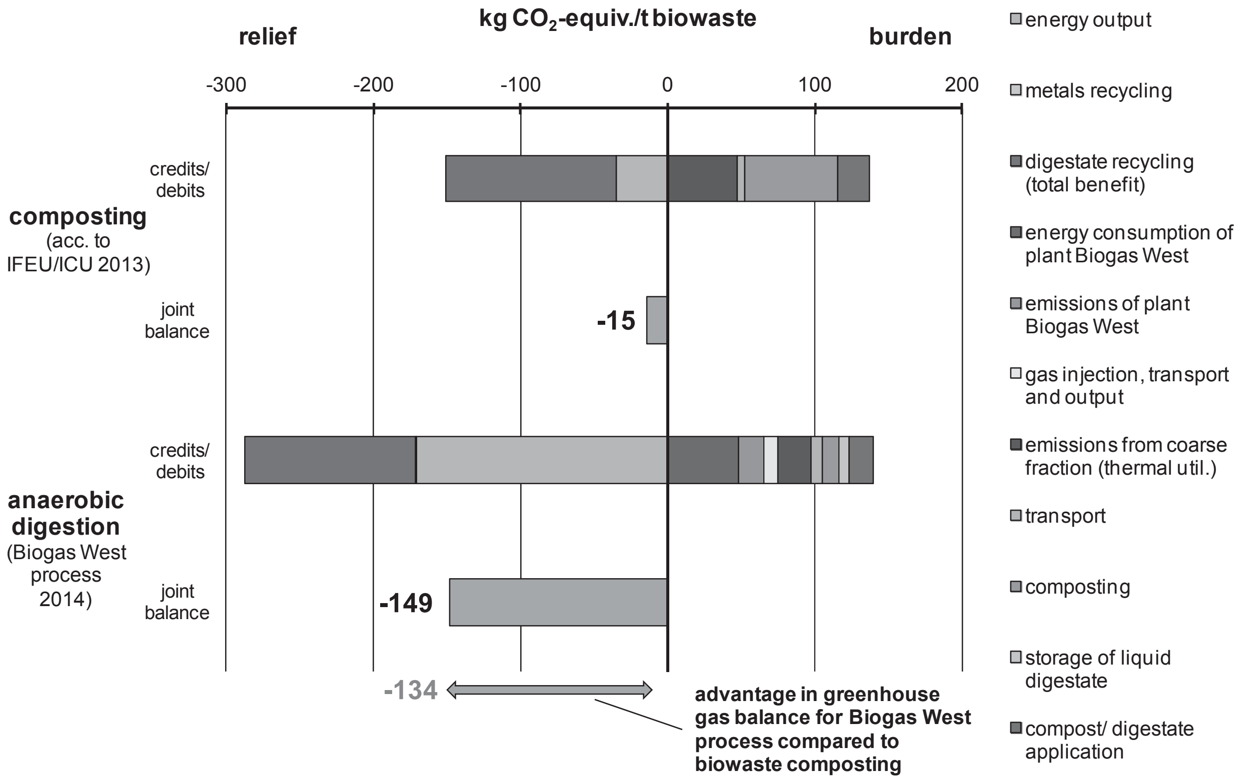

Figure 19 greenhouse gas balance of BSR Biogas West AD-process compared to composting of biowaste

10 Conclusions

The greenhouse gas balance of BSR Biogas West 2014, resulting in -149 kg CO_2-equiv./t biowaste, proves a high relief of greenhouse gases by change of biowaste utilization from composting to biowaste treatment with AD.

Plant and process conception realized in Berlin, including exhaustive digestion and biogas formation in combination with digestate recycling and biomethane generation for use as biofuel, runs with low emissions (934 g TOC-C/t biowaste, 18 g N_2O/t biowaste) and is exemplary for climate protective utilization of separately collected biowaste.

The comprehensive evaluation, conducted throughout the first complete year of regular operation of the BSR Biogas West process, shows that AD of biowaste can be done with moderate energy consumption, high energy efficiency and low emissions resulting in a markedly advantageous greenhouse gas balance, even when the specific biogas yield of biowaste input is not in the highest range.

Combining energy efficient and high-quality biowaste utilization the BSR Biogas West process represents the (new) state of the art and best practice for utilization of source separated biowaste respectively. Thereby it completely fulfills the targets of EU's Waste framework directive and of the German Waste management act of 2012 (KrWG).

11 Literature

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gewitra	2014	Ermittlung der Emissionssituation bei der Verwertung von Bioabfällen. UFOPLAN FKZ 206 33 326/3709 44 320, previously unreleased final report by order of the German Umweltbundesamt (UBA), Troisdorf 2014
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UBA	2012	Optimierung der Verwertung organischer Abfälle. UFOPLAN 3709 33 340, UBA-Texte 31/2012, Dessau-Roßlau 2012

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Erfahrungen mit Power to Gas – Aufbereitungstechnologie für Kläranlagen?

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Experiences with Power-to-gas – upgrading technology for sewage treatment plants?

Abstract

Methane produced in a biological process using surplus electricity from renewable sources such as wind and the sun is being fed into the natural gas grid for the first time in Allendorf (Eder), Germany. The first system of this type in the world went into operation in early March. The MicrobEnergy (Viessmann Group) demonstration plant had been in operation at the Schwandorf sewage works until the end of December 2014.

Inhaltsangabe

In Allendorf (Eder) wird erstmals Methan, das mithilfe eines biologischen Verfahrens aus regenerativem Überschussstrom (z.B. Wind- oder Sonnenstrom) hergestellt wird, in das öffentliche Erdgasnetz eingespeist. Die weltweit erste Anlage ihrer Art ging Anfang März 2015 in Betrieb. Davor war am Standort der Kläranlage Schwandorf eine Power-to-Gas-Demonstrationsanlage von MicrobEnergy (Viessmann Group) in Betrieb.

Keywords

Power to Gas, Kläranlagen, Mikrobiologische Methanisierung, Biomethan,

Power-to-gas, sewage treatment plants, microbiological methanation, biomethane

1 Power-to-Gas als Aufbereitungstechnologie für Kläranlagen

Power-to-Gas, eine Technologie zum Speichern von Überschussstrom im Erdgasnetz, kann sich auch als Aufbereitungstechnologie für Klärgasanlagen eignen.

Eine Demonstrationsanlage des Unternehmens MicrobEnergy (Viessmann Group) war bis Ende Dezember 2014 am Standort der Kläranlage Schwandorf in Betrieb. Die Testergebnisse zeigten eine hervorragende Produktgasqualität von mehr als 98 % Methan-Gehalt mit sehr geringem Wasserstoff-Anteil von weniger als 2 % und einer stabilen Produktionsmenge.

Abb. 1: Mikrobiologische Methanisierung am Klärwerk Schwandorf

Nach Verlegung der Anlage an den Standort Allendorf (Eder) wird seit Anfang März 2015 der vor Ort produzierte Wassersoff mittels dem erprobten, biologischen Verfahren methanisiert und über die vorhandene Biogaseinspeiseanlage in das Erdgasnetz eingespeist. Das benötigte CO2 wird entweder aus der Gasaufbereitungsanlage übernommen oder es findet eine direkte Nutzung des Rohbiogases mit dem darin enthaltenen CO2 statt.

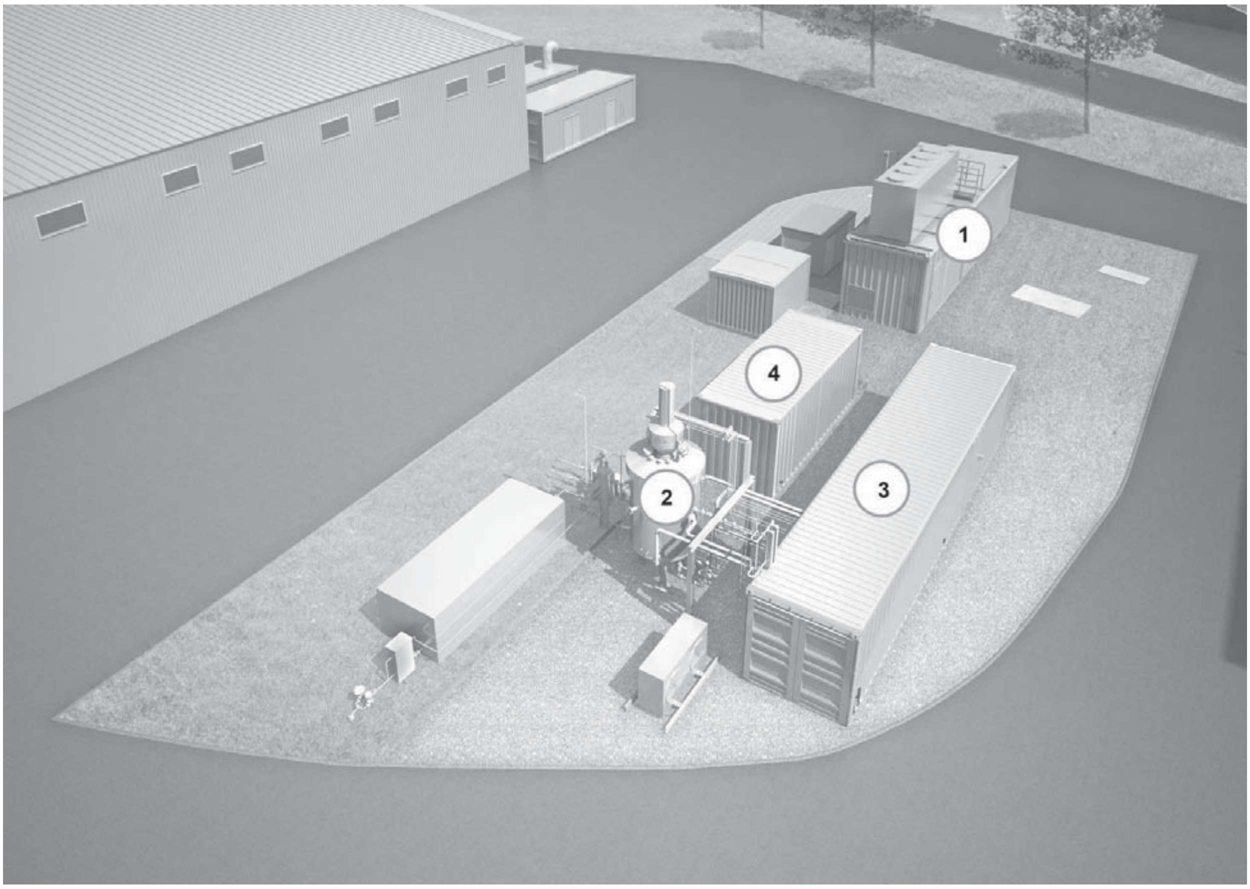

Abb.2: Power-to-Gas-Anlage (1) PEM-Elektrolyseur (2) Mikrobiologische Methanisierung (3) Verfahrenstechnik (4) Steuerungstechnik

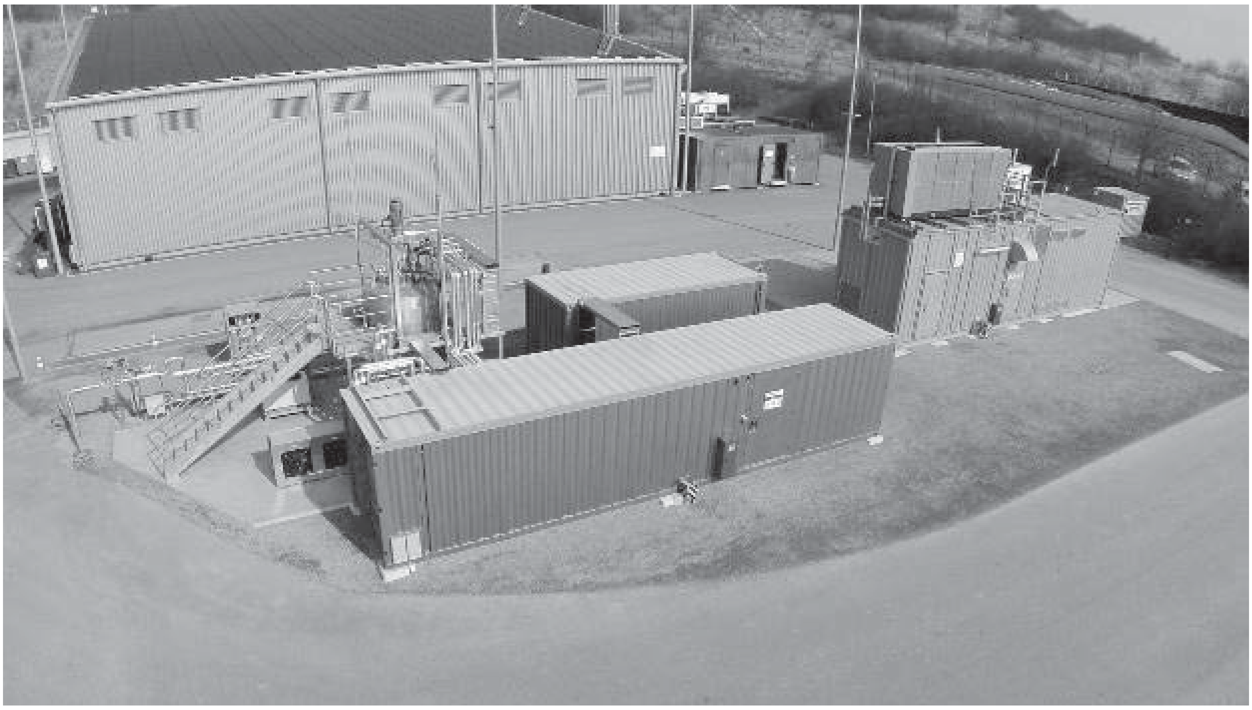

Abb. 3: Power-to-Gas-Anlage am Standort Allendorf (Inbetriebnahme: März 2015)

2 Power-to-Gas: Speicherprozess der Natur nachgebildet

Mit zunehmendem Ausbau von Wind- und Solarenergie werden in wind- und sonnenreichen Zeiten immer größere Mengen an Überschussstrom anfallen, die nicht in das Stromnetz eingespeist werden können. Gleichzeitig können im Zuge der Energiewende durch den Rückbau von konventionellen Kraftwerken in Zeiten von wenig Wind und Sonne Versorgungslücken entstehen. Die Entwicklung von Energiespeichern ist daher eine der größten Herausforderungen der Energiewende.

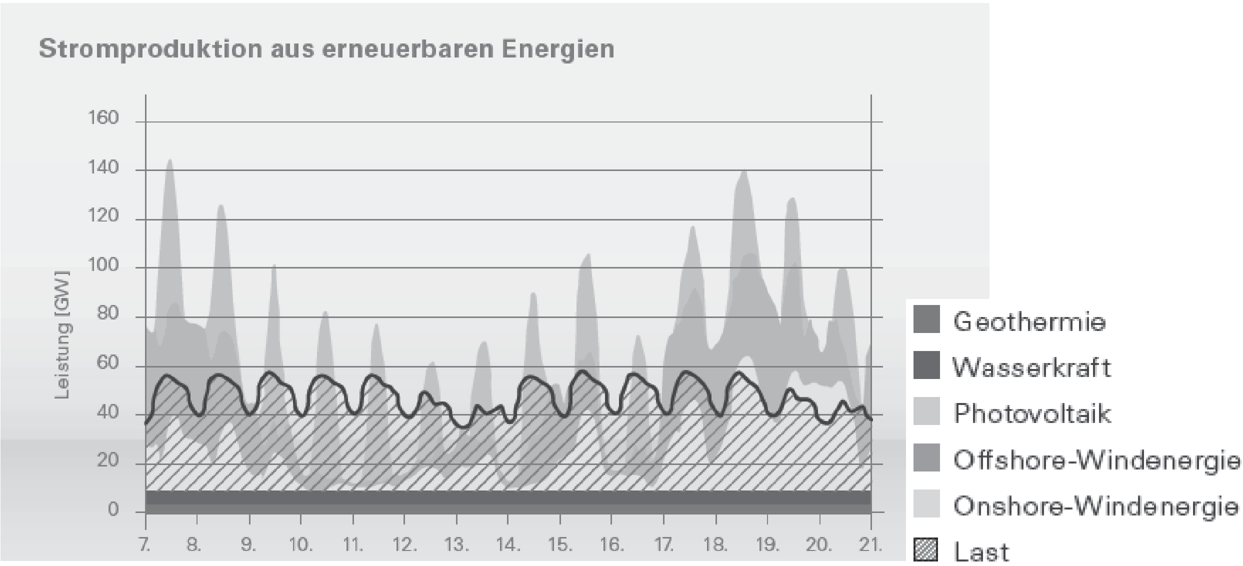

Abb. 4: Beispielhafter Zweiwochenverlauf der nationalen Einspeisung von nicht regelbaren erneuerbaren Energien (Quelle: Fhg IWES)

Eine interessante Lösungsmöglichkeit stellt die Technologie Power-to-Gas dar, die jetzt bei Viessmann angewandt wird. Mit diesem Verfahren kann aus überschüssigem Wind- und Solarstrom durch Elektrolyse aus Wasser Wasserstoff hergestellt werden, der direkt genutzt oder in einem zweiten Schritt zusammen mit Kohlendioxid aus einer Biogasanlage auf mikrobiologischem Wege zu Methangas umgewandelt wird.

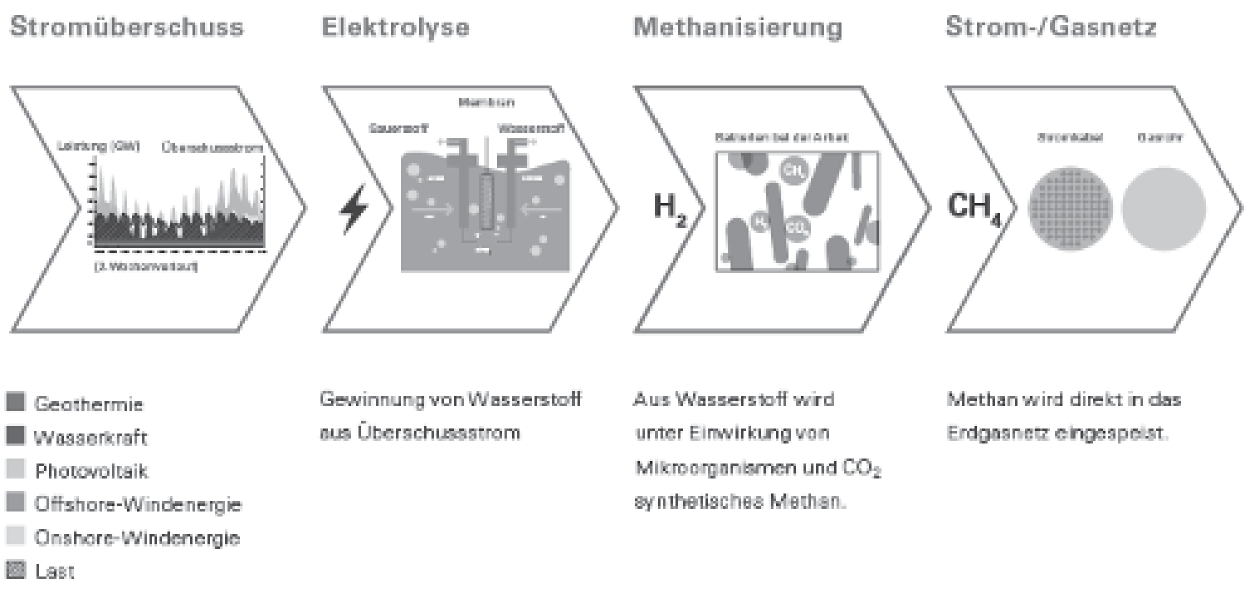

Abb. 5: Power to Gas – Speicherung von Überschussstrom im Erdgasnetz

2.1 Erzeugung und Verbrauch zeitlich und räumlich entkoppeln

Das Gasnetz in Deutschland hat mit seinen Rohrleitungen und unterirdischen Kavernen eine Speicherkapazität von mehreren Monaten. Der Energieträger kann so über lange Zeit gespeichert und unabhängig vom Ort der Erzeugung zur Stromproduktion, der Wärmeversorgung oder in Erdgasautos als klimafreundlicher Energieträger verwendet werden.

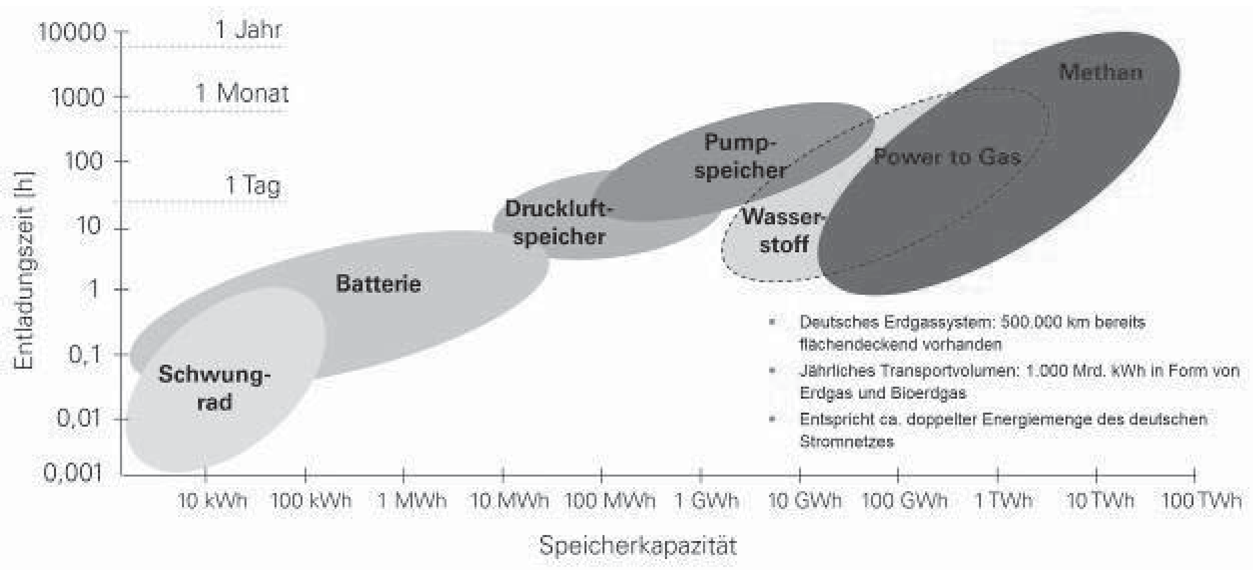

Abb. 6: Kapazitäten verschiedener Energiespeicher (Quelle: eigene Darstellung in Anlehnung nach FVEE 2009

2.2 Hohe Flexibilität bei der Aufnahme von Wind- und Sonnenstrom

Während in bisherigen Power-to-Gas-Projekten die Methanisierung auf chemisch-katalytischem Weg erfolgte, hat das Viessmann Gruppenunternehmen MicrobEnergy das jetzt in großem Maßstab funktionierende Verfahren entwickelt, das eine Umwandlung des im Gärprozess in einer Biogasanlage anfallenden Kohlendioxids und des extern zugegebenen Wasserstoffs zu Methan auf mikrobiologischem Weg ermöglicht. Zur Gewinnung des Wasserstoffs wird ein PEM-Elektrolyseur eingesetzt, der von Carbotech – einem weiteren Viessmann Unternehmen – gebaut wurde. Die biologische Methanisierung zeichnet sich durch eine hohe Flexibilität aus und ist damit ideal geeignet, fluktuierende Energiemengen aus Wind- oder Sonnenkraft aufzunehmen.

2.3 Mikroorganismen erzeugen Methan

Die eigentliche Methanisierung wird dabei von hochspezialisierten Mikroorganismen durchgeführt. Diese nehmen den in Flüssigkeit gelösten Wasserstoff und das Kohlendioxid durch ihre Zellwand auf und „verdauen" es zu Methan – übrig bleibt bei diesem Prozess lediglich noch Wasser.

2.4 Kostensenkung durch Nutzung vorhandener Infrastruktur

Durch die Nutzung vorhandener Biogas- und Klärgasanlagen können die Investitionskosten für Power-to-Gas-Anlagen deutlich gesenkt werden, da an den Standorten Transformatoren, Strom- und Gasnetzanschlüsse oftmals bereits vorhanden sind.

2.5 Demonstrationsanlage und Projektziele

Am Viessmann Unternehmensstammsitz in Allendorf (Eder) wird erstmals Methan, das mithilfe eines biologischen Verfahrens aus regenerativem Überschussstrom (z.B. Wind- oder Sonnenstrom) hergestellt wird, in das öffentliche Erdgasnetz eingespeist. Die weltweit erste Anlage ihrer Art ging Anfang März in Betrieb. Dazu wurde die dazu notwendige Technik mit der Größe von drei Schiffscontainern in die bestehende Biomethananlage in Allendorf (Eder) integriert. Die weitere Ausbaustufe des Systems zur Erzeugung und Verarbeitung von maximal 400 Kubikmetern Wasserstoff pro Stunde (Nm^3/h) wurde bereits genehmigt.

Die wesentlichen Projektziele sind die Erprobung des Elektrolyseurs und der biologischen Methanisierung (Stabilität, Langzeitstabilität), die vollständige Anlagenintegration in die Biomethananlage, das Erreichen einer stabilen und einspeisefähigen Gasqualität und der Nachweis der prozesssicheren dynamischen Fahrweise. Weiterhin soll der Regelenergiebetrieb und der Betrieb mit schwankenden Eingangsgasqualitäten (CO2, Feuchte, Temperatur, zyklisch und jahreszeitlich) erprobt werden. Um das hergestellte synthetische Speichergas vermarkten zu können, wird zudem die Qualifizierung des entstehenden synthetischen Methans für den Biokraftstoffmarkt im Rahmen von Bilanzierungs-, Nachweis- und Zertifizierungsverfahren durchgeführt.

3 Power to Gas: Anwendungsbereich Kläranlagen

Das Power to Gas Verfahren eignet sich auch zur Anwendung an Kläranlagen. In diesem Fall dient das Power-to-Gas-Verfahren zusätzlich als Aufbereitungstechnologie für Rohbiogas aus Biogas- und Kläranlagen. Der anfallende Überschussstrom kann unter Verwendung von Kohlendioxid Klärgas in Methan wandeln. Durch die Nutzung vorhandener Klärgasanlagen können die Investitionskosten für Power to Gas-anlagen deutlich gesenkt werden, da an den Standorten Transformatoren, Strom- und Gasnetzanschlüsse bereits vorhanden sind.

Hierzu wurde an der Kläranlage Schwandorf über eine Versuchsanlage das Verfahren bereits getestet. Dabei wurde ein Elektrolyseur mit einer Leistung von 30 Normkubikmeter Wasserstoff pro Stunde installiert. Dieser wurde über verschiedene Technologien in den Faulturm der Kläranlage eingebracht. Der Wasserstoff wurde von den dort vorhandenen und speziell adaptierten Mikroorganismen in Methan umgesetzt. Ein Vorteil dieses Verfahrens ist die geringe Anforderung an die Reinheit des elektrolytisch erzeugten Wasserstoffs. Der Umwandlungsprozess von Wasserstoff zu Methan kann bei Betriebstemperatur der Kläranlage von 40°C sehr schnell in Gang gesetzt oder abgeschaltet werden, wobei die Mikroorganismen ihren Stoffwechsel bis auf ein Minimum herunter regulieren. Diese Flexibilität ist für die Nutzung des fluktuierenden Überschussstroms von großem Vorteil. Die milden Prozessparameter von vergleichsweise geringen Temperaturen und Drücken machen diesen Weg der Methanisierung im Vergleich zu bisher angewandten katalytischen Verfahren interessant. Das erforderliche Kohlendioxid ist durch den anaeroben Abbauprozess der Kläranlage frei verfügbar.

Empfehlungen zur Limitierung klimarelevanter Emission aus der offenen Mietenkompostierung

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Zusammenfassung

Das LUGV Brandenburg hat seit 2009 der Dr. Reinhold & Kollegen Potsdam zwei Gutachten mit dem Ziel in Auftrag gegeben, die Möglichkeiten der Minderung von Klimagasemissionen aus der offenen Mietenkompostierung aufzuzeigen. Dazu wurden in Zusammenarbeit mit der Gütegemeinschaft Kompost und in Abstimmung mit den parallel laufenden UBA-Projekten umfangreiche Untersuchungen in RAL-gütegesicherten Kompostierungsanlagen durchgeführt. Die Ergebnisse dieser Untersuchungen und erste Schlussfolgerungen sind in Empfehlungen zur Limitierung klimarelevanter Emission aus der offenen Mietenkompostierung eingeflossen.

Es wurde festgestellt, dass der als Feldmessmethode geeignete Nachweis der Feuchtrohdichte geeignet ist, die Beschaffenheit von Rottegut so zu gestalten, dass eine emissionsarme aerobe Mietenkompostierung nach guter fachlicher Praxis unterstützt wird. Dafür wurde ein Vorschlag von Orientierungswerten für die Feuchtrohdichte beim Ansetzen von Ausgangsstoffen zu Kompostmieten entwickelt. Zusätzlich wurden erste Vorschläge für durchlüftungsbeschreibende Restgasgehalte (Stickstoff) in den Rottegutporen unterbreitet. Es kann empfohlen werden, die Anwendung dieser Feldmessmethoden, neben den schon ständig betriebenen Temperaturmessungen, in die Praxis einzuführen. Damit kann erreicht werden, dass die offene Mietenkompostierung ähnlich emissionsarm erfolgen kann, wie in eingehausten Anlagen.

Schlüsselwörter

Mietenrotte, Klimagasemissionen, Prozesssteuerung

1. Einführung

Das Umweltbundesamt hat im Jahr 2006 die Ingenieurgesellschaft für Wissenstransfer GmbH (gewitra) Troisdorf beauftragt, ein Gutachten zum Thema „Ermittlung der Emissionssituation bei der Verwertung von Bioabfällen“ (UFOPLAN 2006, FKZ: 206 33 326) zu erstellen. In einem Folgegutachten zum Thema „Ermittlung der Emissionssituation bei der Vergärung von Bioabfällen und Ermittlung der Emissionssituation bei der Verwertung von Bioabfällen in offenen Kompostierungsanlagen“ (UFOPLAN 2009, FKZ: 3709 44 320) wurden durch die Ingenieurgesellschaft für Wissenstransfer GmbH Troisdorf ergänzende Bewertungen vorgenommen. Die Ergebnisse dieser beiden Gutachten kennzeichnen den aktuellen Stand der Klimagasemissionen bei der Bioabfallbehandlung.

Die Gutachter leiten aus ihren Untersuchungen zu Klimagasemissionen bei der Bioabfallbehandlung folgende Empfehlung ab (nach Clemens, Cuhls, Mähl, 2011):

- Offene Kompostierungsanlagen sind grundsätzlich nicht schlechter als geschlossene Kompostierungsanlagen. Der Anlagenbetrieb ist entscheidend. Günstige Literatur-Werte sind historisch.
- Schwankungen um Faktor 10 in den Emissions-Faktoren belegen die breite Streuung, die aus Unterschieden in Technik, Betrieb und Inputmaterial resultiert.
- Die aktuelle Praxis zeigt, dass der Anlagenbetrieb bisher nicht auf die Reduktion von Klimagasemissionen ausgelegt ist.
- Die geschlossenen Anlagen können über die aktive (technische) Belüftung Defizite (Poren, Wasser) im Rottematerial besser ausgleichen.
- Hohe Emissionen resultieren meistens aus mangelnder fachliche Praxis: Mangelhafte Mietengeometrie, zu wenig Strukturmaterial und zu lange Umsetzintervalle führen zu schlechter Belüftung und ungenügender Sauerstoff-Versorgung.
- Die besten Kompostierungsanlagen emittieren nahezu kein Methan, NMVOC wird zu > 90% im Biofilter abgebaut. Die TA Luft Emissionswerte werden eingehalten.
- Lachgas entsteht vorwiegend in der Nachrotte (Nitrifikation), deshalb Mieten nicht auskühlen lassen und auf weites C:N Verhältnis achten.
- Biofilter reduzieren Methan nicht, wohl aber Ammoniak, was zur Neubildung von Lachgas führt.
- Kompostierungsanlagen mit semipermeabler Membranabdeckung können über die aktive Belüftung ein sehr günstiges Emissionsniveau (CH_4, N_2O, NH_3) erreichen. Weitere Messungen wünschenswert.
- Vergärungsanlagen emittieren aus flüssigem Gärprodukt und aus der Nachrotte erhebliche Mengen an Methan, bis zu 5-10% des Biogasertrags. Die Gärrückstände weisen teilweise noch nennenswertes Restgaspotenzial auf. Hier besteht erhebliches Optimierungspotenzial am Treibhauseffekt. Nach TA Luft werden die Emissionswerte für Ammoniak und Ges.-C_{org} nicht eingehalten.
- Die offene Nachrotte von Gärrückständen (ohne aktive Belüftung) ist nicht akzeptabel.
- Die Kohlendioxid-Äquivalente belaufen sich auf Ø 100 kg CO_2-Äq/Mg (vorwiegend aus Methan).
- Die Anteile der Bioabfallbehandlung am nationalen Emissionsinventar liegen zwischen 0,40 und 0,64 % für Methan, Lachgas und Ammoniak (0,05% der Summe der Kohledioxid-Äquivalente in Deutschland).
- Ausblick: Verbesserter Methanabbau im Biofilter (2-stufig).

- Wünschenswert: Verbindliche gute fachliche Praxis mit Blick auf Klimagas-Emissionen und gegebenenfalls verbindliche technische Standards sowie immissionsschutzrechtliche Anforderungen.

Auf der Grundlage der Ergebnisse der vorgenannten UBA-Berichte und eines 2009 erstellten Berichts des Landesumweltamtes Brandenburg zum Thema „Möglichkeiten zur Vermeidung klimarelevanter Emissionen aus Kompostierungsanlagen durch Weiterentwicklung der guten fachlichen Praxis bei der Rotteprozessführung“ (Reinhold, 2009) wurde im Jahr 2010 Dr. Reinhold & Kollegen durch das Landesamt für Umwelt, Gesundheit und Verbraucherschutz Brandenburg (LUGV) beauftragt ein Projekt zum Thema „Entwicklung und Prüfung von Feldmess- und Diagnosemethoden als Maßnahme zur Vermeidung klimarelevanter Emissionen aus der aeroben Mietenkompostierung“ zu bearbeiten. Entsprechend der besonderen Situation der Bioabfallabfallbehandlung im Land Brandenburg lag der Schwerpunkt auf der offenen Mietenkompostierung (ohne technische Belüftung). Das Projekt-Gutachten wurde unter Mitwirkung der Gütegemeinschaft Kompost BBS e. V. im Jahr 2012 fertiggestellt. Über wesentliche Ergebnisse aus diesem Vorhaben und den weiterführenden Arbeiten soll hier berichtet werden.

2. Zielstellung

Einleitend sollen anonymisierte Ergebnisse der gewitra GmbH aus vier Untersuchungsserien der Emission klimarelevanter Gase (dargestellt am Beispiel Methan) bei der offenen Mietenkompostierung (ohne technische Belüftung) vorgestellt werden. Die Daten stammen aus Arbeiten für das Umweltbundesamt in den Jahren 2008 und 2010, aus Messungen für die Gütegemeinschaft Kompost Berlin, Brandenburg, Sachsen-Anhalt e. V. in 2009 und aus Untersuchungen für eine studentische Projektarbeit in 2010.

Insgesamt zeigen sich sehr große Unterschiede im Emissionsgeschehen. Das kennzeichnet den erheblichen Handlungsbedarf zur Aufklärung von Ursachen für hohe Emissionen und zur Entwicklung von Lösungswegen zur Limitierung der Freisetzung klimarelevanter Gase bei der offenen Mietenkompostierung. Dazu können umfangreiche Messungen zur Erfassung des Rotteverlaufs in Kombination mit Emissionsmessungen beitragen. Solch eine Ursachenforschung führt mit den Emissionsmessungen nach der Gewitra-Tunnelmethode zu einem hohem Arbeitsaufwand (ein Messtrupp von zwei Personen und einer zeitweiligen Hilfskraft von der Bioabfallbehandlungsanlage schafft arbeitstäglich etwa zwei bis drei Einzelmessungen).

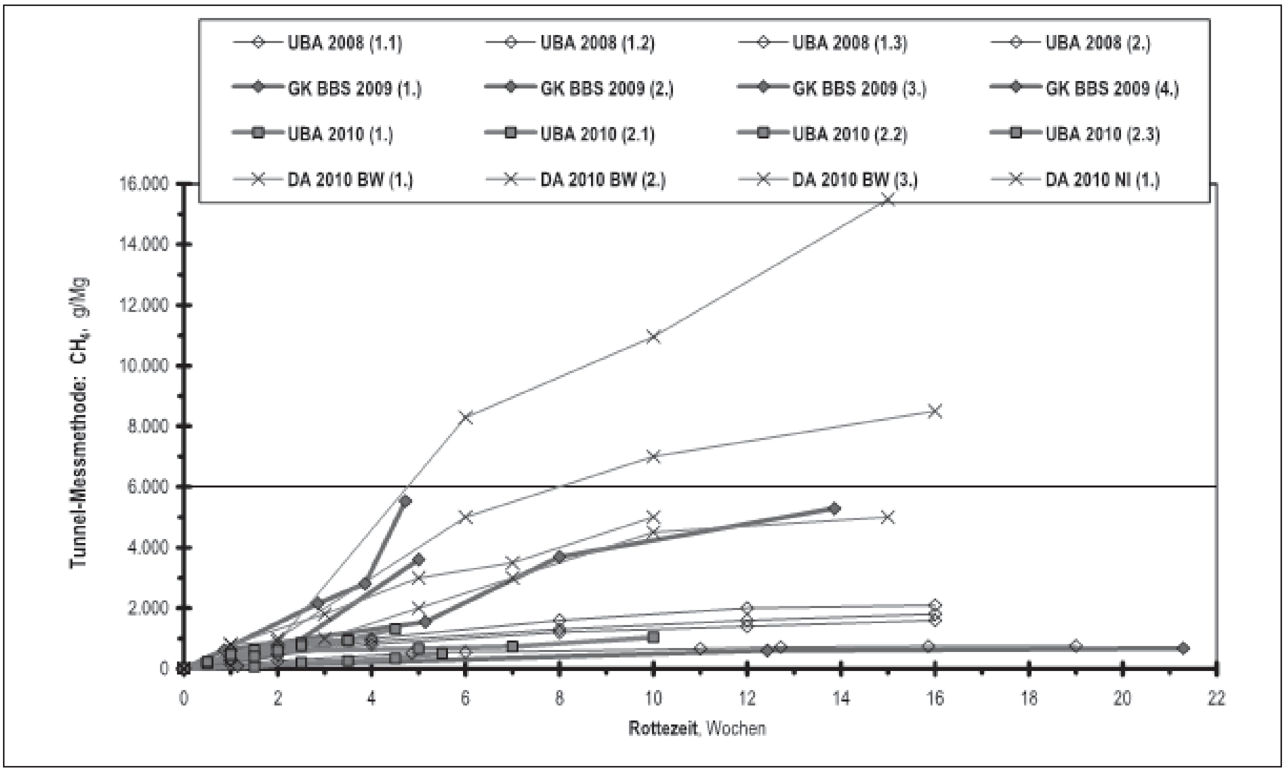

Abbildung 1 Anlagenspezifische Emissionsfaktoren von Methan (CH_4) je Mg Rottegut in Abhängigkeit von der Rottezeit

Es besteht also hoher Bedarf einer methodischen Vereinfachung durch orientierende Vorabschätzung zu erwartender Klimagasemissionen anhand leichter messbarer Rotteprozessmerkmale, dem dar 2012 vorgelegte Bericht zum LUGV-Vorhaben und die daran anschließend für das Land Brandenburg erarbeiteten „Empfehlungen zur Limitierung klimarelevanter Emission aus der offenen Mietenkompostierung“ dienen sollen.

3. Durchführung und Ergebnisse der Untersuchungen

Für eine praxisnahe Bearbeitung des Projektes wurden folgende Testmieten für Untersuchungen zum Rotteprozessverlauf und zur Emission klimarelevanter Gase in RAL-gütegesicherten Kompostierungsanlagen angelegt und untersucht (siehe Tabelle 1)

Tabelle 1 Emissionsrelevante Rotteprozessgestaltung bei der offenen Mietenkompostierung (2 Mietenansätze – Winter und Sommer)

Rotteprozesselemente (Inputmaterial)	**gewählte Varianten**
Mietengeometrie (Grüngut)	Dreiecksmiete klein Dreiecksmiete groß Trapezmiete
Korngröße durch Vorbehandlung, Trapezmiete (Güngut)	Grobkorn (max. 260 mm) Mittelkorn (max. 140 mm) Feinkorn (max. 40 mm)
Strukturmatte unter einer Trapezmiete (Biogut)	mit ohne
Mietenabdeckung bei Trapezmieten (Biogut)	ohne mit Fertigkompost (etwa 30 cm) mit Vlies
Umsetzhäufigkeit von kleinen Dreiecksmieten mit Kompostfräse (Biogut)	2 x 4 x 8 x

Insgesamt konnten somit 28 unterschiedliche Testmieten für das aufwändige Untersuchungsprogramm genutzt werden, wobei folgende Ergebnisse der Feld- und Labormessungen erzielt worden sind (siehe Tabelle 2). Die Ergebnisse zeigen, dass im Verlauf des Rotteprozesses in den unterschiedlichen Testmieten große Messunterschiede aufgetreten sind.

Es wurden vor allem Feldmessungen durchgeführt, wobei folgende Untersuchungen auch durch die Mitarbeiter der Bioabfallkompostierungsanlagen vorgenommen werden können:

- Feuchtrohdichte vor dem An- und Umsetzen
- Selbsterwärmung in verschiedenen Messtiefen im Rottegut (Differenz von Mieten- zu Lufttemperatur)

- Luftdurchtrittsgeschwindigkeit in verschiedenen Messtiefen im Rottegut
- Porengasgehalte (Sauerstoff, Kohlendioxid, Methan) in verschiedenen Messtiefen im Rottegut

Die gewitra-Tunnelmessungen zur Feststellung der Klimagasemissionen wurden durch speziell ausgebildete Fachkräfte vorgenommen und sind relativ aufwändig. Diese Messungen sind daher für eine Eigenüberwachung der Rotteprozessführung durch die Betreiber von Bioabfallbehandlungsanlagen nicht geeignet.

In der Abbildung 2 sind die Messergebnisse zum Zeitpunkt der Emissionsuntersuchungen nach ihrer Ähnlichkeit dargestellt. So ein Clusterdendrogramm bietet einen ersten Überblick über die Zusammenhänge zwischen den vielfältigen Messdaten. Hier bildet sich eine Gruppe von Labormessdaten um die leicht zu ermittelnden Feldmessergebnisse (Feuchtrohdichte, Selbsterwärmung). In diese Gruppe sind auch die Daten zu den Inhaltsstoffen und den Emissionen von kohlenstoffhaltigen Stoffwechselprodukten (Methan, Kohlendioxid) eingebunden.

Die Untersuchungsergebnisse zu den stickstoffdominierten Emissionen (Lachgas, Ammoniak) bilden eine zweite Gruppe, zusammen mit den Daten zur Durchlüftung des Rottegutes und den Rotteguttemperaturen.

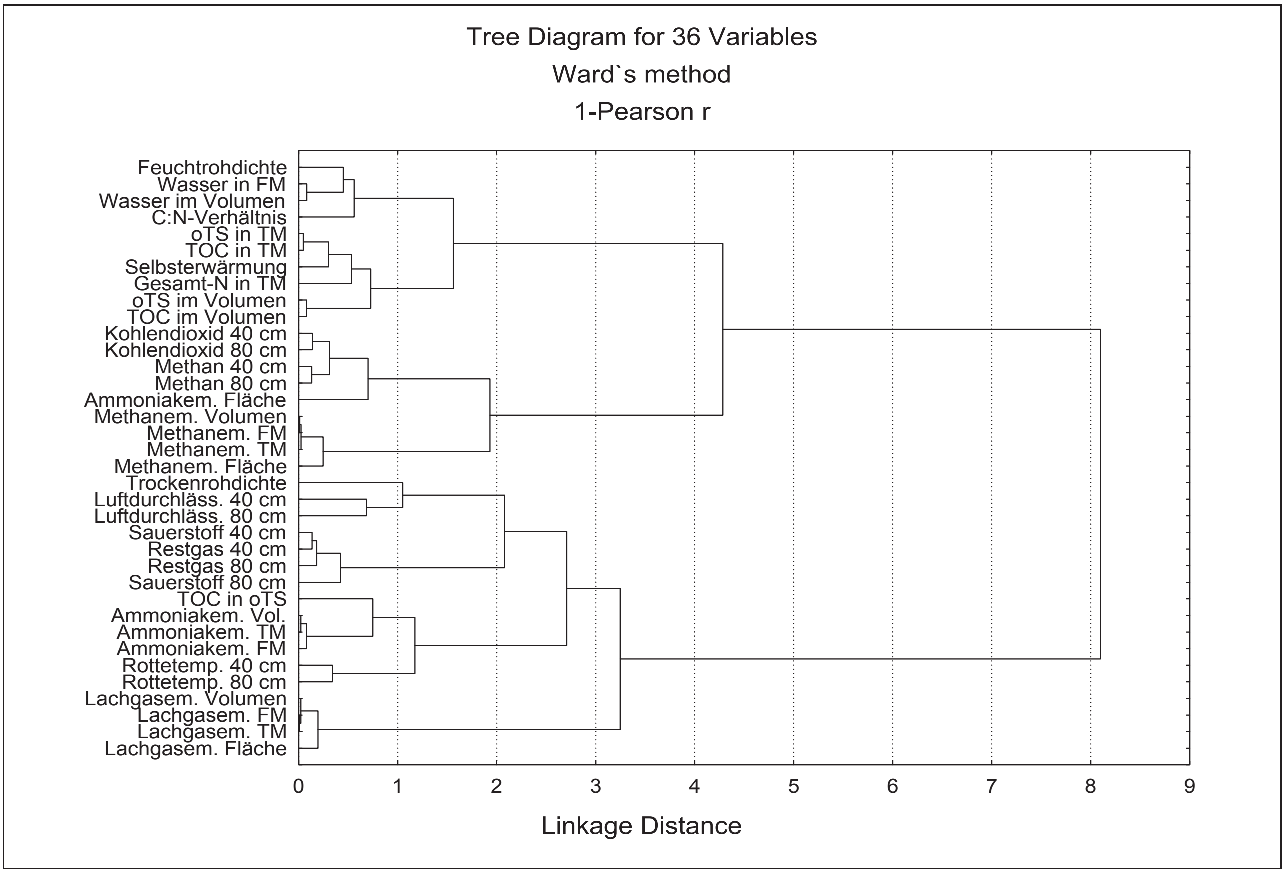

Abbildung 2 Clusterdendrogramm von 28 Stichproben der Messungen am Rottegut zum Zeitpunkt der Emissionsmessungen

Tabelle 2 Mittelwerte und deren Spannbreiten von gemessenen und abgeleiteten Parameter der bei fünf Anlagen mit 28 Testmieten für dieses Vorhaben durchgeführten Untersuchung

Parameter	Maßeinheit (Messtiefe)	n	kleinster Wert	Mittelwert	größter Wert
Rottetag		100	0	47	132
Wassergehalt	H_2O in FM-%	100	22,1	44,5	66,8
	H_2O in kg/l	100	0,14	0,31	0,58
organische Substanz	oTS in TM-%	100	21,9	34,8	53,6
organischer Kohlenstoff	TOC in TM-%	100	9,6	17,7	26,3
Gesamtstickstoff	N_{ges} in TM-%	100	0,69	1,05	1,91
Trockenrohdichte	TM in kg/l	100	0,24	0,37	0,69
TOC in der oTS	TOC in oTS-%	100	43,8	51,0	66,3
C:N-Verhältnis		100	10,1	17,2	26,6
Selbsterwärmung	°C	88	21,0	35,5	68,0
Feuchtrohdichte	FM in kg/l	100	0,47	0,68	0,98
Luftdurchtrittsgeschwindigkeit	mm/s (40 cm)	85	8,6	10,8	11,6
	mm/s (80 cm)	85	6,6	10,3	11,6
Sauerstoffgehalt	Vol.-% (40 cm)	85	0,0	5,9	17,3
in den Rottegutporen	Vol.-% (80 cm)	85	0,0	1,6	16,3
Kohlendioxidgehalt	Vol.-% (40 cm)	85	0,8	21,3	42,1
in den Rottegutporen	Vol.-% (80 cm)	85	2,8	33,8	53,1
Methangehalt	Vol.-% (40 cm)	85	0,0	12,0	55,4
in den Rottegutporen	Vol.-% (80 cm)	85	0,3	24,1	59,5
Restgasgehalt (Stickstoff)	Vol.-% (40 cm)	85	4,9	60,8	82,0
in den Rottegutporen	Vol.-% (80 cm)	85	0,9	40,6	81,3

Rottemperatur	°C (40 cm)	83	36,6	60,2	71,6
Mittelwert der Rottephasen	°C (80 cm)	83	35,2	57,5	71,3
Methanemission	CH_4/(d x m^3)	28	1,8	40,5	202,5
	CH_4/(d x Mg FM)	28	2,4	60,8	321,5
	CH_4/(d x Mg TM)	28	4,4	121,5	795,7
	CH_4/(d x m^2)	28	2,5	70,2	326,1
Lachgasemission	N_2O/(d x m^3)	28	0,01	0,39	2,12
	N_2O/(d x Mg FM)	28	0,01	0,60	2,74
	N_2O/(d x Mg TM)	28	0,03	1,04	5,07
	N_2O/(d x m^2)	28	0,02	0,46	2,91
Ammoniakemission	NH_3/(d x m^3)	28	0,23	1,12	3,65
	NH_3/(d x Mg FM)	28	0,26	1,68	5,12
	NH_3/(d x Mg TM)	28	0,61	2,96	7,51
	NH_3/(d x m^2)	28	0,47	1,61	3,23

4. Datenauswertung und Schlussfolgerungen

Die stark variierenden Messdaten erlauben umfassende statistische Prüfungen der Beziehungen von durch Feldmessungen erfasste Rotteprozessdaten zu Emissionsdaten und zu Labormesswerten. Zuerst sollen die Beziehungen von Feldmessdaten über den Verlauf des Rotteprozesses zu den Emissionsmessergebnissen klimarelevanter Gase aufgezeigt werden. Hier wurden nur für die Methanemissionen statistisch hoch gesicherte Zusammenhänge nachgewiesen – am stärksten bei den Methanemissionen, bezogen auf die Rotteguttrockenmasse (siehe Abbildungen 3 und 4). Die Lachgas- und Ammoniakemissionen konnten wegen fehlender Porengasmessungen nicht so gut regressionsanalytisch geschätzt werden.

Für die Darstellungen in den Abbildungen 3 und 4 wurden die jeweils in der Grafik nicht berücksichtigten Einflussfaktoren als Mittelwert berücksichtigt. Den Abbildungen liegt folgender, durch multiple Regressionsanalyse bestimmter Zusammenhang zugrunde:

Nach schrittweisem Aufbau eines multiplen Regressionsmodells verbleibende statistisch gesicherte Faktoren:

y - Methanemission in g CH_4/(d*Mg TM)

x_1 - Methan in 40 cm Messtiefe in Vol.-%

x_2 - Methan in 80 cm Messtiefe in Vol.-%

x_3 - Rotteguttemperatur in 80 cm Messtiefe

x_4 - Restgasgehalt (Stickstoff) in 40 cm Messtiefe in Vol.-%

Geschätzte Regressionsgleichung:

$y = -408{,}76 + 04410x_1^2 + 0{,}0936x_2^2 + 0{,}1015x_3x_4$

$n = 28$

$r^2_{adj.} = 0{,}8363$

$F = 40{,}87$

$p < 0{,}000001$

Tabelle 3 Sicherung der partiellen Regressionskoeffizienten

Faktor	t-Wert	p
x_1^2	6,569	< 0,0001
x_2^2	5,104	< 0,0001
x_3x_4	3,803	0,0009

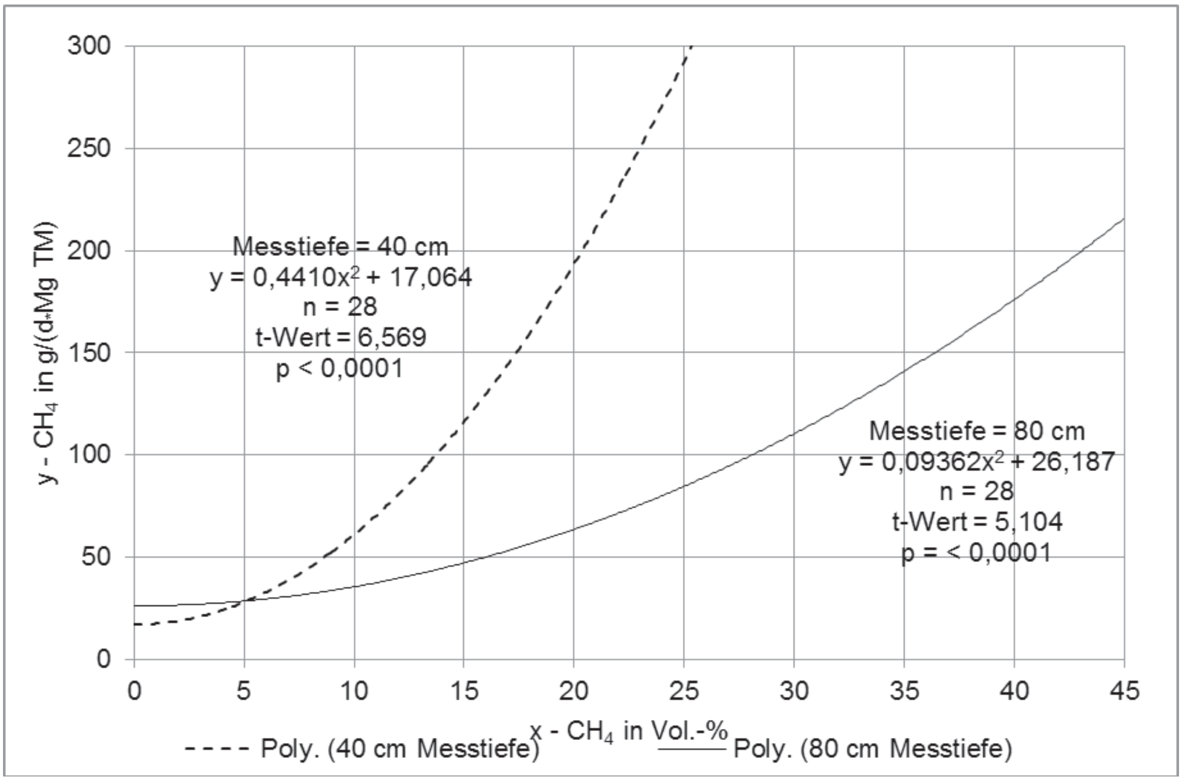

Abbildung 3 Zusammenhang von Methan in den Rottegutporen in 40 bzw. 80 cm Messtiefe und der Methanemission bezogen auf die Rotteguttrockenmasse (p - Irrtumswahrscheinlichkeit nach partiellem t-Wert)

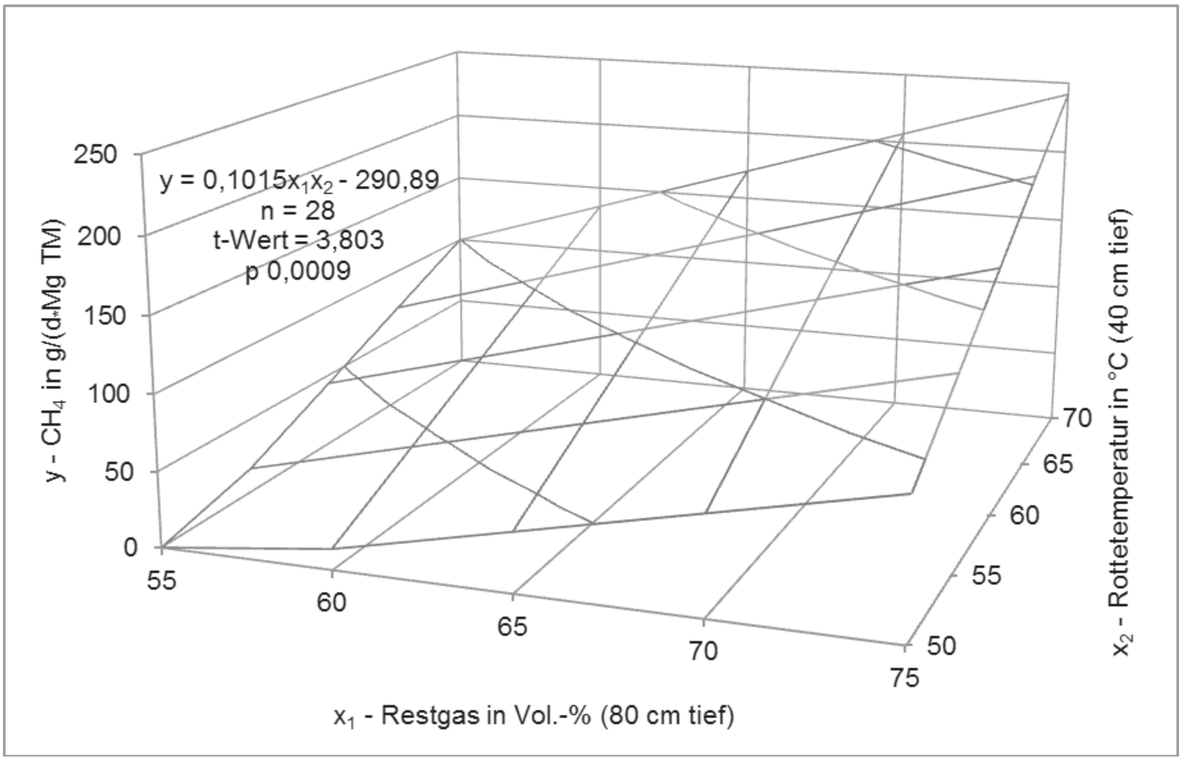

Abbildung 4 Zusammenhang von Restgas (Stickstoff) in den Rottegutporen in 80 cm Messtiefe, mittlerer Rotteguttemperatur in 80 cm Messtiefe und der Methanemission bezogen auf die Rotteguttrockenmasse (p - Irrtumswahrscheinlichkeit nach partiellem t-Wert)

Es wird deutlich, dass zunehmende Methangehalte in den Rottegutporen von Bioabfallkompostmieten mit progressiv ansteigenden Methanemissionen, bezogen auf Die Rotteguttrockenmasse, verbunden sind. Die oberflächennahen Methangehalte erwiesen sich als deutlich wirkungsstärker, als die in tieferen Schichten der Kompostmieten. Wird die Einhaltung einer Tagesemission von 100 g Methan je Mg Rotteguttrockenmasse angestrebt, dürften die Methangehalte im Porengas in 40 cm Messtiefe 8 Vol.-% und in 80 cm Messtiefe 16 Vol.-% nicht übersteigen. Diese Wirkung der Methangehalte in den Rottegutporen erwies sich als besonders deutlich und zeigte sich unabhängig von der ergänzenden Wechselwirkung aus Rottetemperatur in 40 cm Mietentiefe und dem Restgasgehalt (Stickstoff) der Poren in 80 cm Messtiefe. Ein gemeinsamer Anstieg dieser beider Einflussfaktoren erhöhte dem Austritt von Methan aus den Kompostmieten.

Die Wirkung der Rottetemperaturen auf die Methanemissionen sind als Ergebnis eines Konversionsprozesses zu verstehen. Durch hohe Temperaturen in den oberflächennahen Mietenzonen werden Rottegase ausgetrieben, wobei auch Methan mitgeführt wird. Das geschieht besonders intensiv, wenn die Durchlüftung in den tieferen Mietenschichten zunimmt. Der in Abbildung 5 dargestellte Zusammenhang von Methan- und Restgasgehalten in den Rottegutporen zeigt, dass zunehmende Restgasgehalte als ein Ausdruck stärker Mietendurchlüftung, verbunden mit aerober Rotteprozessführung anzusehen sind. Treten aerobe Rottebedingungen in Verbindung mit hohen Temperaturen im Rottegut auf, so wird durch den damit verbundenen intensiven Austausch zwischen Mieten- und Außenluft auch verstärkt Methan abgegeben.

Hier sollen die Ergebnisse zur Bedeutung der Feuchtrohdichte des an- bzw. umgesetzten Rottegutes für die Höhe und der Methangehalte in den Rottegutporen in 40 und 80 cm Messtiefe, der Rottetemperaturen in 40 cm Messtiefe und der Restgasgehalte in den Rottegutporen in 80 cm Messtiefe aufgezeigt und beschrieben werden. Die Ergebnisse der entsprechenden Kovarianzanalysen sind in den Abbildungen 6 bis 9 zusammengestellt.

Die Methangehalte im Porengas aus 40 und 80 cm Messtiefe wurden durch zunehmende Feuchtrohdichten des Rottegutes statistisch gesichert erhöht. Dichte Lagerungen des Rottegutes ist mit einer Verringerung der Luftführung im Substrat verbunden. Es zeigt sich, dass Feuchtrohdichten zwischen 0,50 und 0,65 kg je Liter Rottegut geeignet sind, um die Methanemissionen auf einem hinreichend niedrigen Niveau zu halten. Die auch geprüften Einflussfaktoren Inputmaterialart (Biogut, Grüngut) und Jahreszeit der Kompostierung (Sommer, Winter) zeigten dagegen keine sicheren Wirkungen auf die Höhe der Methangehalte in den Rottegutporen. Leicht abbaubare organische Inputmaterialien, die eine Entstehung von Methan begünstigen, treten also in allen Inputmaterialarten und zu allen Jahreszeiten auf.

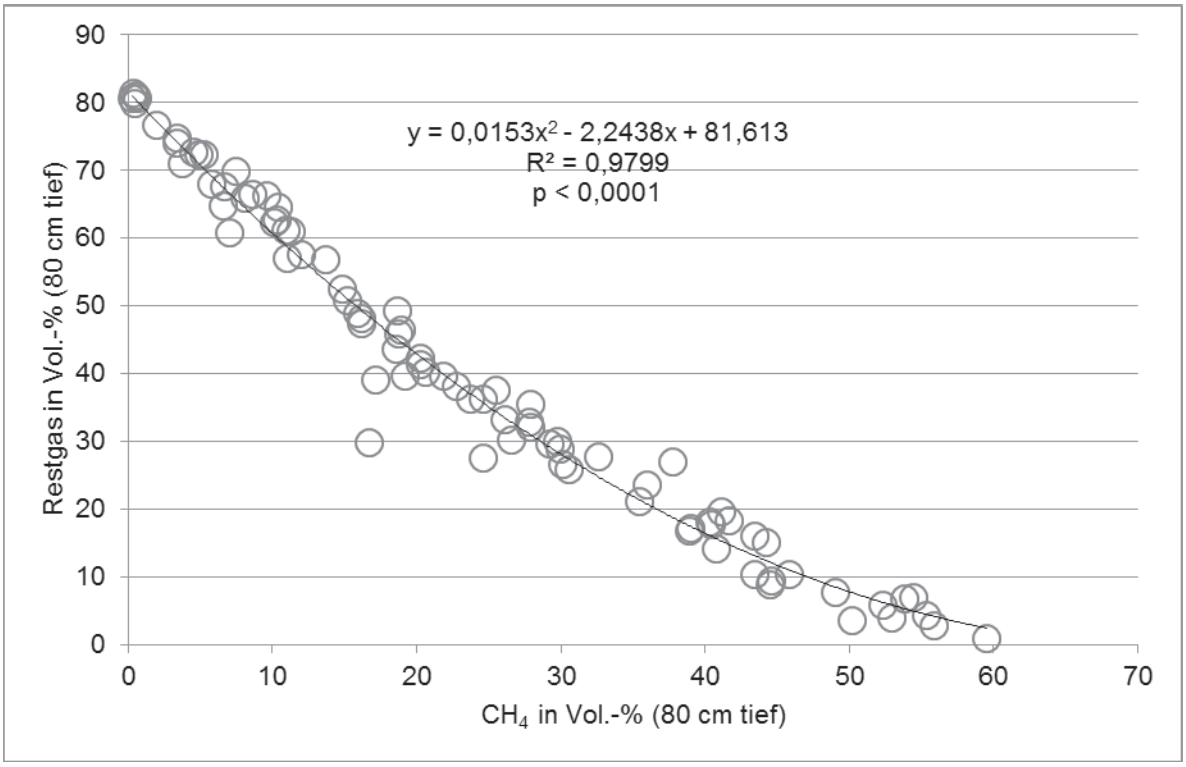

Abbildung 5 Direkter Zusammenhang der Porengasmesswerte für Methan und Restgas (Stickstoff) in 80 cm Tiefe bei der offenen Mietenkompostierung

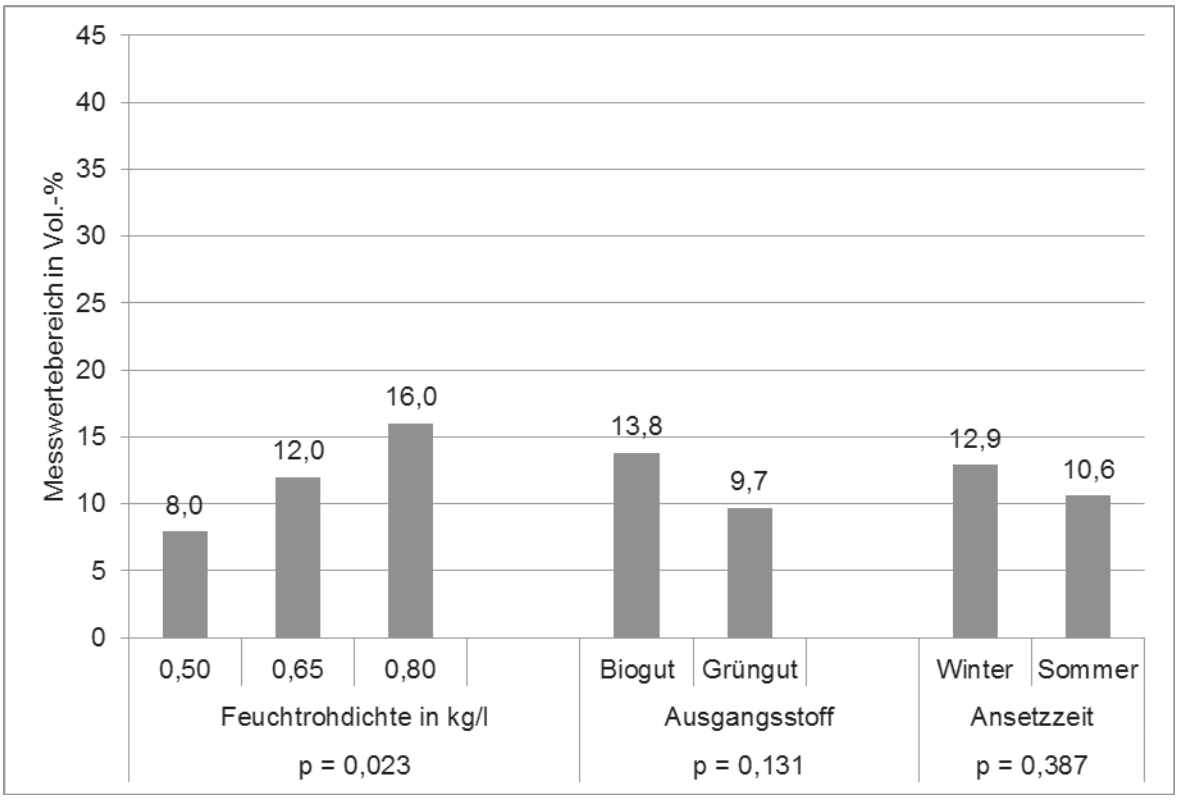

Abbildung 6 Einfluss von Inputstoffen, Jahreszeit und Feuchtrohdichte auf das Methan in den Rottegutporen bei 40 cm Messtiefe (p - Irrtumswahrscheinlichkeit nach Tuckey HSD-Test)

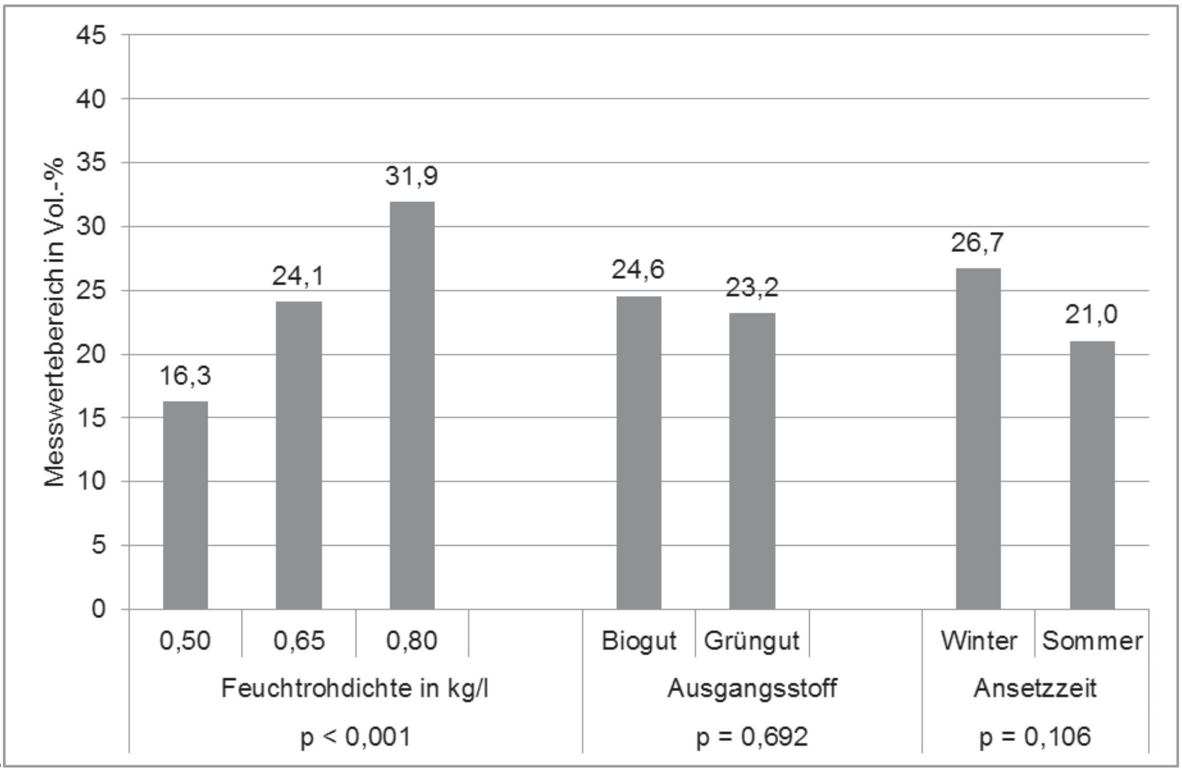

Abbildung 7: Einfluss von Inputstoffen, Jahreszeit und Feuchtrohdichte auf das Methan in den Rottegutporen bei 80 cm Messtiefe (p - Irrtumswahrscheinlichkeit nach Tuckey HSD-Test)

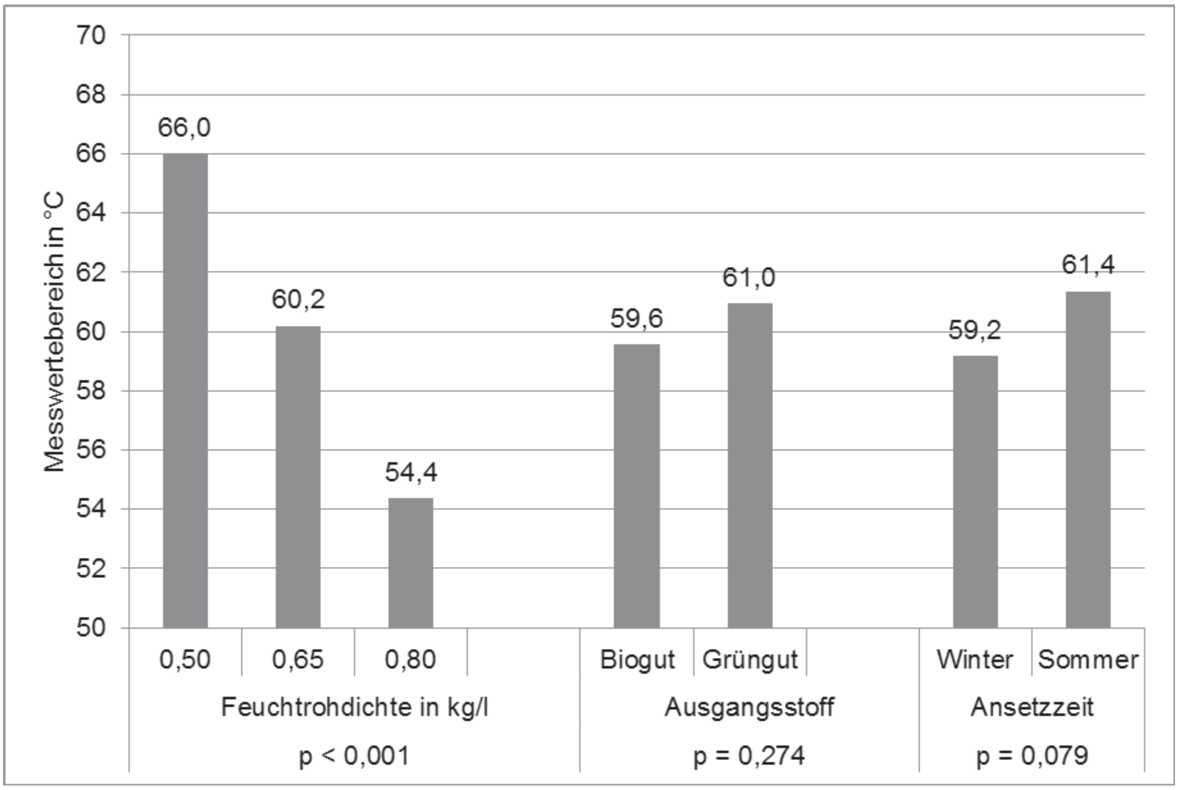

Abbildung 8: Einfluss von Inputstoffen, Jahreszeit und Feuchtrohdichte auf die Rottetemperaturen von Rottegut in 40 cm Messtiefe (p - Irrtumswahrscheinlichkeit nach Tuckey HSD-Test)

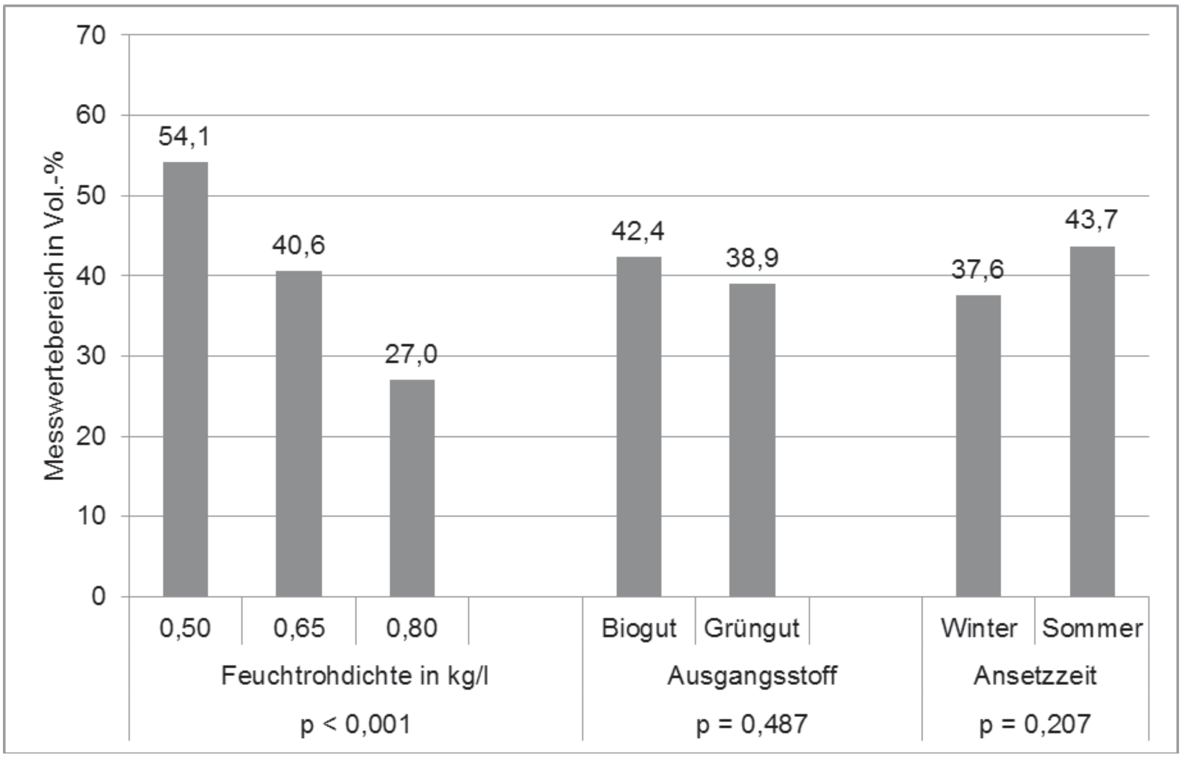

Abbildung 9: Einfluss von Inputstoffen, Jahreszeit und Feuchtrohdichte auf das Restgas (Stickstoff) in den Rottegutporen bei 80 cm Messtiefe (p - Irrtumswahrscheinlichkeit nach Tuckey HSD-Test)

Auch auf die Rottetemperaturen in 40 cm Messtiefe und die Restgasgehalte in 80 cm Messtiefe hatten zunehmende Feuchtrohdichten statistisch hoch gesichert reduzierenden Einfluss. Sehr hohe Mietentemperaturen, die deutlich über die Hygienisierungsanforderungen der Bioabfallverordnung hinausgehen, sind emissionsverstärkend und damit verzichtbar.

Es wird deutlich, dass zunehmende Feuchtrohdichten die Selbsthygienisierung und die Durchlüftung im Rottegut negativ beeinflussen können. Feuchtrohdichten unter 0,65 kg je Liter Rottegut scheinen auch hier angeraten zu sein. Hinsichtlich der Tages-Methanemission spielt die Feuchtrohdichte damit jedoch eine widersprüchliche Rolle, weil sowohl hohe Rotteguttemperaturen als auch eine starke Durchlüftung des Rottegutes die Methanemissionen anteilig fördern. Dem kann durch eine Verkürzung der Rottezeit auf das notwendige Mindestmaß entgegengewirkt werden.

Zusammenfassend bleibt festzustellen, dass der als Feldmessmethode geeignete Nachweis der Feuchtrohdichte geeignet ist, frühzeitig die Beschaffenheit von Rottegut so zu gestalten, dass eine emissionsarme aerobe Mietenkompostierung nach guter fachlicher Praxis unterstützt wird. Dafür kann folgender Vorschlag von Orientierungswerten für die Feuchtrohdichte beim Ansetzen von Ausgangsstoffen zu Kompostmieten unterbreitet werden (siehe Tabelle 3):

Tabelle 3 Vorschläge für anzustrebende Feuchtrohdichten im Rottegut beim Ansetzen von aeroben Kompostmieten (nach Reinhold, 2014)

vorgesehene Mietenhöhe in m		**Feuchtrohdichte von Rottegut in kg FM/l**
Tafel- und Trapezmieten	**Dreiecks-mieten**	
-	1,5	0,60 - 0,65
1,5	2,0	0,55 - 0,60
2,0	2,7	0,50 – 0,55
2,5	3,3	0,45 - 0,50
3,0	4,0	0,40 - 0,45

Zusätzlich bieten Messungen der Rottetemperaturen sowie der Methan- und Restgasgehalte in den Rottegutporen eine Möglichkeit, ohne die aufwändigen Nachweise der Emissionen klimarelevanter Gase mit Hilfe der gewitra-Tunnelmethode, eine grobe Vorabschätzung von zu erwartenden Methanemissionen vornehmen zu können. Das kann die Eigenüberwachung der aeroben Mietenrotte von Bioabfällen auf den Bereich des Emissionsgeschehens ausdehnen und erweitert so den Blick der Kompostierer auf eine optimale Rotteprozessgestaltung. Orientierend kann empfohlen werden, dass die Methangehalte bzw. aussagegleichen Restgasgehalte in den Rottegutporen in 80 cm Messtiefe als Hinweise für eine emissionsarme Rotteprozessgestaltung nutzbar werden können. Dazu werden erste Vorschläge für durchlüftungsbeschreibende Restgasgehalte (Stickstoff) wie folgt unterbreitet (siehe Tabelle 4).

Es kann empfohlen werden, die Anwendung von Feldmessmethoden, neben den schon ständig betriebenen Temperaturmessungen, um die Nachweise der Feuchtrohdichte und der Porengaszusammensetzung zu erweitern. Das wird dazu führen, dass es durch weitere Erfahrungswerte und Entwicklungsarbeiten zu einer schrittweisen Qualifizierung von emissionsreduzierenden Orientierungswerten für diese Feldmessmethoden kommt.

Tabelle 4 Vorschläge zur Nutzung der Messwerte von Restgasgehalten (Stickstoff) in den Rottegutporen für eine emissionsarme Prozessgestaltung der aeroben Mietenkompostierung (nach Reinhold 2014)

Restgasgehalte in den Rottegutporen in 80 cm Messtiefe	**Hinweis zur emissionsarmen Rotteprozessgestaltung**
über 50 Vol.-%	Umsetzen zur Förderung der Durchlüftung nicht erforderlich (nur für eventuell notwendiges Vermischen des Rottegutes)
37 bis 50 Vol.-%	verstärktes Umsetzen zur Förderung der Durchlüftung des Rottegutes empfehlenswert
unter 37 Vol.-%	beim Umsetzen sollte eine Anpassung des Mietenquerschnitts nach den Feuchtrohdichtewerten der Tabelle 3 erfolgen

5. Fazit

Die aerobe Mietenkompostierung kann durch eine angemessene Rotteprozessführung emissionsreduziert gestaltet werden. Dazu ist es erforderlich, den Rotteprozess durch Gewährleistung einer angemessenen Feuchtrohdichte der angesetzten Ausgangsstoffmischungen optimal zu gestalten. Für die Bestimmung der Feuchtrohdichte wurde eine leicht handhabbare Feldmessmethode erfolgreich erprobt.

Eine Kontrolle zur emissionsarmen Gestaltung der aeroben Mietenkompostierung kann durch Messungen der Rottetemperaturen und der Porengaszusammensetzung vorgenommen werden. Die aufwändigen direkten Messungen von Klimagasemissionen nach der gewitra-Tunnelmethode können damit auf Härtefälle eingegrenzt werden. Die Rotteguttemperaturen sollten die notwendige Hygienisierung der Bioabfälle gewährleisten, sollten jedoch im Sinne einer emissionsarmen Prozessführung sowohl hinsichtlich ihrer Höhe als auch zeitlich begrenzt werden.

Die neuen Feldmessmethoden können die Eigenüberwachung zur Rotteprozessführung bei der aeroben Mietenkompostierung deutlich aufwerten. Das kann bei Einhaltung von Orientierungswerten als Nachweis für eine Gleichwertigkeit der offenen Mietenkompostierung bei der Emissionsminderung (klimarelevanter Gase) im Vergleich zu eingehausten Kompostierungsanlagen bzw. als Hinweis zur aeroben Rotteprozessführung dienen.

Für das Land Brandenburg wurden auf der Grundlage der vorgestellten Ergebnisse Empfehlungen zur Limitierung klimarelevanter Emission aus der offenen Mietenkompostierung (ohne technische Belüftung) erstellt. Mitglieder der Gütegemeinschaften Kompost arbeiten derzeit an einer Erweiterung der Empfehlungen für die Rotte von Bioabfällen mit technischer Belüftung der Mieten. Darüber hinaus wird unter Koordinierung des Deutschen Biomasseforschungszentrums Leipzig an der emissionsarmen Gestaltung der Feststoffvergärung von Bioabfällen gearbeitet, wobei die oben genannten Erkenntnisse für die Nachrotte der Gärreste erschlossen werden sollen. Wie die vorgestellten Forschungsergebnisse für eine emissionsarme Gestaltung von Rotteprozessen auch für die mechanisch-biologischen Restmüllbehandlung genutzt werden können, sollte durch gezielte Forschungsvorhaben beantwortet werden.

Emission situation of bio-waste digestation

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Abstract

This paper focus on the greenhouse gas (GHG) emissions measured at 12 representative anaerobic digestion (AD) plants of the separately collected organic fraction of household waste (bio- waste). The emission analysis included the determination of methane (CH_4), nitrous oxide (N_2O) and ammonia (NH_3). The results of the emission measurements were used to assess the ecological impact of bio-waste digestion and to describe possible mitigation measures to reduce the occurring GHG emissions. GHG balances were calculated based on the measured emissions as well as the analysis of GHG credits. The results show that GHG emissions can be minimized, if the technology and operation of the plant are adjusted accordingly. The open storage of active material (e.g. insufficient fermented residues from batch fermentation systems), open digestate storage tanks, missing acidic scrubbers in front of bio-filters or insufficient air supply during the post-composting of digestate can cause relevant GHG emissions. Consequently avoiding open storage of insufficient fermented residues and using aerated post-composting with short turnover periods, smaller heaps and an optimized amount of structure (woody) material can reduce GHG emissions.

Keywords

Anaerobic digestion, bio-waste, Emission measurement, Greenhouse gas balance, GHG mitigation

1 Background

Gaseous emissions are of great importance referring to the operation of biogas plants because they can affect the safety, the greenhouse gas (GHG) balance, and the economy of plants significantly. Depending on the used technology and the kind of operation, GHG emissions like methane, nitrous oxide, and ammonia are occurring. Methane emissions dominate GHG emissions of biogas plants. Due to the global warming potential (GWP) of 25 relative to carbon dioxide (IPCC, 2007), methane emissions have a strong effect on the climate change. Leakages, process disturbances, and unavoidable emissions during operation can influence the total GHG performance of the biogas plant negatively. Regarding measured emissions of biogas plants in operation, only a small number of detailed studies are available.

Due to the fact that there are only few data describing the emission situation of AD plants based on bio-waste, in the study described here, 12 representative bio-waste treatment plants with AD process as part of the overall operation were analyzed. The overall objective of the study was a detailed analysis of GHG emissions generated from biogas production from bio-waste. The DBFZ investigated the emission situation of biogas plants based on bio-waste in Germany within a research project in cooperation with gewitra mbH and Dr. Reinhold & Kollegen during 2009 - 2012. The project was supported by German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

In Germany, approximately 9 million tons of bio-waste and green waste per year were collected separately in 2011 (DESTATIS, 2013). Most of this collected bio-waste and green cuts are used in composting processes. About 1.15 million tons of bio-waste per year and 0.05 tons of green cuts per year are used for digestion in biogas facilities (FRICKE ET AL., 2013). By the end of 2013, there have been about 130 plants generating biogas from organic waste in operation. Compared to agricultural biogas plants, there is a higher share of dry fermentation processes in AD plants based on bio-waste. About one half of the bio-waste digestion plants are operated as dry fermentation plants in Germany, whereas half of the dry fermentation plants are operated discontinuously (batch system). Due to the robustness of the process and the possibility to treat substrates which are hardly pumpable and contain disturbing materials (e.g., stones, metals, glass), the use of batch systems in case of dry fermentation processes of bio-waste is increasing.

2 Methods

Twelve biogas plants were selected for the detection of plant-based emissions of methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3). Based on the measured emission rates, GHG balances in compliance with the analysis of GHG credits (e.g., for biogas production, fertilizer, and humus effect of fermentation products and composts) were prepared. Thus, the electricity production and heat utilization of biogas as well as the credits of the various fermentation residues were analyzed to estimate the specific GHG performance of the investigated facilities. Finally, the measurements with respect to mitigation of GHG emissions were analyzed and described.

2.1 Investigated biogas plants

The emission analysis includes four continuously operated wet fermentation plants (continuous stirred-tank reactor, CSTR), five continuous dry fermentation plants (plug-flow fermenter), and three batch fermentation processes (discontinuous operation, 'garage style' digesters). Table 1 shows the investigated 12 AD plants based on bio-waste with their specific characteristics.

Table 1 Characteristics of investigated AD plants based on bio-waste

Plant no.	kW_{el}	Kind of fermentation[a]	Temperature[b]	Mode of Operation[c]	HRT in days[d]	Residues storage tank	Post-composting[e]	Type of aeration (post-composting)	External heat utilization[f]
1	630	Wet	M	Multi	8	Covered	x	Open, unaerated	
2	536	Wet	T	Multi	20	Covered	x	Open, unaerated	x
3	986	Wet	M	Single	17	Open			
4	1200	Wet	M	Multi	25	Open, covered			
5	1790	Dry	T	Single	25	Gas-proof covered			
6	1413	Dry	T	Single	21	Covered	x	Open, unaerated	
7	816	Dry	T	Single	28		x	Enclosed, aerated (pressure ventilation)	
8	625	Dry	T	Single	14	Gas-proof covered	x	Enclosed, aerated and unaerated (pressure ventilation)	x
9	640	Dry	T	Single	21	Covered	x	Enclosed, aerated (pressure ventilation)	
10	625	Batch	M	Single	28		x	Enclosed, aerated (pressure ventilation)	x
11	680	Batch	M	Single	21		x	Open, aerated, enclosed	x
12	370	Batch	M	Single	21		x	Open, unaerated	x

[a]Wet = wet fermentation, dry = dry fermentation, batch = batch system (discontinuous). [b] M = mesophilic, T = thermophilic. [c]Multi=Multi stage, Single = Single stage. [d]Hydraulic retention time. [e]x = post-composting process. [f]x = external heat utilization.

The treated bio-waste is used completely for digestion in AD plant nos. 2, 4, and 5. Most AD plants operate with partial stream digestion of bio-waste. In these plants, just the bio-waste from separate collection is used for fermentation, whereas the green cut and structure (woody) material is added after digestion within the composting process.

AD plant nos. 1, 2, and 12 were operated with open, unaerated post-composting processes. AD plant no. 3 had a covered but no enclosed composting steps. In AD plant no. 4, larger quantities of sludge from wastewater treatment were treated. Thus, primarily liquid digestate was generated. The small amounts of solid digestate were stored on site and were used for external composting. The solid digestate of AD plant no. 5 were stored open after separation. Post-composting processes with active ventilation (pressure ventilation) and enclosed composting systems were used at AD plant nos. 7, 9, and 10. A defined step of aeration in which the air is integrated into the exhaust gas treatment (bio-filter) was considered at plant no. 10.

All investigated biogas facilities operated with bio-filters as gas treatment. However, most of plant operators did not use acidic scrubbers at biogas facilities. Only four of 12 plants operated with acidic scrubbers, and the proper operation was not always ensured. Five plants used the bio-filter combined with humidifier. The exhaust gas should be treated with acid scrubbers to deposit NH_3 and minimize N_2O formation in the bio-filter (e.g., plant nos. 5 and 9). It should be recognized that there were also diffuse emission sources which were not collected by bio-filters (e.g., open doors of delivery hall at AD plant nos. 6 and 7; post-composting at AD plant nos. 8, 9, 11).

Often, digestate - whether separated or not separated - is stored open temporarily or for longer periods. Four of the seven examined plants which stored liquid digestate or process waters used covered storage tank (AD plant nos. 4, 5, 8, and 9). Two plants (nos. 5 and 8) with gas-proof covered storage tank are able to use the exhaust gas by involving into the CHP.

2.2 Emission measurements

The emission analysis included two measurement periods in each plant (each one1 week in 2010 and 2011), in which all plant components, from substrate delivery to storage of digestate and composting were investigated. The measured emissions of both periods were averaged. Several sampling points at AD plant and compost heaps were examined. Following the inspection of the biogas facilities on site, potential significant emission sources within the process chain were identified. The following emission sources were investigated: delivery and conditioning of substrate (material handling), storage of fermentation residues (digestate), fermenter, before and after exhaust gas treatment (acid scrubber and bio-filter), and exhaust of CHP unit (combined heat and power plant) as well as post-composting process of digestate. The emission measurements focused on the emission detection at the AD plant and post-composting processes – not the utilization of biogas in CHP units. Therefore, not all CHP were measured. Thus, an average of CHP emissions was considered (see 'Emissions from CHP'). For the emission measurements of the composting process, four or five sections of the windrow were selected for each measurement period, which differed in time of composting resp. age of rotting material.

According to the characteristics of the gases, the applied measurement techniques were adjusted. Leakage detection techniques were used to find the critical spots within the process; open and closed domes were used to determine the main emission sources. Regarding the methods of emission measurements, there are differences between captured and diffuse emission sources. Accordingly, different measurements for emissions from encapsulated areas (e.g., delivery hall with collection of exhaust) and diffuse emission sources during several measured periods were used. Waste treatment facilities often have gas collection systems that collect air from the captured process steps and deliver the gas after a cleaning stage into the atmosphere. In most cases, the cleaning step is a bio-filter. Because of that, in all investigated AD plants, the exhaust streams before and after treatment by bio-filters were examined. Depending on the plant system, further sampling points were analyzed. In case of encapsulated emission sources, the exhaust air flow was examined directly. Emissions of post-composting with active aeration (e.g., actively ventilated tunnel or container systems) were measured by using encapsulated areas with air extraction. In case of open windrows composting without active aeration, a wind tunnel as emission measurement was used. An air flow was generated by using a ventilator. Further information according to the methods of emission measurement at biogas plants are published in (LIEBETRAU ET AL., 2010).

2.3 Assumptions - GHG balances

Based on a survey of plant operator, additional emission-related data (e.g., energy demand, amount, and kind of heat utilization) were collected to prepare the GHG balance of each plant. For the total GHG balances, the emissions as well as credits for the kind of products (combined heat and electricity from biogas; fertilizer and humus supply from fermentation residues) were considered. The overall GHG performance of each AD plant included in particular the following: GHG emissions according to the measured components of AD plant, calculated emissions of the electricity demand (AD plant and CHP), calculated emissions during the application of the fermentation residues, credits for the electricity production from biogas (substitution of fossil electricity supply), credits for the utilization of exhaust heat (substitution of fossil heat), and credits for the use of fermentation products (substitution of fossil fertilizer and peat, humus effects).

The considered GHG emissions for all processes of bio-waste digestion were converted into CO_2 equivalents (CO_2-eq) by using characterization factors. The following factors according to the GWP for a 100-year time period were stated: CO_2 = 1, CH_4 = 25, N_2O = 298 (IPCC, 2007). With respect to the NH_3 emissions, it is assumed that 1% of the NH_3 is converted to N_2O emissions (IPCC, 2007).

As a functional unit of GHG balances, 'ton input bio-waste treated at facility (fresh matter)' was used. This unit included the total amount of waste treated at the facility (bio-waste and green waste - if any) - not only the amount of bio-waste in the fermentation process. In few biogas plants, municipal bio-waste from separate collection and green waste from gardens and parks were treated, but only the bio-waste is used in the step of digestion. After the fermentation process, the digestate is often combined with the green cuts within the post-composting process. Thus, the measured emissions of post-composting processes based on the treated waste at the facility in total.

In addition to the measured GHG emissions of the AD plants, further assumptions to calculate the GHG performance were considered.

2.3.1 Emissions from CHP

Due to the fact that not all CHP units were measured, an average emission value for the CHP is assumed. According to measurements of gewitra (personal communications), the median of CH_4 and N_2O emissions of 161 measured CHP units in the range from 300 to 1,000 kW_{el} were determined with 1,760 g CH_4 per ton of bio-waste and 2.1 g of N_2O per ton of bio-waste treated at the facility. Considering the emission factors (IPCC, 2007) for N_2O (298) and CH4 (25), a GWP of 44.6 kg CO_2-eq per ton of bio-waste was estimated for all CHP units.

2.3.2 Electricity production

The electricity production from biogas replaces fossil fuels and can be considered as credit (THRÄN, D. & PFEIFFER, D., 2011).The amount of credit for the electricity production depends on the amount of produced electricity referring to the data of plant operators. The electricity mix of Germany in 2011 with 559 g CO_2-eq per kWh_{el} (UBA, 2012) was assumed to calculate the credit of electricity production. The energy demand of the investigated biogas plants was determined according to the data of plant operators. It was estimated to cover the electricity demand by using external electricity from the grid.

2.3.3 Heat utilization

The exhaust heat of electricity generation in CHP units can - if used - substitute heat production based on fossil fuels (THRÄN, D. & PFEIFFER, D., 2011). The avoided GHG emissions of fossil heat supply by providing heat for external utilization (e.g., district heating, drying process) was stated as heat credits. The amount of heat credit may vary depending on the amount of heat and type of fossil heat, which is replaced in the specific case. With regard to the substitution of fossil heat, an average of the specified external heat mix of 291 g CO_2-eq per kWh_{th} (THRÄN, D. & PFEIFFER, D., 2011) was used to calculate the heat credits.

2.3.4 Digestate - fertilizer and humus effects

According to the kind of digestate (finished compost, fresh compost, liquid fermentation residues, solid digestate), different GHG emissions can be saved and considered to the GHG balances as credits. Referring to the kind of digestate, the following credits were determined: substitution of mineral fertilizer (nitrogen, phosphorus, potassium), substitution of peat (only in case of finished compost), humus accumulation (carbon-sink), and humus reproduction (i.e., for maintaining soil fertility).

With respect to the nutrient content (i.e., nitrogen, phosphorus, potassium amounts) of investigated digestates, the production of mineral fertilizer can be substituted and stated in GHG balances as credit. The following emission factors for the production of mineral fertilizer were assumed according to (BLE, 2010): 6.41 kg CO_2-eq per kg nitrogen (N), 1.18 kg CO_2-eq per kg phosphorus (P_2O_5), and 0.663 kg CO_2-eq per kg potassium (K_2O).

Humus effects of digestate at investigated AD plants were considered if applied on agricultural land. According to the kind of digestate, the substitution effect compared to straw was analyzed by Dr. Reinhold&Kollegen. Therefore, the amount of straw was calculated which might be used for biogas production if the application of digestate on agricultural land is assumed. Differed to the kind of digestate, the amount of straw per ton of digestate (fresh matter) was calculated as follows: 2.11 (finished compost), 1.82 (fresh compost), 0.91 (digestate with post-composting), and 0.15 (liquid digestate). The electricity production of the assumed biogas production due to the fermentation of straw was considered as credit for humus reproduction of digestate.

The substitution of peat was estimated only in case of finished compost. According to the assumptions in (VOGT ET AL., 2002) 1 kg dry peat (respectively, 2 kg fossil carbon dioxide) is replaced by 1 kg compost (organic dry matter). Referring to the humus accumulation (carbon sink) of composted digestate, the amount of organic carbon (Corg) as published in (KNAPPE ET AL., 2012) was assumed as follows: 21.6 kg Corg per ton of digestate for fresh compost and 64.5 kg Corg per ton of digestate for finished compost. In consideration of the stoichiometric ratio of Corg relative to CO_2, 1 kg Corg can fix 3.7 kg CO_2.

2.3.5 Application of digestate

The application of digestate on agricultural land can cause N_2O emissions as well as NH_3 emissions (WULF ET AL., 2002). With respect to the NH_3 emissions, it was assumed that 1% of the NH_3 is converted to N_2O emissions (IPCC, 2007).

3 Results and discussion

3.1 GHG emissions

Various fermentation processes such as wet fermentation, dry fermentation, and batch fermentation were analyzed according to the emission situation. The results show that the emissions are dominated not by the kind of the fermentation process or the technology but by the manner of plant operation. Figure 1 shows the measured emissions of CH_4, N_2O, and NH_3 (converted to carbon dioxide equivalents) of the investigated AD plants.

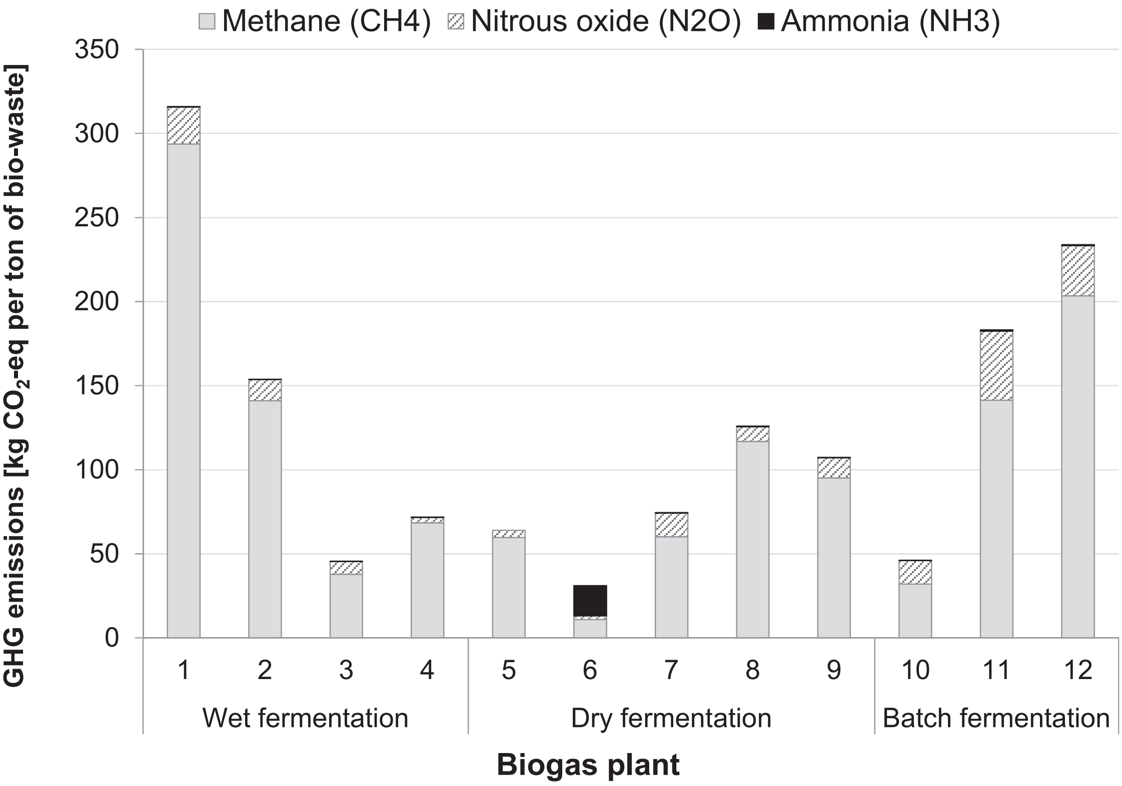

Figure 1 GHG emissions of the investigated bio-waste AD plants differed to the kind of GHG emission.

The range of determined plant emissions varied between 40 and 320 kg CO_2-eq per ton of bio-waste. The detailed presentation on the type of GHGs shows that the CH_4 emissions - except for plant no. 6 - dominate the indicated GHG equivalents of biogas facilities.

Important sources of GHG emissions were identified. The component-specific GHG emissions of the bio-waste digestion plants are presented in Figure 2.

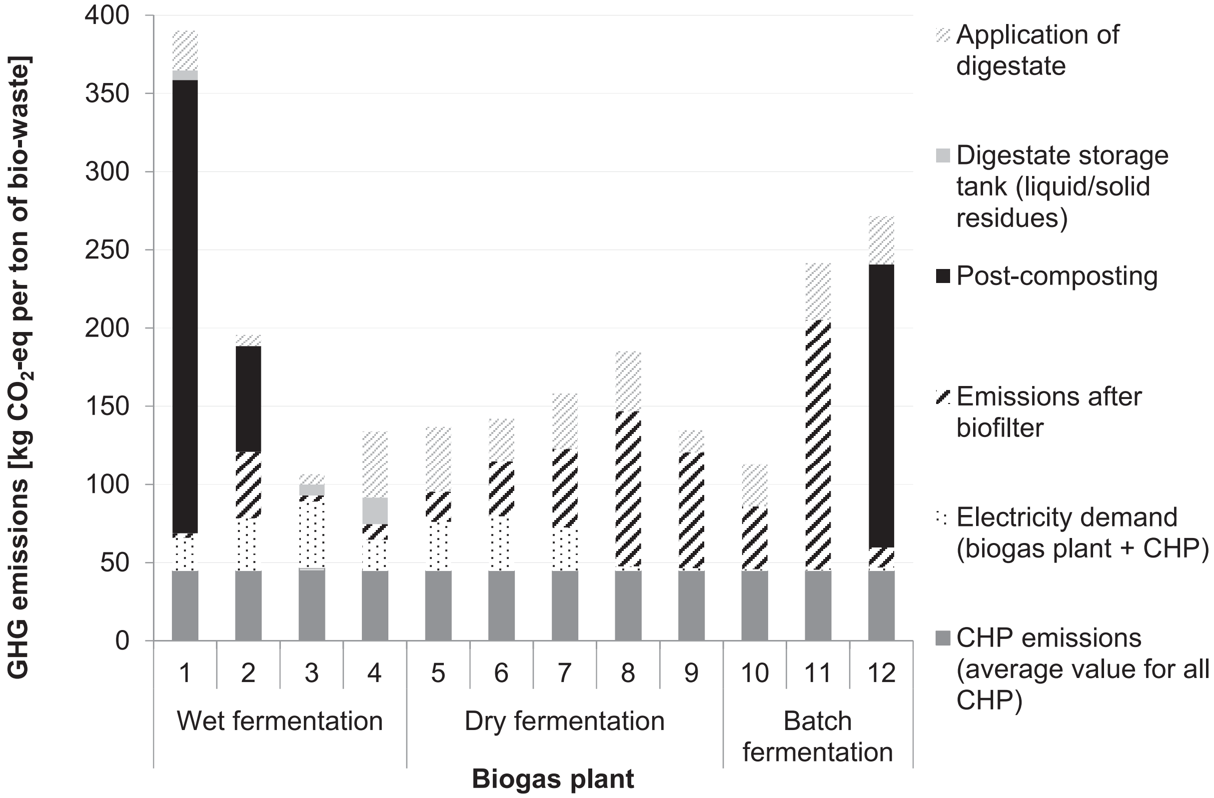

Figure 2 GHG emissions of bio-waste digestion plants differed to kind of plant components.

Especially, the inadequate aeration directly after fermentation (in order to interrupt the methanogenic activity) processes as well as unaerated or less aerated post-composting processes caused extremely high GHG emissions (see plant no. 1, no. 2, or no. 12). In case of some of the investigated biogas plants, the emissions of post-composting are summarized in the amount of 'emissions after bio-filter' (e.g., AD plant no. 10). The overall emissions of AD plant no. 10 were quite low because all parts of the fermentation and post-composting process were totally encapsulated.

Furthermore, AD plant no. 6 showed higher NH_3 emissions due to the drying of digestate at higher temperature and higher pH value. In this case, the existing downstream acidic scrubber was out of operation during the measurements. The operation of the bio-filters can also be problematic; extremely wet bio-filters for example can cause additional CH_4 production as observed at AD plant no. 8.

Finally, on almost all AD plants, emission sources were identified whose intensity can be reduced if the state-of-the-art treatment technology was used (e.g., acid scrubber before bio-filter, aeration of post-composting). The results show that the open storage of fermentation residues (with or without separation step) should be avoided. In addition to unaerated post-composting processes and open storage of active material (e.g., solid digestate), the CHP was one of the most important sources of CH_4.

3.2 GHG balances

The overall GHG balance of the investigated AD plants depends on the measured GHG emissions on the one hand (see 'GHG emissions') and on the credits for the generated products (e.g., combined heat and electricity from biogas; fertilizer and humus supply from fermentation residues) on the other hand. The calculated GHG credits according to the AD plant concept are presented in Figure 3.

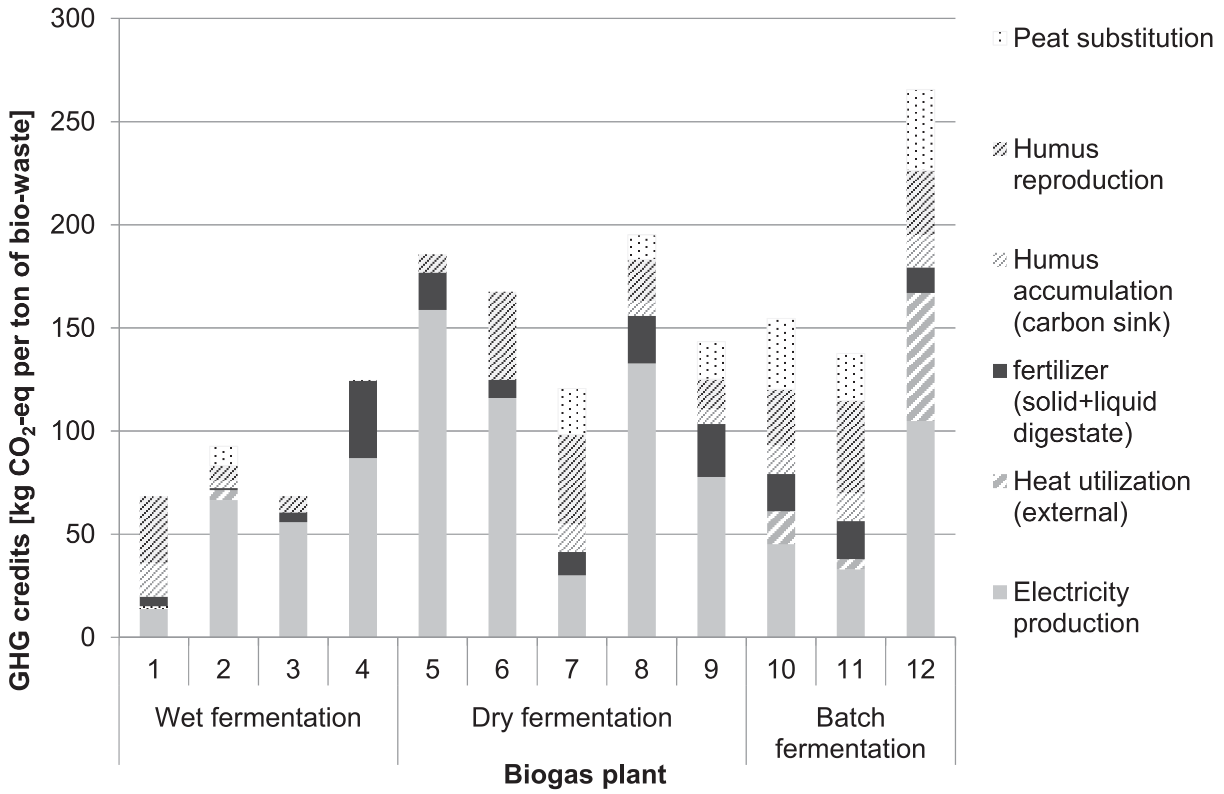

Figure 3 GHG credits of investigated bio-waste digestion plants.

Finally, the highest amount of GHG credits of humus reproduction can be expected from composted digestate. In general, the following order of humus reproduction can be assumed: post-composted digestate (finished and fresh compost) > solid digestate > liquid digestate. In case of finished compost, additional GHG credits for the substitution of peat (by application in soil producing facilities, e.g.) can be considered.

Regarding the GHG credits, the highest importance of an efficient fermentation had the production of energy. A high share of electricity generation led to high GHG credits. As far as the utilization of exhaust heat of electricity production was possible, it had also a positive influence on the GHG performance of the AD plant. Moreover, the use of digestate showed positive effects on the GHG balances. In addition to the nutrient effect through the utilization of the fermentation residues as a fertilizer (substitution of mineral fertilizer), GHG emissions can be saved due to the humus effect of digestate. Especially, composted digestate like fresh and finished compost contributed to the humus accumulation (carbon sink) and the humus reproduction of digestate. Compared to the production of fresh or finished compost digestate without post-composting process, which is used within the agriculture directly, less GHG credits were given. However, the risk of high emissions during the post-treatment of the fermentation residues was avoided.

The total range of GHG balances (including credits) varied between −49 and 323 kg CO_2-eq per ton of bio-waste due to different plant concepts and measured emissions (see Figure 4). The balance is shown as a result of total GHG emissions of AD plant and total GHG credits (black column).

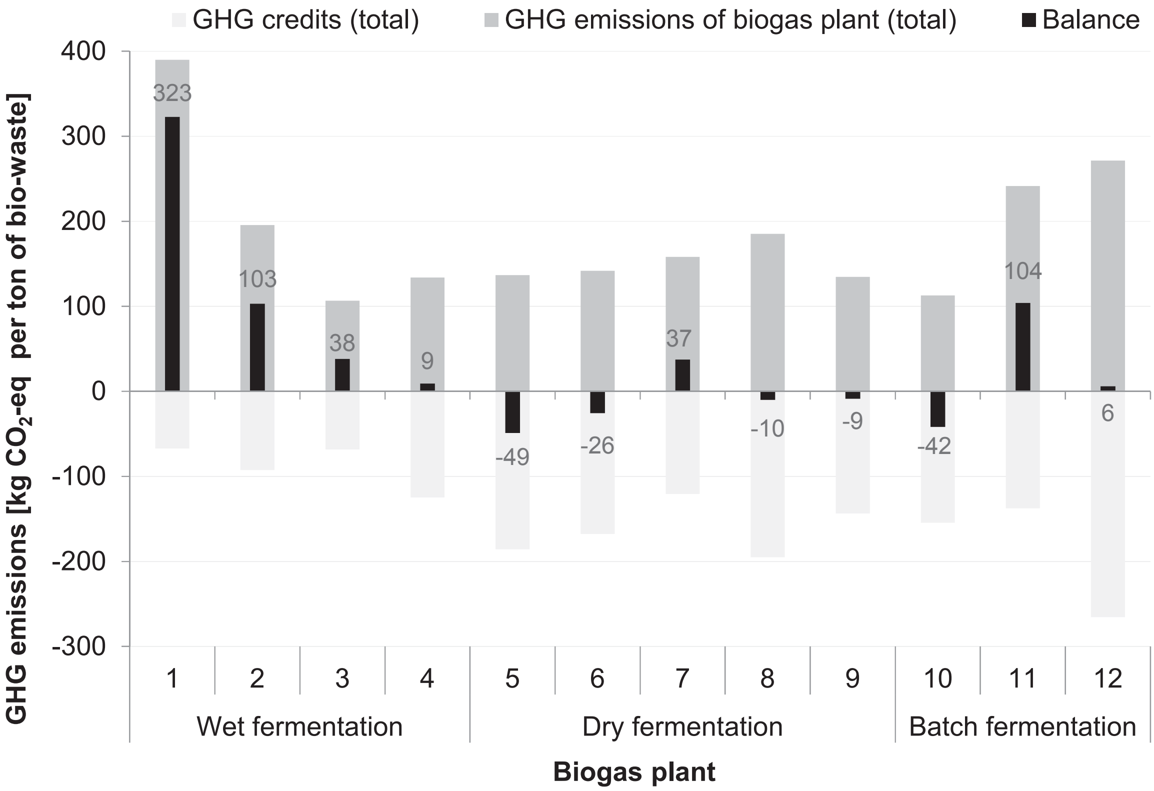

Figure 4 Total GHG balance of bio-waste digestion plants with GHG emissions of AD plant and GHG credits.

4 Conclusions

Based on the emission measurements, significant sources of emissions were identified. In general, the emission situation is not uniform, the plants show very different emission rates. Basically, the kind of operation of the plant and the handling of digestate determine the amount of GHG emissions. Inadequate digestion of the substrate caused not only low gas production, respectively, electricity generation, but also high emissions during the post-composting process of digestate. It can be stated that all investigated biogas facilities showed potential for optimization. The following measures are able to reduce GHG emission of bio-waste digestion: intensive aeration of the (solid) digestate after fermentation; gas-tight storage tank for fermentation residue and integration into biogas utilization; avoidance of any open storage of digestate and fermentation residues; and small, aerated compost windrows combined with sufficient structural materials and frequent turnover as well as the use of acidic scrubbers in front of the bio-filter.

The overall GHG balances of the investigated AD plants depend on the measured emissions as well as the amount of credits for the generated products (e.g., combined heat and electricity from biogas; fertilizer and humus effects from fermentation residues). The consideration of GHG credits can optimize the overall GHG performance of the biogas facilities.

With respect to the development of methodology of emission measurements and the standardization of procedure for the determination of emissions on biogas plants, further investigations are necessary. In this regard, the reliable measurement of stationary and diffuse emission sources is of high importance. Uncertain are the emissions sources (e.g. emissions from pressure relief valves) that are not coupled to the gas system of the plant, but still cause GHG emissions. Concerning the emissions, the treatment and evaluation of temporary occurring emissions caused by certain operational conditions are still unclear. Moreover, the further development of ecological assessment of biogas pathways with respect to the humus effects of digestate in comparison to other pathways is of great importance.

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Pflicht zur Biotonne? – Spielräume bei der Bewertung

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Obligatory bio-waste-container?

Abstract

§ 11 KrWG obliges public waste management authorities to collect bio-waste separately – but only as far as this is necessary in order to comply with § 7 II to IV and § 8 I KrWG (the rules for re-covery). This limitation is important. Whether the separate collection is necessary or not depends on what is best for the environment in the particular case – the recovery of separately collected bio-waste or the recovery of all bio-waste or parts of it together with other waste. Therefore, a life cycle assessment is needed. The article shows that public waste management authorities have a wide margin of judgement in generating this. Even if the separate waste collection proves to be the best environmental option, it does not need to be introduced if this is not economically reasonable. If the correct legal criteria for assessing the economical reasonability are applied, the often voiced statement that only in absolute exceptional cases the separate collection is economically unreasonable, proves to be wrong.

Inhaltsangabe

§ 11 Abs. 1 KrWG verpflichtet zur Getrenntsammlung von Bioabfällen ab 2015 – allerdings nur soweit dies zur Erfüllung der Anforderungen nach § 7 Abs. 2 bis 4 und § 8 Abs. 1 KrWG (kurz: Verwertungsanforderungen) erforderlich ist. Dieser Einschränkung wird in der Diskussion häufig zu wenig Bedeutung beigemessen. Der nachfolgende Beitrag befasst sich damit, wie die öffentlich-rechtlichen Entsorgungsträger prüfen müssen, ob sie zur Einführung einer Getrenntsammlung von Bioabfällen verpflichtet sind. Er zeigt ihre Beurteilungsspielräume bei dieser Prüfung und ihre Bedeutung in der Praxis auf.

Keywords

Bioabfall, Getrenntsammlung, Ökobilanz, wirtschaftliche Zumutbarkeit, Abfallhierarchie, Verwertung

bio-waste, separate collection, environmental life cycle assessment, economical reasonability, waste hierarchy, recovery

1 Keine gesetzgeberische Grundentscheidung für Getrenntsammlung

Gerne wird vorgebracht, bei der Prüfung von Pflichten zur Getrenntsammlung sei zu beachten, dass der Gesetzgeber mit § 11 Abs. 1 Kreislaufwirtschaftsgesetz eine Grundentscheidung für die Getrenntsammlung von Bioabfällen und zugunsten stofflicher Verwertungsverfahren getroffen habe. Von einer solchen Grundentscheidung kann indes nur für die Stoffströme Papier, Kunststoff, Glas und Metall ausgegangen werden. Diese sind gemäß § 14 Abs. 1 Kreislaufwirtschaftsgesetz zum Zweck des Recyclings getrennt zu sammeln, soweit technisch möglich und wirtschaftlich zumutbar. Von der Frage der Art der Verwertung der Abfälle wird die Getrenntsammlungspflicht hier nicht abhängig gemacht. Für Bioabfälle hat der Gesetzgeber hingegen eine deutlich andere Regelung getroffen und die Pflicht zur Getrenntsammlung davon abhängig gemacht, dass dies zur Erfüllung der Verwertungsanforderungen erforderlich ist. Hierin liegt keine Grundentscheidung zugunsten einer Getrenntsammlung, sondern diese wird vielmehr nur unter bestimmten Voraussetzungen angeordnet. Auch eine Vorfestlegung auf eine stoffliche Verwertung ist hier nicht zu erkennen.

2 Ökologiebewertung ist entscheidend

Für die Pflicht zur Getrenntsammlung kommt es entscheidend auf einen ökologischen Vergleich an. Die Getrenntsammlung muss nur eingeführt werden, wenn dies zur Erfüllung der Verwertungsanforderungen nach §§ 7 und 8 KrWG erforderlich ist. Nach § 8 Abs. 1 Satz 1 KrWG[1] hat bei der Erfüllung der Verwertungspflicht diejenige der in § 6 Abs. 1 Nr. 2 bis 4 genannten Verwertungsmaßnahmen (Vorbereitung zur Wiederverwendung, Recycling und sonstige, u. a. energetischer Verwertung) Vorrang, die den Schutz von Mensch und Umwelt am besten gewährleistet. Um dies zu ermitteln, ist ein ökologischer Vergleich der Maßnahmen bei Getrenntsammlung einerseits und Verzicht auf Getrenntsammlung andererseits durchzuführen.

2.1 Keine absolute Geltung der Abfallhierarchie

Häufig wird angeführt, das Erfordernis einer stofflichen Verwertung der Bioabfälle mache eine Getrenntsammlung notwendig. Dass der Bioabfall stofflich zu verwerten sein soll, wird dabei aus der Abfallhierarchie hergeleitet, innerhalb derer das Recycling der energetischen Verwertung vorgeht (so z.B. MUGV BBG, S.2: „Der Vorrang der hochwertigen stofflichen Verwertung der im Restabfall enthaltenen organischen Bestandteile setzt die getrennte Erfassung der Bioabfälle voraus.“). Eine so große Bedeutung kommt der Abfallhierarchie jedoch nicht zu. § 8 Abs. 1 Satz 1 KrWG löst sich von der Abfallhierarchie, verweist auch nicht auf § 6 Abs. 2 S. 1 KrWG, der die Hierarchie als Ausgangspunkt nennt, und stellt im Ergebnis nur darauf ab, was den Schutz von Mensch und Umwelt am besten gewährleistet. Die Abfallhierarchie hat dessen ungeachtet ohnehin nur die Wirkung, dass die größere Umweltverträglichkeit einer in der Hierarchie vorran-

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[1] Hier wird zugrunde gelegt, dass der Vergleich zwischen mehreren Verwertungsmaßnahmen stattfindet, dass also der öffentlich-rechtliche Entsorgungsträger für den Restabfall auch eine Verwertungsverfahren vorsieht.

gigen Maßnahme vermutet wird (SCHINK, § 6 Rn. 32). Es ist aber der Nachweis möglich, dass eine nach der Abfallhierarchie nachrangige Maßnahme die bessere Umweltoption ist (vgl. KERSANDT, § 11 Rn. 18; SCHOMERUS, § 8 Rn. 4).

2.2 Hochwertig ist nicht gleich stofflich

Des Weiteren wird mitunter angeführt, nur eine stoffliche Verwertung des Bioabfalls sei eine hochwertige Verwertung (so MUGV BBG, S. 5: „Danach kann die im KrWG geforderte hochwertige Verwertung nur durch Verfahren erreicht werden, die obligatorisch eine stoffliche Verwertung der Abfälle beinhalten.“). Die Begriffe „hochwertig“ und „stofflich“ sind jedoch nicht gleichzusetzen. Die Entscheidung darüber, ob stofflich oder energetisch verwertet wird, richtet sich nach § 8 Abs. 1 Satz 1 (und 2) KrWG (was den Schutz von Mensch und Umwelt am besten gewährleistet). Gemäß § 8 Abs. 1 Satz 3 KrWG ist dann bei der Ausgestaltung der nach Satz 1 (und 2) durchzuführenden Verwertungsmaßnahme eine den Schutz von Mensch und Umwelt am besten gewährleistende, hochwertige Verwertung anzustreben. Erst nach der Entscheidung darüber, ob stofflich oder energetisch verwertet wird, kommt die Hochwertigkeit ins Spiel. Bei dem Hochwertigkeitsgebot, das im Übrigen nicht als konkrete Rechtspflicht ausgestaltet ist (SCHINK, § 8 Rn. 14; SCHOMERUS, § 8 Rn. 14; QUEITSCH, S. 222), geht es nicht um die Auswahl zwischen stofflicher und energetischer Verwertung, sondern darum, einer energetischen Verwertung mit schlechtem Feuerungswirkungsgrad oder einem sog. Downcycling beim Recycling entgegenzuwirken (SCHOMERUS, § 8 Rn. 15).

2.3 Heizwertklausel steht nicht entgegen

Auch gebietet die Heizwertklausel nach § 8 Abs. 3 Satz 1 KrWG keine stoffliche Verwertung des Biomülls. Hiernach ist bei einem Heizwert des einzelnen Abfalls von mindestens 11.000 Kilojoule pro Kilogramm anzunehmen, dass die energetische Verwertung einer stofflichen Verwertung gleichrangig ist. Das bedeutet aber nicht, dass eine energetische Verwertung von Abfällen mit geringerem Heizwert von vornherein unzulässig wäre. Wenn der Heizwert niedriger liegt, darf dennoch energetisch verwertet werden, wenn dies den Schutz von Mensch und Umwelt am besten gewährleistet (vgl. BT-DRS. 17/6052, S. 79; SCHINK, § 8 Rn. 21; SCHOMERUS, § 8 Rn. 24).

3 Vergleich des Status quo mit welchen Verwertungsverfahren für Bioabfälle?

Bei der ökologischen Bewertung ist die Verfahrensweise mit den Abfällen bei Getrenntsammlung einerseits und Verzicht auf Getrenntsammlung andererseits in ihren ökologischen Folgen zu vergleichen. Die Verfahrensweise bei Verzicht auf Getrenntsammlung wird zumeist dem Status quo beim öffentlich-rechtlichen Entsorgungsträger entsprechen. Doch mit welchem Behandlungsverfahren für die Bioabfälle soll dieser Status quo verglichen werden? Das Gesetz enthält hierzu keine Vorgaben. Im IFEU-Gutachten 2012 wird festgestellt, dass eine klare ökologische Vorteilhaftigkeit der Getrenntsammlung nur mit einer Vergärung nach einem fortgeschrittenen Stand der Technik, die eine stoffliche und energetische Verwertung der Abfälle (Kaskadennutzung) gewährleistet, erreicht wird (IFEU 2012, S. 88; vgl. auch MUGV BBG, S. 2: „Eine eindeutige ökologische Vorteil-haftigkeit gegenüber anderen Verwertungswegen kann eindeutig aber nur für die stoffliche Verwertung in Form einer Kaskadennutzung nachgewiesen werden.“). Ein solches Verfahren ist rechtlich nicht vorgeschrieben, weder im Kreislaufwirtschaftsgesetz noch der Bioabfallverordnung. Ein Vergleich mit diesem Verfahren ist indes nicht geboten, solange der Bund keine entsprechende Form der Verwertung, etwa über eine Rechtsverordnung nach § 8 Abs. 2 KrWG, vorgibt.

Der öffentlich-rechtliche Entsorgungsträger hat bei der Durchführung der ökologischen Bewertung dort, wo das Gesetz keine konkreten Vorgaben enthält, einen Beurteilungsspielraum. In dessen Rahmen kann er sich ohne Weiteres auch für den Vergleich mit anderen möglichen Behandlungsverfahren für den Bioabfall entscheiden. Ein sachgerechtes Kriterium für die Auswahl kann dabei sein, welche Behandlungsanlagen in der Region zur Verfügung stehen. Auch der Vergleich mit einer Kompostierung der gesamten Bioabfälle ist dem öffentlich-rechtlichen Entsorgungsträger rechtlich nicht versagt, zumal diese für Bioabfälle in Deutschland bislang gängige Praxis ist. Das Hochwertigkeitsgebot steht dem nicht entgegen. Allgemein wird davon ausgegangen, dass nach diesem Maßstab allenfalls offensichtlich niederwertige Verwertungen unzulässig sind (so auch die Gesetzesbegründung, BT-DRS. 17/6052, S. 79; SCHINK, § 8 Rn. 7). Die Kompostierung ermöglicht eine stoffliche Verwertung der Bioabfälle mit demselben Ressourcengewinn wie die Vergärung. Es besteht keine Grundlage dafür, dieses Verfahren nicht als hochwertig anzusehen (BMUB 2014, S.4). Eine Pflicht zur Wahl von Luxusvarianten beinhaltet das Hochwertigkeitsgebot nicht.

4 Keine Einbeziehung bereits getrennt erfassten Bioabfalls (Eigenkompost, Grünabfälle) – „Biotonnenbeifang“ in die Bewertung

In den ökologischen Vergleich muss eine Verlagerung zuvor eigenkompostierter Abfälle in die Biotonne nicht einbezogen werden, weil für diese nicht überlassungspflichtigen Abfälle keine Verwertungspflichten des öffentlich-rechtlichen Entsorgungsträgers bestehen und die Getrenntsammlungspflicht auf diese auch nicht abzielen soll. Auch bislang schon getrennt gesammelte Grünabfälle müssen nicht in den Vergleich einbezogen werden. Beide Fraktionen können wegen der bereits erfolgenden getrennten Erfassung keine Rolle für die Frage spielen, ob eine Getrenntsammlung geboten ist.

Die Reduzierung der Ökologiebewertung der Biotonne auf die Fraktion "Hausmüllorganik" ist vor dem Hintergrund des "Biotonnen-Auftrags" des KrWG § 11, nach dem - richtig - die Biotonne die einzige Möglichkeit ist, um eben diese Hausmüllorganik zu erfassen, folgerichtig. Für die Erfassung von Grüngut ist keine Biotonne erforderlich (Alternativen sind vorhanden), die Umlenkung eigenkompostierter Materialien ist ebenfalls nicht Auftrag der Biotonne, abgesehen von der nicht bestehenden Überlassungspflicht. Ob die Biotonne über die übrige miterfasste eigenkompostierte und Grüngut-Organik einen ökologischen Vorteil bringt, ist unerheblich, denn auf einen anderen als den bisherigen Umgang mit diesen zuvor bereits getrennt erfassten „Beifang”-Materialien zielt die Getrenntsammlung nicht ab. Je nachdem, ob der „Biotonnen-Beifang” in die Betrachtung einbezogen wird oder nicht, kann sich das Ergebnis der Bewertung nach § 8 KrWG ändern. Gegenüber der Gesamtheit des Biotonnen-Inhaltes ergibt sich mitunter ein Klima-Vorteil der Biotonne, wenn dieser vergoren wird. Dieser klimaentlastende Effekt resultiert oft einzig aus dem rechtlich nicht geforderten "Beifang" aus Grüngut und eigenkompostiertem Material. Für die Hausmüllorganik bewirkt die Biotonne bei höherwertiger Restabfallbehandlung praktisch immer einen Nachteil.

5 Gewichtung gegenläufiger Bewertung bei unterschiedlichen Umweltfaktoren durch öffentlich-rechtlichen Entsorgungsträger wählbar

Die Beurteilung der verschiedenen Verwertungsmaßnahmen kann im Hinblick auf verschiedene Umweltfaktoren gegenläufig sein. Im Hinblick auf den Ressourcenschutz für Phosphor ist die Biotonne als vorteilhaft zu bewerten. Dem Faktor Ressourcenschutz mit Blick auf Phosphaterz wird von IFEU/UBA lediglich eine mittlere ökologische Bedeutung (im Vergleich etwa zu einer sehr hohen Bedeutung des Treibhauseffekts) beigemessen. Der Phosphor-Gewinn wird erkauft mit einer Klima-Belastung, die besonders hoch ausfällt, wenn der öffentlich-rechtliche Entsorgungsträger eine Kompostierung einsetzt.

5.1 Keine allgemein anerkannte Verrechnungsmethode für Umweltauswirkungen

Für eine Abschlussbewertung dieser einander entgegen stehenden Vor- und Nachteile der verglichenen Konzepte nach § 6 Abs. 2 KrWG existiert keine allseits anerkannte Verrechnungsmethode für alle Umweltwirkungen untereinander. Denkbar sind etwa der

Ansatz der Schadens- und Nutzenkosten der Beschaffungsalternativen oder eine verbalargumentative Abwägung.

5.2 Beurteilungsspielraum des öffentlich-rechtlichen Entsorgungsträgers bei der Gewichtung

Solange das Gesetz keine Verrechnungsmethode vorgibt, ist der öffentlich-rechtliche Entsorgungsträger grundsätzlich frei, wie er die Vor- und Nachteile in verschiedenen Wirkungsbereichen bei der ökologischen Bewertung zueinander gewichtet, solange sich diese in vertretbarer Weise begründen lässt. Zu beachten sind die Vorgaben nach §§ 8 Abs. 1 Satz 1, 6 Abs. 2 KrWG zu den insbesondere zu berücksichtigenden Kriterien: Es sind erstens die zu erwartenden Emissionen, zweitens das Maß der Schonung der natürlichen Ressourcen, drittens die einzusetzende oder zu gewinnende Energie und viertens die Anreicherung von Schadstoffen in Erzeugnissen, in Abfällen zur Verwertung oder in daraus gewonnenen Erzeugnissen zu berücksichtigen. Teilweise existieren auch landesrechtliche Vorgaben, die zu beachten sind, soweit sie bundesrechtlichen Vorgaben nicht widersprechen. § 1 Abs. 2 Satz 2 des Brandenburgischen Abfall- und Bodenschutzgesetzes fordert etwa, den Schutz der Atmosphäre und die Vorsorge für die Folgen der globalen Klimaerwärmung besonders zu berücksichtigen.

6 Wirtschaftliche Zumutbarkeit

Die Pflicht zur Wahl der den Schutz von Mensch und Umwelt am besten gewährleistenden Form der Verwertung kann nach § 8 Abs. 1 Satz 4 in Verbindung mit § 7 Abs. 4 KrWG entfallen. Hiernach ist die Pflicht (nur) zu erfüllen, soweit dies technisch möglich und wirtschaftlich zumutbar ist, insbesondere für einen gewonnenen Stoff oder gewonnene Energie ein Markt vorhanden ist oder neu geschaffen werden kann. Während die technische Möglichkeit hier i. d. R. kein Problem darstellen dürfte, liegt ein Scheitern der Pflicht an der wirtschaftlichen Zumutbarkeit in vielen Fällen schon näher.

Die wirtschaftliche Zumutbarkeit ist nach der Legaldefinition in § 7 Abs. 4 S. 3 KrWG gegeben, wenn die mit der Verwertung verbundenen Kosten nicht außer Verhältnis zu den Kosten stehen, die für eine Abfallbeseitigung, übertragen auf § 8 KrWG: für eine nachrangige Form der Verwertung zu tragen wären.

Teilweise wird die Auffassung vertreten, es könne für die Zumutbarkeit eine Rolle spielen, dass die Gebührenfinanzierung Kosten für den einzelnen Abfallerzeuger/-besitzer minimiert und damit Maßnahmen finanziert werden könnten, die bei einer Einzelverwertung durch Abfallerzeuger wegen der hohen Kosten nicht zumutbar wären (SCHINK, § 6, Rn. 60; ebenso VON BECHTOLSHEIM/CHARLIER/WAGNER, S. 117). Häufig wird auf den Anstieg der Gesamtbelastung der Bürger durch die Abfallgebühren oder die jährlichen

Mehrkosten pro Bürger abgestellt. Neuerdings wird sogar die These vertreten, Unzumutbarkeit sei nur im Falle eines unverhältnismäßigen Gebührenniveaus im Ganzen gegeben (BMUB 2015). Für alle diese Ansätze bietet das allein auf einen abstrakten Vergleich zweier Kostenblöcke abstellende Gesetz jedoch keine Grundlage. Die Auffassung lässt sich auch nicht in Einklang mit der gesetzgeberischen Intention bringen, gerade auch dem in § 11 KrWG angesprochenen öffentlich-rechtlichen Entsorgungsträgern über die Bezugnahme auf § 7 Abs. 4 KrWG eine Berufung auf wirtschaftliche Unzumutbarkeit zu ermöglichen.

Im Ergebnis hat also ein Kostenvergleich für die Verwertung bei Getrenntsammlung einerseits und Verzicht auf Getrenntsammlung andererseits stattzufinden; die so ermittelten Kosten sind zueinander ins Verhältnis zu setzen.

Selbst wenn sich die Getrenntsammlung als umweltvorteilhaft darstellt, kann eine Pflicht hierzu an der wirtschaftlichen Zumutbarkeit scheitern. Richtiger Bewertungsmaßstab hierfür ist nicht die Betrachtung der prozentualen oder absoluten Gebührensteigerung für den einzelnen Bürger oder die Verhältnismäßigkeit des gesamten Gebührenniveaus, sondern ein Vergleich der absoluten Kosten des Umgangs mit dem Bioabfall bei Getrenntsammlung einerseits und ohne Getrenntsammlung andererseits.

7 Zusammenfassung

Die ökologische Bewertung der Verwertungsform ist der entscheidende Beurteilungsmaßstab für die Frage, ob eine Getrenntsammlung von Bioabfällen zur Erfüllung der Verwertungsanforderungen erforderlich ist. Hierbei darf der Status quo nach Wahl mit den Verfahren „Kompostierung“ oder „Vergärung“ verglichen werden – die Wahl kann etwa anhand der lokalen Möglichkeiten getroffen werden. Es ist zulässig, nur die dem Hausmüll entzogene Organik als alleinige „Zielmasse“ einer Biotonne und alleinige bislang noch nicht getrennt gesammelte Organik zu betrachten. Ggf. gegenläufige Ergebnisse in den unterschiedlichen Wirkungskategorien dürfen zum Zwecke der Zusammenführung zu einem Gesamtergebnis frei gewichtet werden, soweit dies nachvollziehbar geschieht (unter Beachtung der in § 6 Abs. 2 Satz 3 KrWG genannten Faktoren und etwaiger landesrechtlicher Vorgaben).

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Flächendeckender Ausbau der Biotonne in Deutschland Stand und Perspektiven für die Kaskadennutzung

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Expansion to a comprehensive bin collection system for biowaste in Germany Current situation and perspective for the combined recycling

Abstract

Since January 1st 2015, the Waste Management Act (§ 11 paragraph 2 KrWG) obligates waste producers and mandated waste management authorities to collect biowaste separately. Although many waste management authorities (örE) have established such a waste management offer, not all of them did. But there is a trend to a comprehensive offer and the expansion of already existing bin collection systems for biowaste. Already increasing amounts of biowaste illustrate this. Within the UFOPLAN-research project "Compulsory implementation of separate collection of biowaste" released in 2014, u.e.c. Berlin and GAVIA examined the implementation of obligation to collect biowaste separately, existing concerns against the expansion of separate collection and recommendations for an optimal system design. The present article deals with the knowledge of this research project, the current development and the offered chances for the waste management industry.

Inhaltsangabe

Seit dem 1. Januar 2015 verpflichtet das Kreislaufwirtschaftsgesetz gemäß § 11 Abs. 1 KrWG Abfallerzeuger und öffentlich-rechtliche Entsorgungsträger (örE) dazu, überlassungspflichtige Bioabfälle getrennt zu sammeln. Ein entsprechendes Entsorgungsangebot haben bislang zwar die meisten, längst aber nicht alle örE geschaffen. Jedoch zeigt sich ein anhaltender Trend hin zum flächendeckenden Angebot und dem Ausbau der Getrenntsammlung von Bioabfällen. Bereits zunehmende Bioabfallmengen verdeutlichen dies. Im Rahmen des 2014 veröffentlichten UFOPLAN-Projektes „Verpflichtende Umsetzung der Getrenntsammlung von Bioabfällen" wurden durch u.e.c. Berlin und GAVIA die Umsetzung der Getrenntsammlungspflicht, Vorbehalte gegen eine Ausweitung der Biotonnensammlung und Handlungsempfehlungen für eine zielführende Gestaltung der Getrenntsammlung untersucht. Der vorliegende Artikel beschäftigt sich mit den Erkenntnissen dieses Forschungsprojektes, den aktuell zu beobachtenden Entwicklungen und den sich für die Entsorgungswirtschaft bietenden Chancen.

Keywords

Bioabfall, Biogut, Biotonne, Kompostierung, Vergärung, Kaskadennutzung

Biowaste, biowaste bin, composting, anaerobic digestion, combined recycling

1 Einführung

Seit dem 1. Januar 2015 sind gemäß § 11 Abs. 1 KrWG überlassungspflichtige Bioabfälle aus Haushalten getrennt zu sammeln. Während in vielen Teilen Deutschlands Angebote zur Getrenntsammlung von Küchen- und Gartenabfällen bereits seit Jahren durch den öffentlich-rechtlichen Entsorgungsträger bestehen, erfolgt in einigen Gebietskörperschaften die Umsetzung der Gesetzesvorgabe durch Einführung einer Biotonnensammlung erst jetzt - in weiteren Regionen steht dies nach wie vor aus.

Dabei ist die getrennte Erfassung von Bioabfällen als notwendige Voraussetzung für eine Erschließung des im Bioabfall enthaltenen stofflichen und energetisch nutzbaren Potentials anzusehen. Welchen Beitrag zur Energiewende die ohnehin anfallenden organischen Abfälle leisten sollten, ist eine der aktuellen gesellschaftlichen Fragestellungen in der Abfallwirtschaft und bislang noch nicht abschließend geklärt.

Ob die im KrWG formulierten Anforderung zur Getrenntsammlung und Behandlung von Bioabfällen präzisiert werden müssen und wenn ja, wie, war Gegenstand des im Jahr 2014 abgeschlossenen UFOPLAN-Projektes, das von den Unternehmen u.e.c. Berlin und GAVIA bearbeitet wurde. Der vorliegende Artikel befasst sich weiterführend mit den aktuellen Entwicklungen und den sich aufgrund zunehmender Bioabfallmengen bietenden Chancen für die Akteure der Entsorgungswirtschaft.

2 Theoretisches und praktisches Bioabfallpotential

Jährlich fallen rund 21,1 Mio. Mg Bioabfälle in Küchen und Gärten deutscher Privathaushalte an. Allein 6,6 Mio. Mg/a davon sind Abfälle, die in Küchen bzw. Haushalten anfallen. Diese Ergebnisse beruhen auf einem Massenstrommodell, das statistisch erfasste Werte (z.B. Bevölkerungszahlen, Grundstücksflächen, Wohnstruktur auf Landkreisebene) mit Literaturwerten zur Abschätzung des Küchen- und Gartenabfallpotentials kombiniert. (KRAUSE ET.AL. 2014)

Die Stoffstrommodellierung der verschiedenen Entsorgungswege zeigt, dass im Jahr 2012 mit 7,5 Mio. Mg rund 36 % des privaten Bioabfallaufkommens über die Biotonnensammlung (nachfolgend als Biogut bezeichnet) und die getrennte Gartenabfallsammlung (nachfolgend als Grüngut bezeichnet) der öffentlich-rechtlichen Entsorgungsträger (örE) erfasst wurden. Gleichzeitig wurden aber noch immer rund 4,5 Mio. Mg/a Bioabfall über den Restabfall entsorgt. Die Stoffströme in Abbildung 1 stellen ausschließlich die Bioabfallmengen aus Privathaushalten dar - in den statistisch erfassten Mengen der örE ebenfalls enthaltene Abfälle aus der kommunalen Landschaftspflege sowie Fremdstoffe bleiben unberücksichtigt.

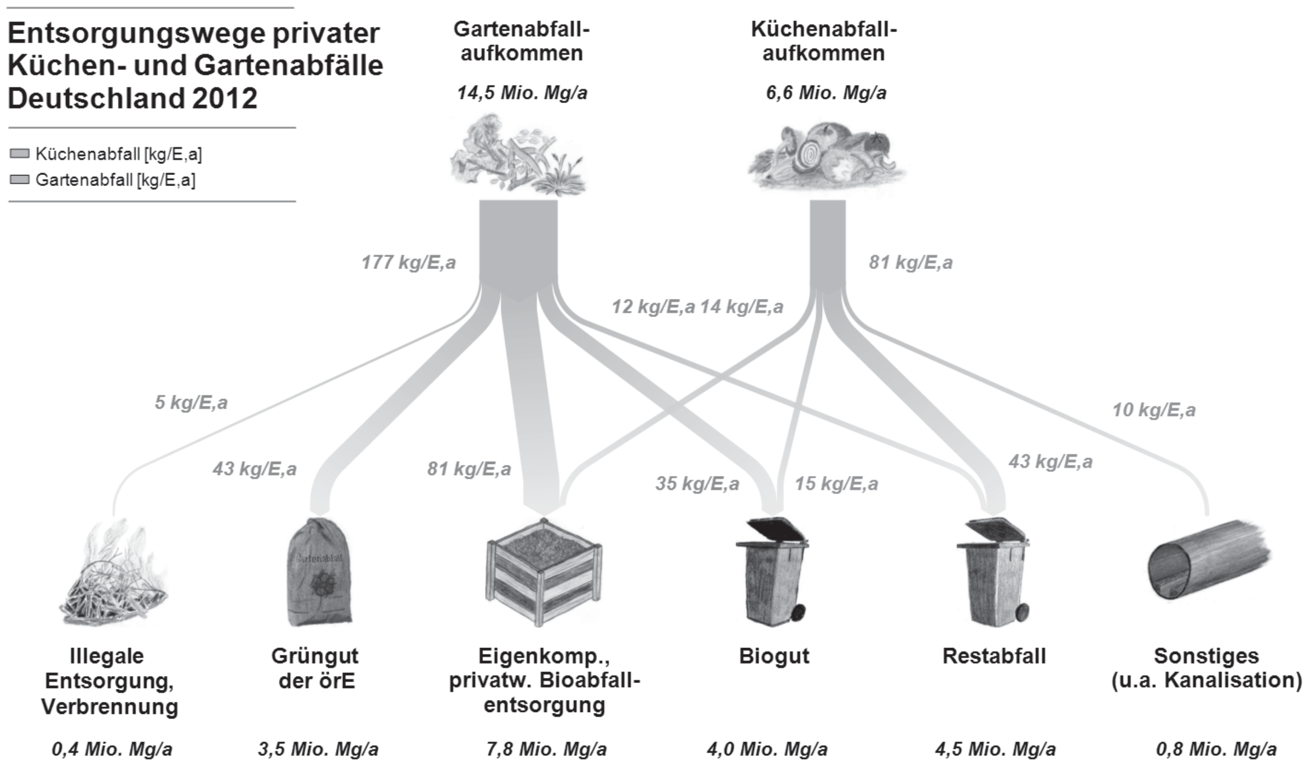

Abbildung 1 Entsorgungswege privater Küchen- und Gartenabfälle, Deutschland 2012

Im Vergleich zum Modellierungsergebnis des Basisjahrs 2010 im Forschungsprojektes, welches 3,9 Mio. Mg Biogut und 3,4 Mio. Mg Grüngut aus Privathaushalten ergab, ist ein geringer Anstieg der getrennt erfassten Bioabfallmengen festzustellen. Dieser kann bereits als Vorbereitung auf die seit 2012 mit der Novelle des KrWG beschlossene Getrenntsammelpflicht bis 1. Januar 2015 und die hiermit verbundene öffentliche Diskussion gedeutet werden.

Bei der Bestimmung des praktisch nutzbaren Bioabfallpotentials ist zu berücksichtigen, dass selbst bei einem flächendeckenden Biotonnenangebot der getrennten Erfassung, beispielsweise durch die teilweise fehlende Mitwirkungsbereitschaft der Haushalte, Grenzen gesetzt sind. Aus dem Vergleich diverser Sortieranalysen von Entsorgungsgebieten mit bzw. ohne Biotonne geht hervor, dass selbst bei intensiver Nutzung der Biotonne rund 15 - 20 kg/E,a an Organik im Restabfall verbleiben (Abbildung 2). Liegen die Werte höher, sind zusätzliche Optimierungen der bestehenden Erfassungssysteme sinnvoll und möglich.

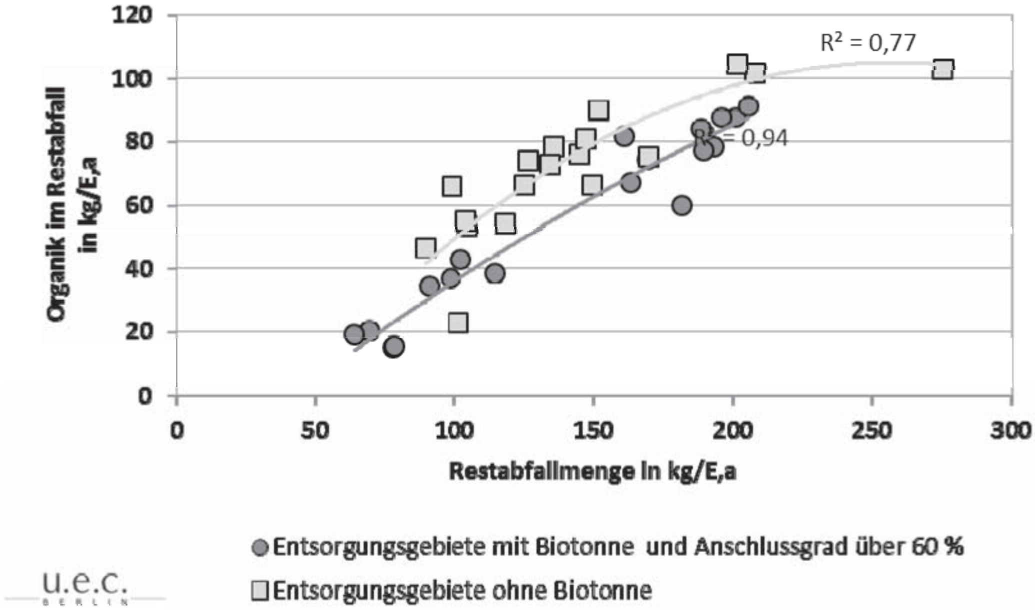

Abbildung 2 Im Restabfall enthaltene Organikmenge in Gebieten mit bzw. ohne Biotonne (Krause et.al. 2014)

Zur Untersuchung der im Erfassungssystems Biogut wirkenden Einflussfaktoren wurde eine statistische Analyse auf Basis von 105 Landkreisen Deutschlands durchgeführt. Das Ergebnis der hierin enthaltenen multivariaten Regression zeigt, dass die getrennt erfasste Biogutmenge insbesondere von den Stellschrauben Anschlussgrad an die Biotonne, Befreiungsmöglichkeit durch Eigenverwertung, Siedlungsstruktur, erfasster Grüngutmenge und eingesetzter Behältergröße abhängig ist.

Unter Variation der signifikanten Einflussfaktoren kann anhand des folgenden linearen Zusammenhangs die zu erfassende Biogutmenge in einem Entsorgungsgebiet näherungsweise ermittelt werden:

$$BioG = 1 \, x \, AnG - 0{,}03 \, x \, BevD - 0{,}12 \, x \, GrG + 30{,}31 \, x \, BeM + 0{,}34 \, x \, BehG - 38{,}11$$

Dabei sind:	BioG:	Erfasste Biogutmenge in kg/E,a
	AnG:	Anschlussgrad in %
	BevD:	Bevölkerungsdichte in E/km²
	GrG:	Parallel erfasste private Grüngutmenge in kg/E,a
	BeM:	Befreiungsmöglichkeit von der Biotonne, ja = 1, nein = 0
	BehG:	Durchschnittlich genutzte Behältergröße Biotonne in Liter
	38,11:	Absolutglied der Regression

Die Ergebnisse zeigen, dass eine starke Grünguterfassung sowie eine verdichtete Siedlungsstruktur zu einer Minderung der erfassten Biogutmenge führen, während sich die Ausweitung des Anschlussgrades sowie größere Behältervolumina mengensteigernd auswirken. Die Einflussstärke der jeweiligen Faktoren wird dabei durch die Höhe des entsprechenden Koeffizienten bestimmt.

Bei der Anwendung der linearen Gleichung sollte allerdings kein Term isoliert betrachtet / festgelegt werden. Sieht ein Entsorgungsträger bei Einführung der Biotonnensammlung eine Befreiungsmöglichkeit vor, erhöht sich gemäß obiger Prognose zwar zunächst die Biogutmenge. Gleichzeitig wird sich in Folge der Befreiungsmöglichkeit aber ein deutlich geringerer Anschlussgrad einstellen, wodurch in Summe die erwartete Biogutmenge niedriger ausfällt. Für weitere Details der statistischen Analyse wird auf den Abschlussbericht verwiesen.

Um das mittels Biotonne bundesweit maximal erfassbare Potential abzuschätzen, bedient sich die Studie einer Minimum-Maximum-Betrachtung und variiert den Anschlussgrad (zwischen 70 und 100 %). Da das seit 2012 geltende Kreislaufwirtschaftsgesetz alle Entsorgungsträger verpflichtet, überlassungspflichtige Bioabfälle aus Haushalten spätestens ab dem 1. Januar 2015 getrennt zu sammeln (§ 11 Abs. 1 KrWG), könnten durch die flächendeckende Getrenntsammlung mittels Biotonne statt der bisher rund 4 Mio. Mg zukünftig mindestens 6,4 Mg/a an Biogut (Maximum 9,4 Mio. Mg/a) erfasst und hochwertig verwertet werden. Wird zusätzlich die Bioabfallerfassung im Bestand verbessert, kann das Mengenaufkommen noch weiter gesteigert werden.

3 Entwicklungen der Getrenntsammlung

Während der mittels Biotonne getrennt erfasste Abfall in Deutschland im Verlauf des ersten Jahrzehnts bei rund 4,2 Mio. Mg/a stagnierte, ist inzwischen ein leichter Trend der Mengenzunahme zu verzeichnen. So wurden im Jahr 2012 über die Biogutsammlung erstmals 4,4 Mio. Mg erfasst. Gleichzeitig betrug die aus Privathaushalten und der Landschaftspflege kommunaler Flächen getrennt gesammelte Grüngutmenge ähnlich wie in den Jahren zuvor 4,7 Mio. Mg. Eine Verlagerung von Gartenabfällen in das im Ausbau befindliche Sammelsystem der Biotonne lässt sich auf Bundesebene bisher zumindest nicht beobachten.

Während in nahezu allen entsorgungspflichtigen Körperschaften Entsorgungsangebote für Grüngut zur Verfügung stehen, bestand im Jahr 2010 für die Getrenntsammlung von Küchenabfällen über eine Biotonne des örE in 77 Landkreisen noch kein Angebot. In weiteren 39 Landkreisen verfügten die Bürger zumindest in Teilen des Entsorgungsgebietes über eine Anschlussmöglichkeit an die Biotonne. Entsprechend der im Forschungsprojekt durchgeführten Fragebogenerhebung lag der Anschlussgrad an die Biotonne im Zeitraum 2011 / 2012 bei rund 52 %. Demnach nutzen knapp 40 Mio. Einwohner Deutschlands derzeit noch keine Biotonne.

Am 1. Januar 2015 bestand für die Bürger in 67 Landkreisen noch keine Möglichkeit der Getrenntentsorgung von Küchenabfällen. In 6 dieser Landkreise ist die Schaffung eines Biotonnenangebotes für das Jahr 2016 und in 2 weiteren für das Jahr 2018 jedoch bereits geplant. Den aktuellen Kenntnisstand zum Biotonnenangebot in Deutschland zeigt Abbildung 3.

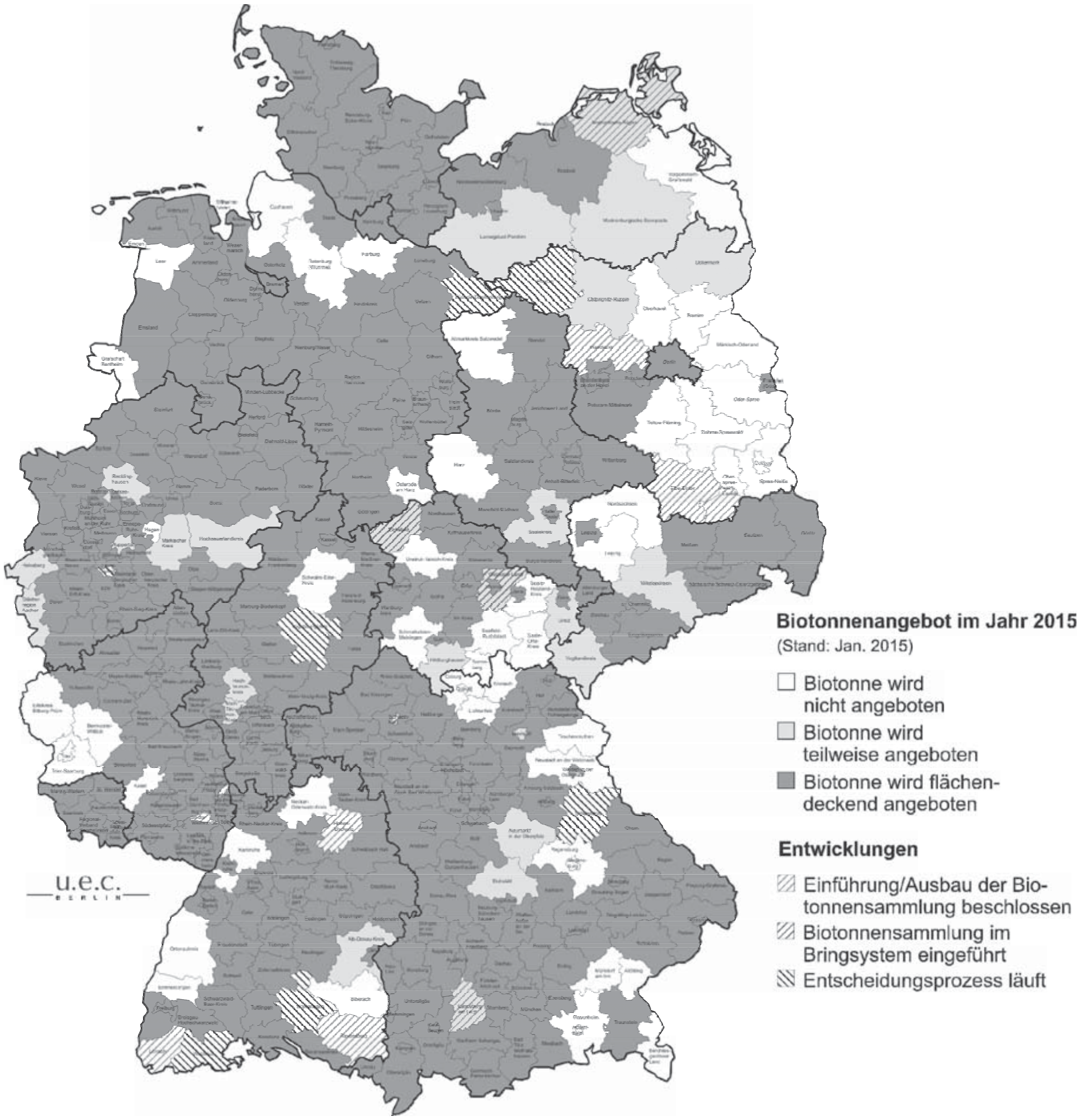

Abbildung 3 Biotonnenangebot der örE im Jahr 2015 und entsprechende Entwicklungen

Es ist zu erwarten, dass der Entwicklungstrend weiter anhält und bis zum Jahr 2020 auch die letzten Kommunen ein Sammelsystem einführen. Dass sich die Umsetzung zeitlich verzögert, ist nach den Erfahrungen mit der Umsetzung des Ablagerungsverbotes 2005 beachtenswert.

4 Zielsetzung einer hochwertigen Bioabfallverwertung

Unter Berücksichtigung des § 8 Abs. 1 S. 3 KrWG haben die öffentlich-rechtlichen Entsorgungsträger bei der Verwertung von Bioabfällen eine hochwertige Verwertung anzustreben. Die Beurteilung der verfügbaren Verwertungsverfahren hat dabei im Einzelfall und in Anwendung einer umfassenden Lebenszyklusanalyse unter Berücksichtigung aller unter § 6 Abs. 2 KrWG genannten Maßgaben zu erfolgen. Wie das BMUB in einer Stellungnahme zu den rechtlichen Vorgaben erst kürzlich erneut klarstellte, steht die Notwendigkeit zur Nutzung eines stofflichen Verwertungsverfahrens dabei außer Frage. Denn genau diese für Abfallarten wie Papier, Kunststoff, Glas und Metall völlig unstrittige Vorfestlegung ist auch auf Bioabfall anzuwenden. (BMUB, 2015)

Bereits durchgeführte ökobilanzielle Betrachtungen zeigten, dass die Verwertung von Biogut in Kombination von Vergärung und Kompostierung (Kaskadennutzung) gegenüber der ausschließlichen Kompostierung vorteilhaft ist. Diese Aussage gilt allerdings nur unter der Voraussetzung eines modernen Anlagenbaus und gewissenhafter Anlagenführung. Dies vorausgeschickt sieht auch die Bundesregierung die zukünftige Ausrichtung der Biogutverwertung mit Schwerpunkt auf der Kaskadennutzung: „Bei dafür geeigneten Bioabfällen ist die Vergärung von Bioabfällen der Kompostierung prinzipiell vorzuziehen, da dabei sowohl eine Nutzung des Energiegehaltes als auch die Nutzung der stofflichen Eigenschaften des Bioabfalls möglich ist (Kaskadennutzung).“ (BUNDESREGIERUNG, 2014). Welche Perspektive der Ausbau der Kaskadennutzung in Hinblick auf die Energieerzeugung haben kann, zeigt Tabelle 1.

Tabelle 1 Stand und Perspektive der Kaskadennutzung (OETJEN-DEHNE, 2015)

	Stand 2012: 1,1 Mio. Mg Biogut in Deutschland	**Potential, wenn 85 % der potentiellen Gesamtmenge = 5,44 Mio. Mg Bioabfall künftig auch energetisch genutzt werden**
Spez. Biogasmenge	106 Nm³/Mg	106 Nm³/Mg
Methangehalt	59%	59%
Stromproduktion	300 GWh/a	1.484 GWh
Wärmeproduktion	360 GWh/a	1.780 GWh

Soll die Kaskadennutzung trotz im Einzelfall höherer Kosten ausgebaut werden, bedarf es einer gezielten Lenkung der Stoffströme. Der Gesetzgeber prüft daher die Aufnahme

„stoffstromspezifischer und -lenkender Anforderungen an die Hochwertigkeit der Verwertung … einschließlich möglicher Kaskadennutzung“ im Zuge der geplanten Neufassung der Bioabfallverordnung (BUNDESREGIERUNG, 2014).

Aber auch die bislang installierten Anlagen zur Kaskadennutzung und zur Kompostierung getrennt erfasster Bioabfälle setzen den heutigen Stand der Technik in Bezug auf Effizienz und Umweltauswirkungen noch nicht oder nicht konsequent genug um. Es ist deshalb Zeit, dass sich auch die Branche der Verwertungsanlagen für Bioabfall diesen Herausforderungen stellt.

5 Wachstumsmarkt Bioabfall - Chancen für die Verwertung

Der leichte Wachstumstrend im Markt der Erfassung und Verwertung von Biogut wird sich nach unserer Einschätzung weiter fortsetzen und bietet den unterschiedlichen Marktteilnehmern Chancen. So auch auf dem Gebiet der Kaskadennutzung.

5.1 Ergänzung bestehender Kompostierungsanlagen

Die regional bestehenden Kompostierungsanlagen können sich zwar für ein kurzfristiges Abfangen schnell ansteigender Biogutmengen als hilfreich erweisen, sobald mengenseitige Planungssicherheit besteht, sollte jedoch eine Nachrüstung der vorhandenen Kompostierungsanlage um eine Vergärungsstufe geprüft werden.

Entsprechende Untersuchungen wurden beispielsweise in Schleswig-Holstein mit Unterstützung der Anlagenbetreiber und des Ministeriums durchgeführt und zeigten die Machbarkeit der Nachrüstung auf (OETJEN-DEHNE, 2010). Die damals geschätzten Mehrkosten von 20 Euro/Mg bzw. 1,6 Euro je Einwohner und Jahr für die Kaskadennutzung sind teilweise unterschritten worden. Aktuell sind in Schleswig-Holstein drei Kompostierungsanlagen mit einer Vergärungsstufe nachgerüstet worden.

Auch in anderen Bundesländern liegen positive Erfahrungen mit der Ergänzung von Bestandsanlagen vor. Aktuell beabsichtigt der Rhein-Neckar-Kreis eine Umstellung auf eine Kaskadennutzung. Nach Systemänderung des Biotonnenangebots auf eine für den Bürger kostenfreie, freiwillige BioEnergietonne stieg die erfasste Menge von rund 6.000 Mg im Jahr 2011 binnen kürzester Zeit auf über 40.000 Mg im Jahr 2014. Im nun folgenden Schritt soll der bisherigen Kompostierungsanlage eine den neuen Biogutmengen entsprechende Vergärungsstufe vorgeschaltet werden.

5.2 Umnutzung von MBA-Anlagen

Eine zunehmende Zahl von Betreibern mechanisch-biologischer Restabfallbehandlungsanlagen stehen unter anderem infolge der zurückgehenden Restabfallmengen vor der Frage, wie die bestehende und bei weitem noch nicht abgeschriebene Anlagenkapazität ausgelastet werden kann. Die Umstellung der biologischen Verfahrensstufe (Intensivrotte oder Fermenter) von der Restabfallbehandlung auf eine Behandlung getrennt gesammelter Bioabfälle oder eine kombinierte Behandlung kann auch hier eine Lösung sein.

Als erste MBA wurde ein Teil der Anlagenkapazität der MBA Lübeck für die Verarbeitung von Bioabfall umgerüstet. Auch der Abfallentsorgungsverband Schwarze Elster plant aktuell, den Nass-Vergärungsteil der MBA Freienhufen künftig vollständig für die Biogutverwertung zu nutzen. Bei weiteren MBA-Anlagen mit Vergärungsstufe werden derzeit vergleichbare Prüfungen vorgenommen.

Ist die MBA als aerobe Anlage ausgeführt worden, kommt eine Weiternutzung der nicht ausgelasteten Anlagenkapazität der Rottetunnel für die Kompostierung in Frage. Denkbar ist ebenso, die Anlage um eine Vergärungsstufte zu erweitern und die Rottetunnel dann zur Nachkompostierung zu nutzen. Allerdings sind damit neue Investitionen verbunden, die gegenüber der Kompostierungslösung zu höheren Behandlungskosten führen.

Eine 2014 abgeschlossene Kostenvergleichsrechnung ergab für die Nutzung zur Kompostierung Kosten zwischen 25 und 40 Euro/Mg (netto), für die Variante Kaskadennutzung wurde nach Abzug von Erlösen für den erzeugten Strom Kosten im Bereich von 70 Euro/Mg (netto) ermittelt. Wenn dennoch eine Kaskadennutzung umgesetzt wird, dann nur, weil es den Verantwortlichen wichtig ist, einen Beitrag zur Minderung von Klimagasen zu leisten und die spezifische Kostensteigerung im Bereich von 2 Euro pro Kopf und Jahr dem Gebührenzahler vermittelbar ist.

5.3 Anlagenneubau

Bei Einführung einer Biotonne oder der Steigerung der Erfassungsmengen stellt sich den öffentlich-rechtlichen Entsorgungsträgern die Frage, ob die zur hochwertigen Verwertung benötigte Anlagenkapazität neu geschaffen werden muss oder der regionale Markt (noch) ausreichend große Kapazitäten bereitstellen kann.

Untersuchungen zur Kostenentwicklung der Kaskadennutzung in Abhängigkeit vom Durchsatz zeigen, dass große Anlagen einen deutlichen Kostenvorteil haben.

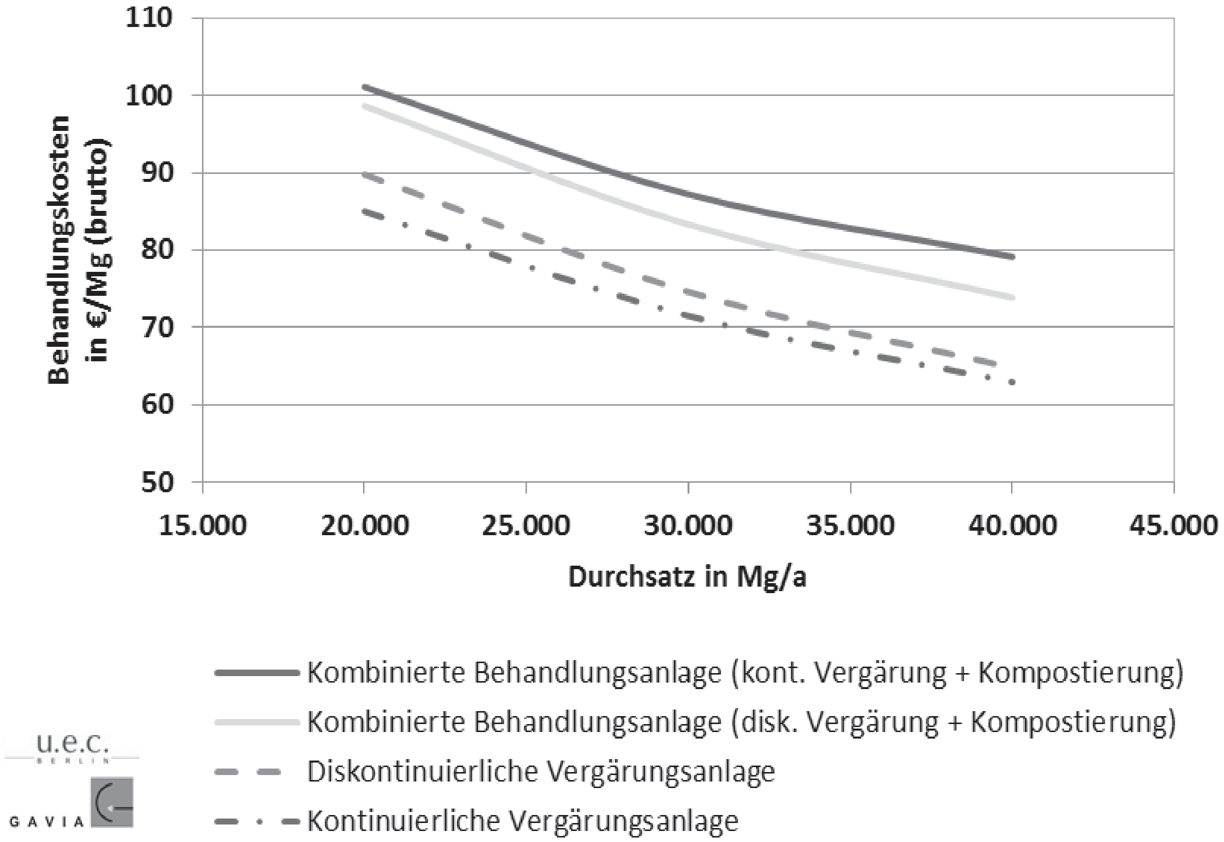

Abbildung 4 Spezifische Behandlungskosten für die Kaskadennutzung in Abhängigkeit vom Verfahren und vom Durchsatz (brutto), OETJEN-DEHNE, 2015

In vielen Fällen stehen, zum Beispiel aufgrund kleiner Einzugsgebiete, Inputmengen von mindestens 18.000 - 20.000 Mg/a aber nicht zur Verfügung. Werden trotzdem – wie bisher erst einmal realisiert - Kleinanlagen zur Biogutvergärung gebaut, werden zur Kompensation Abstriche bei der Anlagenausführung gemacht, die in Bezug auf Klimagasemissionen kritisch anzusehen sind.

Sind also die Biogutmengen eines einzelnen örE zu gering, bleibt entweder der Weg über eine Dienstleistungsausschreibung oder es werden Kooperationslösungen mit anderen Kommunen gesucht und realisiert.

Bei ausreichend großen Biogutmengen kommt ein Neubau in Frage. So beabsichtigt zum Beispiel der Landkreis Ludwigsburg seine bisher in anderen Kreisen lediglich kompostierten Biogutmengen ab 2018 ortsnah in einer neu zu errichtenden Vergärungsanlage zu behandeln und somit eine zusätzliche energetische Nutzung einzuführen.

In den vergangenen zwei Jahren wurden bereits mehrere Anlagenneubauten realisiert. So hat aktuell der ZAKB im Kreis Bergstraße eine gänzlich neue Anlage, bestehend aus einer Trockenvergärung durch Boxenfermentation mit nachgeschalteter Intensivrotte für 32.000 Mg/a errichtet, die sich seit Ende 2014 in der Inbetriebnahme befindet. Eine Geschlossene Ausführung des Lagerbehälters für flüssige Gärreste und ein zusätzliches

Schwachgassystem minimieren den Methanschlupf der Anlage und sorgen so für eine verbesserte Klimabilanz.

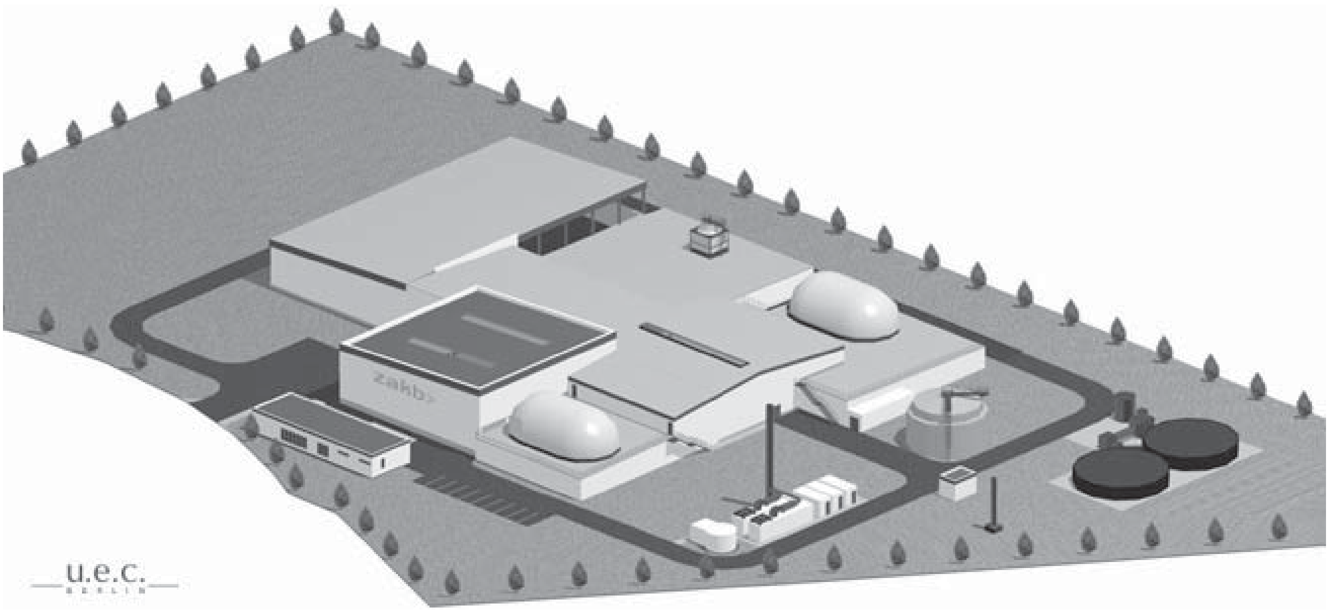

Abbildung 5 Kombinierte Vergärungs- / Kompostierungsanlage des ZAKB (Kreis Bergstraße)

Andere Planungen oder bereits genehmigte Anlagenneubauten sind bisher nicht zur Ausführung gekommen. Die abwartende Haltung der Projektträger hat verschiedene Gründe. Neben der Vertretbarkeit der Kosten und Fragen bezüglich der Verwertbarkeit des flüssigen Gärrestes sorgt auch die anstehende Novelle der Düngeverordnung für eine Verzögerung.

6 Ausblick

Der flächendeckende Ausbau der getrennten Erfassung von Biogut ist vor allem dann sinnvoll, wenn die Biomasse auch hochwertig verwertet wird. Solange keine anderen Verfahren die Betriebsreife nachgewiesen haben, ist deshalb die kombinierte energetische und stoffliche Nutzung der Biomasse weiter auszubauen.

Da der höhere Kosten-Aufwand dieser Anlagen nicht vollständig über Einspeiseerlöse für Strom und Wärme gedeckt werden kann, ist der zu erwartende Entsorgungspreis im Vergleich zu einer Kompostierung immer höher. Es liegt daher nahe, von der Gestaltungsmöglichkeit des § 8 Abs. 2 KrWG Gebrauch zu machen und die Rahmenbedingungen, unter denen eine hochwertige Verwertung von Biogut gegeben ist, bundeseinheitlich festzulegen. In diesem Fall hat der Preis eine Lenkungsfunktion, da dann einerseits nicht mehr Äpfel mit Birnen verglichen werden würden und andererseits Anlagen zur Kaskadennutzung mit einer effizienten Nutzung der erzeugten Energie einen relevanten Kostenvorteil generieren können.

Die Nachrüstung von i.d.R. alten Kompostierungsanlagen, die Nutzung freier Kapazitäten in MBA-Anlagen und deren ggf. erforderliche Ergänzung um Vergärungsstufen oder der Anlagenneubau setzt solche verlässliche Rahmenbedingungen voraus.

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Auswirkungen von Wertstofftonne und Recyclingquoten auf die Restabfallzusammensetzung

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Effect of recycling bin and recycling rates on the composition of residual waste

Abstract

In the course of the implementation of occurred and intended legal modifications (obligation to collect bio-waste and further recyclable fractions separately assigned from the Act on life-cycle management, intended resource law) modified amounts and compositions of residual wastes are also expected. Furthermore, in the context of the discussion about the improvement of recycling and a new resource law, different proposals for its design were made. INFA has developed a proposal to improve the recycling quantity, which includes cluster-specific requirements for collection quantities and requirements for recycling rates. In the case, that a recycling bin or a bio-waste bin is implemented or the proposed collecting amounts for different resources are met, impacts on the amount and composition of the remained residual waste are expected. These impacts and potential strategies will be illustrated especially for mechanical biological treatment plants for residual waste.

Inhaltsangabe

Im Zuge der Umsetzung der erfolgten und geplanten abfallrechtlichen Änderungen (Getrenntsammlungspflicht für Bioabfälle und andere Wertstoffe durch das KrWG, zuk. Wertstoffgesetz) sind auch veränderte Restabfallmengen und –zusammensetzungen zu erwarten. Dabei sind im Rahmen der Diskussionen um die Verbesserung der stofflichen Verwertung und ein neues Wertstoffgesetz auch verschiedene Vorschläge zu deren Ausgestaltung gemacht worden. INFA hat dazu einen Vorschlag für ein Modell mit clusterspezifischen Vorgaben zu Wertstofferfassungsmengen und Vorgaben für die Recyclingquoten verschiedener Wertstoffe erarbeitet. Werden zukünftig eine Wertstofftonne oder auch eine Biotonne eingeführt oder die vorgeschlagenen Erfassungsmengen eingehalten, so hat dieses Auswirkungen auf die Menge und Zusammensetzung des verbleibenden Restabfalls. Die Auswirkungen und mögliche Strategien werden ins besondere für mechanisch-biologische Restabfallbehandlungsanlagen dargestellt.

Keywords

Kreislauf- und Ressourcenwirtschaft, Erfassungsmengen, stoffliche Verwertung, Recyclingquoten, Restabfallmenge, Restabfallzusammensetzung

Recycling- and resource management, collection quantity, material recycling, recycling rates, residual waste amount, residual waste composition

1 Hintergrund und Aufgabenstellung

Mit dem neuen Kreislaufwirtschaftsgesetz (KrWG) wurde eine neue fünfstufige Abfallhierarchie (§ 6 KrWG) definiert, die die grundsätzliche Stufenfolge aus Abfallvermeidung, Wiederverwendung, Recycling und sonstiger, u. a. energetischer Verwertung von Abfällen und schließlich der Abfallbeseitigung festlegt. Darüber hinaus sollen nach § 14 KrWG bis 2020 insgesamt Recyclingquoten von mindestens 65 % für Siedlungsabfälle sowie von mindestens 70 % für Bau- und Abbruchabfälle erreicht werden.

Um das hohe Ressourcenpotenzial werthaltiger Abfälle effizienter zu erschließen, sind Bioabfälle sowie Papier-, Metall-, Kunststoff- und Glasabfälle unter den Voraussetzungen des § 11 Abs. 1 KrWG bzw. § 14 Abs. 1 KrWG spätestens ab dem 1. Januar 2015 getrennt zu sammeln.

Darüber hinaus wird auf Grundlage der Erfahrungen mit der Verpackungsverordnung und deren Schwächen derzeit ein neues Wertstoffgesetz diskutiert. Im Rahmen dieser Diskussionen wurden verschiedene Vorschläge zu deren Ausgestaltung gemacht.

2 Vorschlag für Vorgaben zu den Erfassungsmengen und Recyclingquoten

Im Auftrag einer Gemeinschaftsinitiative aus namhaften kommunalen und privaten Entsorgungsunternehmen, die für eine Neuordnung der Wertstoffwirtschaft eintritt, hat INFA einen Vorschlag für ambitionierte Vorgaben erarbeitet. Das Modell sollte im Gegensatz zu dem bisher diskutierten und auf der Verpackungsverordnung aufbauenden Wertstoffgesetz, das sich auf Metalle, Kunststoffe und Verbunde beschränkt, alle wesentlichen Wertstoffströme berücksichtigen. Dafür wurden das nachfolgend dargestellte Modell für getrennt zu erfassende Wertstoffmengen sowie Vorgaben zu Recyclingquoten, die als Quoten der stofflichen Verwertung zu verstehen sind, erarbeitet.

2.1 Vorschlag für Vorgaben zu Erfassungsmengen

In dem erarbeiteten Vorschlag sind derzeit somit Vorgaben für die Wertstoffe Altpapier, Glas, Bio- und Grünabfälle, Metalle, Kunststoffe, Getränkekartons und Altholz dargestellt. Das Modell ist aber auf weitere Wertstoffe erweiterbar. Die Vorgaben sind auf der Ebene der Kreise und kreisfreien Städte zu erfüllen. Zur Berücksichtigung der Siedlungsstruktur erfolgt bei den Vorgaben zu den zu erfassenden Wertstoffmengen eine Differenzierung nach der Einwohnerdichte in fünf Cluster.

Tabelle 1 Vorgaben für spezifische Erfassungsmengen

Vorgaben für die Erfassungsmengen [kg/(E*a)]						
Wertstoff	**Struktur-Cluster**	≤ 150 E/km²	> 150 - 500 E/km²	> 500 - 1.000 E/km²	> 1.000 - 2.000 E/km²	> 2.000 E/km²
Variante 1 (z. B. als Stufe 1 bei Einführung)						
Altpapier	**Erfassungsmenge (Min.)**	**75**	**85**	**80**	**75**	**65**
	Menge im Restabfall (Max.)	8	8	13	15	18
Glas	**Erfassungsmenge (Min.)**	**25**	**25**	**25**	**25**	**20**
	Menge im Restabfall (Max.)	5	5	6	7	9
Bioabfall (Biotonne)	**Erfassungsmenge (Min.)**	**50**	**70**	**80**	**70**	**35**
	Menge im Restabfall (Max.)	25	30	35	40	70
Bio- und Grünabfall[1]	**Erfassungsmenge (Min.)**	**135**	**160**	**150**	**130**	**75**
	Menge im Restabfall (Max.)	25	30	35	40	70
Metalle	**Erfassungsmenge (Min.)**	**10**	**10**	**10**	**10**	**10**
	Menge im Restabfall (Max.)	3	3	3	3	3
Kunststoffe	**Erfassungsmenge (Min.)**	**25**	**25**	**20**	**20**	**15**
	Menge im Restabfall (Max.)	7	7	9	9	13
Getränkekartons	**Erfassungsmenge (Min.)**	**3**	**3**	**3**	**3**	**2**
	Menge im Restabfall (Max.)	1	1	1	1	1
Altholz	**Erfassungsmenge (Min.)**	**20**	**20**	**20**	**25**	**25**
	Menge im Restabfall (Max.)	2	2	2	2	2
Variante 2 (z. B. als Stufe 2 mittelfristig)						
Altpapier	**Erfassungsmenge (Min.)**	**90**	**90**	**90**	**90**	**75**
	Menge im Restabfall (Max.)	8	8	13	15	18
Glas	**Erfassungsmenge (Min.)**	**30**	**30**	**25**	**25**	**20**
	Menge im Restabfall (Max.)	5	5	6	7	9
Bioabfall (Biotonne)	**Erfassungsmenge (Min.)**	**95**	**110**	**100**	**80**	**35**
	Menge im Restabfall (Max.)	25	30	35	40	70
Bio- und Grünabfall[1]	**Erfassungsmenge (Min.)**	**165**	**170**	**170**	**130**	**75**
	Menge im Restabfall (Max.)	25	30	35	40	70
Metalle	**Erfassungsmenge (Min.)**	**12**	**12**	**12**	**12**	**10**
	Menge im Restabfall (Max.)	3	3	3	3	3
Kunststoffe	**Erfassungsmenge (Min.)**	**25**	**25**	**20**	**20**	**15**
	Menge im Restabfall (Max.)	7	7	9	9	13
Getränkekartons	**Erfassungsmenge (Min.)**	**4**	**4**	**3**	**3**	**2**
	Menge im Restabfall (Max.)	1	1	1	1	1
Altholz	**Erfassungsmenge (Min.)**	**25**	**30**	**25**	**30**	**30**
	Menge im Restabfall (Max.)	2	2	2	2	2

[1] Bioabfallmenge (Biotonne) ist hier enthalten

Die Vorgabe einer einwohnerspezifischen Mindestmenge an Wertstoffen (in kg/(E*a)) ist auf die getrennte Erfassung der Wertstoffe ausgerichtet. Darüber hinaus werden Wertstoffe aus dem Sperrmüll, die bei der Sperrmüllsammlung separat abgefahren oder über eine Sperrmüllsortierung ausgeschleust werden, berücksichtigt. Die ggfs. aus dem Restabfall für eine stoffliche Verwertung aussortierten Wertstoffmengen fließen nicht ein. Zur Herleitung der Vorgaben wurden die derzeit getrennt erfassten Wertstoffmengen (Basis: bundesweite örE-Daten aus Abfallbilanzen 2011) sowie die Wertstoffpotenziale (Basis: Daten aus i. W. INFA-Abfallsortieranalysen) ausgewertet. Es wurden zwei Varianten erarbeitet, die auch in zeitlicher Staffelung in Form eines Stufenmodells angesetzt werden können (Vgl. Tabelle 1).

Variante 1 (z. B. als Stufe 1 bei Einführung) basiert auf der derzeit im Durchschnitt in jedem Cluster erfassten Wertstoffmenge sowie dem noch im Restabfall vorhandenen Wertstoffpotenzial. Es wurde je Cluster eine zusätzlich abzuschöpfende Menge definiert und dem heutigen Mittelwert aufgeschlagen. Die zusätzlich abschöpfbare Menge wurde auf der Basis einer definierten Maximalmenge im Restabfall (s. u.) sowie aus Anteilen aus dem Sperrmüll abgeleitet. Variante 2 (z. B. als Stufe 2 mittelfristig) basiert auf dem Vergleich der derzeitigen Erfassungsmengen innerhalb eines Clusters im Sinne eines Benchmarkings. Da ambitionierte Erfassungsmengen angestrebt werden, wurde als Sollwert das 75 %-Quartil angesetzt, d. h. bereits 25 % der örE erreichen diese Menge derzeit, 75 % noch nicht. In beiden Varianten wurden die Werte für die vorgeschlagenen Erfassungsmengen (in Schritten von 5 kg/(E*a)) gerundet.

Ergänzend zu den Erfassungsmengen wurde ein maximaler Wertstoffgehalt im Restabfall (in kg/(E*a)) definiert, der alternativ zum Nachweis der hinreichenden Abschöpfung bei Nicht-Erreichen der Erfassungsmenge herangezogen werden kann. Der Wert orientiert sich am Wertstoffgehalt im Restabfall der jeweils 25 % besten örE jedes Clusters.

Für die organischen Abfälle wurde eine Vorgabe für die Summe an Bio- und Grünabfällen in Kombination mit einer Mindestmenge für die Biotonne festgelegt; beide Vorgaben sind zu erfüllen. Bei den Mengenvorgaben für Kunststoffe, Metalle und Altholz wurden neben den Mengen aus den Wertstoffsystemen (Holsysteme, Depotcontainer und Wertstoffhöfe) auch die Mengen aus dem Sperrmüll berücksichtigt. Im Sinne einer möglichen Vereinfachung des Modells könnte auf Grund der bereits sehr hohen Abschöpfung aus dem Restabfall auf die Mengenvorgaben bei den Getränkekartons und ggf. auch beim Altholz (hier ggf. weitere Entfrachtung des Sperrmülls) verzichtet werden.

2.2 Vorschlag für Vorgaben von Recyclingquoten

Die in Tabelle 2 vorgeschlagenen Recyclingquoten sind Mindestquoten für den Anteil der stofflichen Verwertung. Dabei wird bei den Bioabfällen auch die Vergärung im Sinne einer Kaskadennutzung und bei den Kunststoffen ausschließlich die werkstoffliche Verwertung dem Recycling zugeordnet.

Tabelle 2 Vorgaben für die Recyclingquoten

Wertstoff	Vorgaben für die Recyclingquote	
	Quote [Masse-%]*	Herleitung
Altpapier	**90**	ca. 6 % Störstoffe, Berücksichtigung von Fehlchargen
Glas	**90**	ca. 6 % Fremd- und Störstoffe (Deckel etc.), Berücksichtigung von Fehlchargen
Bioabfall[1]	**80**	ca. 12 - 15 % vom Input als Brennstoff abgetrennt (teilweise auch höhere Anteile)
Grünabfall[1]	**70**	ca. 25 – 30 % als hochwertiger Brennstoff abtrennbar; anteilige energetische Nutzung politisch gewollt und heute vielfach praktiziert
Fe-Metalle[2]	**95**	Ausbringung ca. 95 %
NE-Metalle[2]	**70**	Ausbringung 70 - 80 %, NE-Metalle zusätzlich i. d. R. extern weiter aufbereitet
Kunststoffe	**50**	Annahme: nahezu vollständig Sortierung mit Kunststoffartentrennung sowie stoffliche Verwertung der Mischkunststoffe zu 20 - 25 %
Getränkekartons	**80**	Ausbringung ca. 80 %
Altholz	**20**	derzeit erfahrungsgemäß 20 - 30 % stoffliche Verwertung, hier fortgeschrieben

* bezogen auf die erfasste Wertstoffmenge
[1] spezifische Konzepte der Bio- und Grünabfallbehandlung sind zu berücksichtigen
[2] ggf. Zusammenfassung zu einer Quote

Die Vorgabe wird als Quote (%) bezogen auf die getrennt erfasste Wertstoffmenge ausgedrückt. Maßgeblich für den stofflich verwerteten Anteil ist der Eingang bei einer Letztempfängeranlage (Papierwerk, Kompostwerk, Metallhütte etc.), in der ein Produkt hergestellt wird, das keiner weiteren abfallspezifischen Behandlung mehr bedarf.

Die Recyclingquoten wurden so abgeleitet, dass sie durch alle Erfassungssysteme erreichbar sind, und dass Aufbereitungsprozesse in externen Anlagen (z. B. Altpapiersortierung) zukünftig nicht unterbunden werden. Bei allen Fraktionen, die in einer Zwischenaufbereitungs-/Sortieranlage zugeführt werden (können) wurde eine Ausschleusung von Störstoffen sowie die technisch bedingte Ausbringungsgrenze berücksichtigt.

Bei den Bio- und Grünabfällen ist eine anteilige, hochwertige energetische Nutzung als nachwachsende Rohstoffe sinnvoll und politisch gewollt. Hier sind ggf. Ausnahmeregelungen für spezifische Konzepte mit geringeren stofflichen Verwertungsanteilen bei Nachweis einer hochwertigen energetischen Verwertung zu entwickeln.

3 Auswirkungen der Erfassungsmengen und Recyclingquoten auf die Restabfälle

Auswirkungen einer erweiterten Wertstoff- sowie Bioabfallerfassung sind im Hinblick auf folgende Aspekte zu erwarten:

- Reduzierung der Restabfallmenge
- Veränderung der Restabfallzusammensetzung durch Reduzierung der im Restabfall verbleibenden Wertstoffanteile, vor allem an Metallen, Kunststoffen und Bioabfall
- Bei weitergehenden Anforderungen auch an die übrigen Wertstoffe (Altpapier, Glas etc.) könnten sich entsprechend auch diese Anteile im Restabfall verändern
- Veränderung des Heizwertes durch veränderte Restabfallzusammensetzungen.

Das Ausmaß der Veränderungen hängt dabei sowohl von den örtlichen Randbedingungen als auch den tatsächlichen Mengenveränderungen ab. Nachfolgend wird insbesondere auf die Auswirkungen für mechanisch-biologische Restabfallbehandlungsanlagen eingegangen, deren Konzepte auf der Ausschleusung von Metallen und Kunststoffen (letztere als Brennstofffraktion) sowie der anschließenden biologischen Behandlung beruhen.

Bei der Einführung einer Wertstofftonne verringert sich der Restabfall erfahrungsgemäß um 3 – 7 kg/(E*a). Dabei wird der Restabfall insbesondere von den Metallen und Kunststoffen entfrachtet, wodurch sich die Ausbeute in der mechanischen Stufe einer MBA entsprechend verringert. Geringere Metallmengen haben auf Grund des positiven Marktwertes Einfluss auf die Wirtschaftlichkeit der Anlagen, die vorherige Abtrennung der Kunststoffe wird sich auf die Heizwerte der i. d. R. hergestellten Ersatzbrennstoffe auswirken.

Nach Umsetzung der nach § 11 Abs. 1 KrWG ab dem 01.01.2015 geltende Pflicht zur getrennten Erfassung von Bioabfällen könnten nach Einschätzung des aktuell dazu erstellten Vorhabens des Umweltbundesamtes zusätzliche Bioabfallmengen von 2 bis 5 Mio. Mg/a in Deutschland getrennt erfasst werden, wobei ein Teil des dargestellten Potenzials aus Grünabfällen besteht, die dann von einer bestehenden Grünabfallsammlung oder von der Eigenkompostierung abgezogen werden. Insbesondere in Gebietskörperschaften, die noch keine Biotonne (oder nur in begrenztem Umfang) einsetzen, kann sich die zu behandelnde Restabfallmenge deutlich reduzieren, was im Falle einer eigenen dafür vorgehaltenen Anlage nicht zu entsprechenden Einsparungen führt, wenn kein Ausgleich durch andere Mengen erreicht werden kann. Eine Entfrachtung des Restabfalls von Bioabfällen führt darüber hinaus i. d. R. zu einer Reduktion des Wassergehaltes und einem Anstieg des Heizwertes des verbleibenden Restabfalls. Im Bereich der mechanischen Stufe kann dies zu einer Verbesserung der Sortierbarkeit des Restabfalls führen. Bei mechanisch-biologischen Restabfallbehandlungsanlagen mit einer Vergärungsstufe ist ein Rückgang der produzierten Biogasmengen und damit der prozierten Strom- und Wärmemenge zu erwarten, was Auswirkungen auf die Wirtschaftlichkeit dieser Behandlungsanlagen hat. Bei mechanisch-biologischen Stabilisierungsanlagen (MBS) kann je nach Umfang der Organikreduzierung der biologische Trocknungsprozess beeinflusst werden.

Im Rahmen der Präsentation werden beispielhafte Auswirkungen der hier dargestellten Zusammenhänge auf die Restabfallmenge und –zusammensetzung dargestellt, mit denen sich Betreiber von mechanisch-biologischen Restabfallbehandlungsanlagen vor dem Hintergrund der umgesetzten und zu erwartenden gesetzlichen Änderungen zukünftig ggf. auseinandersetzen müssen.

Die Initiative „Arbeitsgemeinschaft Graue Wertstofftonne“ (aus öffentlich-rechtlichen Entsorgungsträgern, privaten und öffentlichen Abfallverwertungsanlagen sowie abfallwirtschaftlichen Organisationen) setzt sich dafür ein, dass Gebietskörperschaften, die wegen einer funktionierenden Bioabfalltrennung trockene und sortierfähige Restabfälle besitzen und ihre Restabfälle ohnehin schon sortieren, auf eine Wertstofftonne verzichten können sollten.

Die MBA-Technologie, die ursprünglich als Behandlungsverfahren für Restabfall entwickelt wurde, hat zudem den Vorteil, ein modular aufgebautes, stoffstromspezifisches Behandlungsverfahren zu sein, welches das Potenzial und die Flexibilität zur Weiterentwicklung bei veränderten Randbedingungen oder neuen Anforderungen hat. Es sind Lösungen zu entwickeln, wie aufgrund einer sich evtl. verringernden Restabfallmenge frei werdende Kapazitäten zukünftig sinnvoll nutzbar wären. Hierzu werden bereits heute verschiedene Ansätze verfolgt.

So kann im Zuge interkommunaler Kooperationen bei Behandlungskonzepten das vorhandene Anlagenpotenzial zielgerichtet mit Blick auf die jeweiligen Stärken des Anlagenverbundes auf des bestmögliche Konzept und einen entsprechenden Stoffstromaustausch ausgerichtet werden.

Darüber hinaus kann aus der Pflicht zur getrennten Erfassung von Bioabfällen ein Ausbau der Behandlungskapazitäten für Bioabfälle erforderlich werden. Hier können MBA-Anlagen mit ihren biologischen Stufen, die technisch mit denen der Bioabfallbehandlung vergleichbar sind, durch eine (Teil-)Umnutzung Behandlungskapazitäten bereitstellen (und tun dies teilweise auch bereits).

Auch kann die Eignung und/oder Umrüstung der MBA-Anlage zur Aufbereitung weiterer Stoffströme geprüft werden. Denkbar sind hier eine zukünftige Aufbereitung der Materialien aus der Wertstofftonne oder auch die Aufbereitung von vermischt erfassten Gewerbeabfällen. Letzteres wird vor dem Hintergrund der derzeitigen Novellierung der Gewerbeabfallverordnung zukünftig ein deutlich stärkeres Gewicht bekommen. Für die beiden letztgenannten Stoffströme kann, in Abhängigkeit der Rahmenbedingungen vor Ort und der vorhandenen Anlagentechnologie, eine Erweiterung der Aggregate erforderlich sein, um die für eine stoffliche Verwertung erforderlichen Qualitäten der sortierten Fraktionen zu gewährleisten.

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Entwicklung der Abfallwirtschaft und des Stoffstrommanagements am Beispiel der Region Hannover

Roland Middendorf

Aha Zweckverband Abfallwirtschaft Region Hannover, Deutschland

Development of waste- and material flow management taking the Hanover region as an example

Abstract

The region of Hanover can look back on years of experience regarding the recovery of waste and recyclable materials. In this period of time numerous waste processing plants with a highly innovative character have been built which were widely recognized also beyond the region. The material flow management (MFM) of the municipal waste management companies thus requires the application of appropriate, future-oriented strategies. The companies are challenged on each level and in all their service areas, with the aim of a systematic further development of the service task entrusted to the municipal waste disposal companies. The Waste Disposal Association for the region of Hanover, abbreviated aha in German, has created the necessary prerequisites and continuously improves them.

Inhaltsangabe

Die Region Hannover kann bei der Verwertung von Abfällen und Wertstoffen auf eine langjährige Erfahrung zurückblicken. In dieser Zeit sind etliche Behandlungsanlagen gebaut worden deren Innovativer Charakter weit über die Grenzen der Region Anerkennung gefunden hat. Das Stoffstrommanagement kommunaler Entsorgungsbetriebe über einen Zeitraum von Jahrzehnten erfordert entsprechend angepasste Strategien. Die Herausforderungen begegnen den Unternehmen hierbei auf allen Ebenen und in allen Dienstleistungsbereichen. Vor dem Hintergrund dieser vielschichtigen Veränderungen gilt es für die kommunale Entsorgungswirtschaft die Aufgabe der Daseinsvorsorge konsequent weiter zu entwickeln. Der Zweckverband Abfallwirtschaft Region Hannover, kurz aha, hat die entsprechenden Voraussetzungen geschaffen und entwickelt sie kontinuierlich weiter.

Keywords

Region Hannover; Stoffstrommanagement, Wertstoff, ökologische Abfallwirtschaft, integriertes Abfallwirtschaftskonzept,

1 Einleitung

1.1 Die Entwicklung der Abfallwirtschaft in der Region Hannover

In der Region Hannover leben 1,1 Mio. Einwohner auf einer Fläche von ca. 2.300 km^2. Der Zweckverband Abfallwirtschaft Region Hannover (aha) ist der öffentlich – rechtlich organisierte Entsorgungsträger (örE). Er betreibt die Abfall- und Wertstoffabfuhr, 21

Wertstoffhöfe sowie diverse Abfallbehandlungsanlagen und drei Deponiestandorte. In der Region Hannover fielen 2014 rund 524.000 Mg Abfälle an. Hierin sind getrennt erfasste Wertstoffe wie Papier, Leichtverpackungen, Metall oder Elektronikschrott noch nicht enthalten. Die Abfälle werden nach Herkunft, Heizwert und Transportentfernung optimiert verschiedenen Behandlungsanlagen zugeführt. Mehrere Kontingente in externen Abfallverbrennungsanlagen und die aha eigene Mechanisch-Biologische Restabfallbehandlungsanlage (MBA) Hannover stehen für die Restabfallbehandlung zur Verfügung.

1.2 Schritte zu einer integrierten ökologisch ausgerichteten Abfallwirtschaft

Vor der Festlegung geeigneter Behandlungsverfahren steht die Systemauswahl zur Erfassung der unterschiedlichen Abfälle. Diese ist in jedem Fall regional auszurichten. Dabei hat sich die Kombination von Hol- und Bring Systemen bewährt. Ein wesentlicher Punkt bei der Einrichtung dieser Systeme sind die jeweiligen Erfassungskosten. Tabelle 1 zeigt die in der Region Hannover eingerichteten Sammelsysteme.

Tabelle 1: Wertstoffsammelsysteme in der Region Hannover

Fraktion	Logistik	Systembeschreibung
Bioabfall	H	alle Wertschöpfungsstufen bei aha
Grünabfall	B u. H	aha-Sammlung u. Verwertung u. 55 landwirtschaftliche Annahmestellen, Abholung auf Bestellung
Altpapier	B u.H	aha-Sammlung, Vergabe v. Sortierung u. Verwertung
Altholz	B u. H	aha-Sammlung und Sortierung, Vergabe der Verwertung
Metalle	B u. H	aha-Sammlung und Sortierung, Vergabe der Verwertung
E-Schrott	B u. H	Abholung auf Bestellung, O-Tonne, EAR oder Vergabe
LVP	B u. H	Sammel-Auftrag der dS an aha für LHH und Umland
SNVP	B u. H	O-Tonne, Vergabe der Verwertung
Altkleider	B u. H	O-Tonne, Wertstoffinsel, Vergabe der Verwertung
Alle o.g. Fraktionen	B	21 aha eigene Wertstoffhöfe, entgeltfreie Abgabe aller Fraktionen,Verwertung analog Einzelfraktion

H = Holsystem B = Bringsystem

Die Entwicklung von der Beseitigung zu einem stoffspezifischen Abfallmanagement ist in Bild 2 dargestellt.

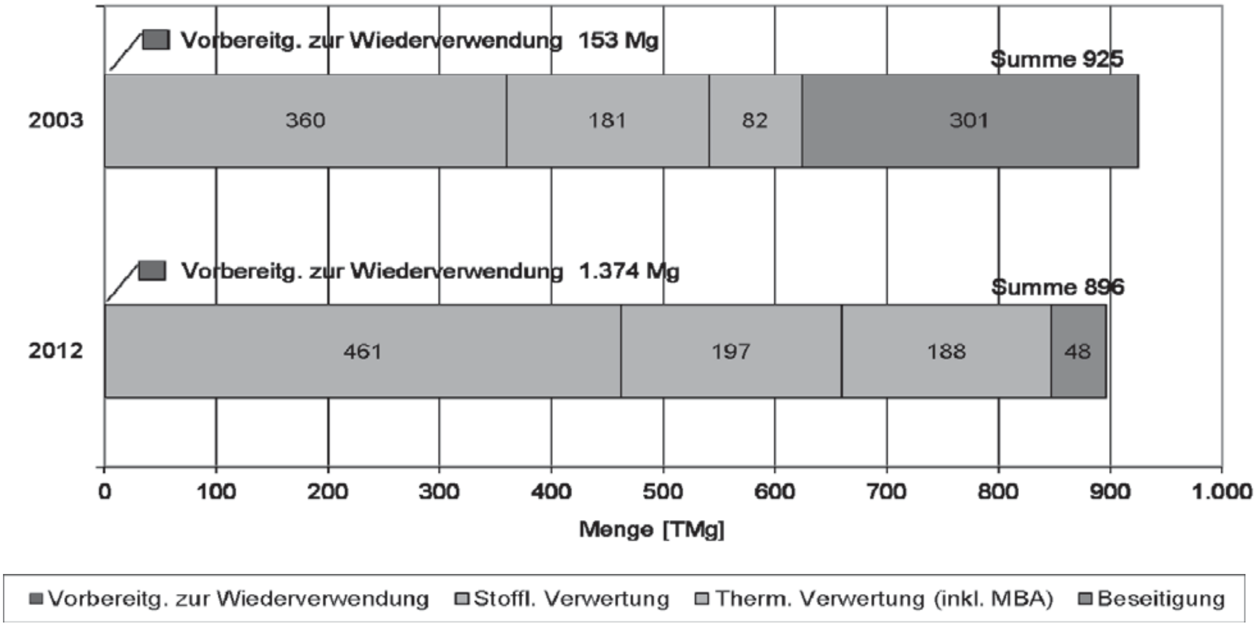

Bild 2: Entwicklung Abfallmengen bezogen auf die Verwertung und Beseitigung

Aus Bild 2 wird deutlich, dass die Verwertungsquoten deutlich gesteigert werden konnten und hierbei insbesondere die energetische Verwertung an Bedeutung zugenommen hat. In dieser Entwicklung ist der Marktpreis ein wesentliches Steuerungselement. In gleichem Maße sind zunehmend ökologische Ziele in den Vordergrund gerückt. Dabei wird die Einsparung von – Klimagasen als Parameter für die Ökobilanzierung abgebildet.

2 Stoffstrommanagement

2.1 Integriertes Stoffstrommanagement

In Abbildung 2 sind die für die eigenen Behandlungsanlagen wesentlichen Stoffströme der Region Hannover dargestellt.

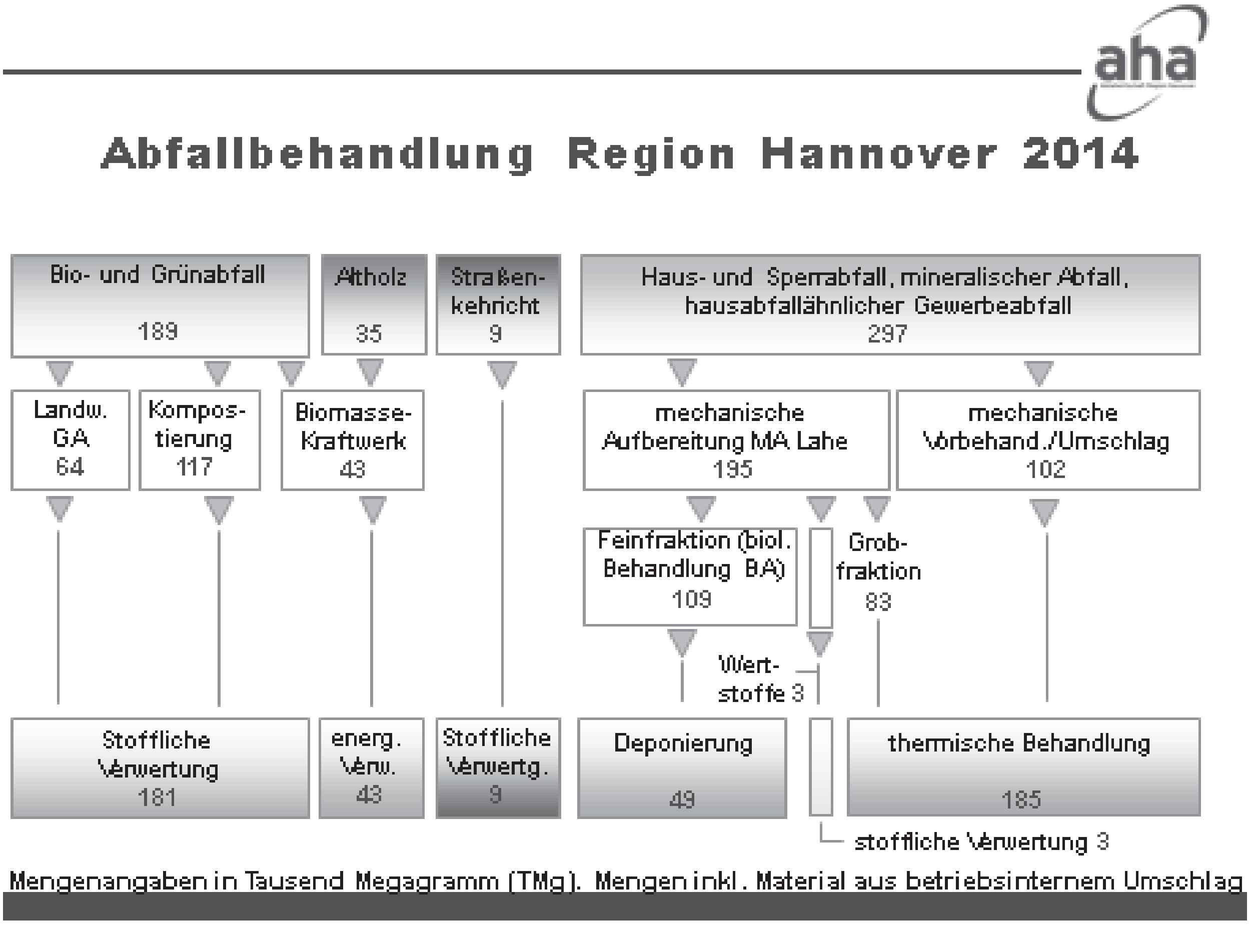

Bild 2: Stoffströme in der Region Hannover

Die jeweiligen Verfahrensschritte der hierbei zugrundeliegenden Behandlung beginnen mit einfacher Shredder- und Siebtechnik bis hin zur komplexen Behandlungsverfahren wie beispielsweise der Trockenvergärung.

Die Verwertungsquoten bezogen auf die Gesamtmenge aus Bild 2 sind nachfolgend in Abhängigkeit von der Komplexität der Verfahrenstechnik in Tabelle 3 dargestellt. Daneben sind Anhaltswerte für die spezifischen Behandlungskosten angegeben. Dabei zeigt sich, dass mit vermeintlich einfacher Technik bereits deutliche Verwertungsquoten erreicht werden können. Allein durch einfache Shredder und Siebtechnik mit einfacher Fe-Abscheidung können rund 57 % der Abfälle in der Region Hannover verwertet werden. Nicht dargestellt hierbei sind die Folgekosten für die thermische Verwertung, die in Abhängigkeit von der Aufbereitungstiefe und den örtlichen Marktverhältnissen deutlich variieren.

Tabelle 3: Verfahrenstechnik und nach Bild 2

Aufbereitung	Menge 1000 Mg/a	Anteil %	Kosten €/Mg
Einfache mechanische Aufbereitung von homogenen Abfällen (Shreddern und Sieben)	73	14	15 - 20
Weitergehende mechanische Aufbereitung von gemischten Abfällen (inkl. Fe-Abscheidung)	220	43	20 - 25
Einfache biologische Aufbereitung (Kompostierung)	117	22	20-27
Weitergehende biologische Aufbereitung (Vergärung)	109	21	60

Weitergehendes Stoffstrommanagement am Beispiel von Restabfall

Bereits 2000 wurde in Hannover eine moderne mechanische Abfallaufbereitung mit einer Kapazität von 200.000 Mg/a errichtet.

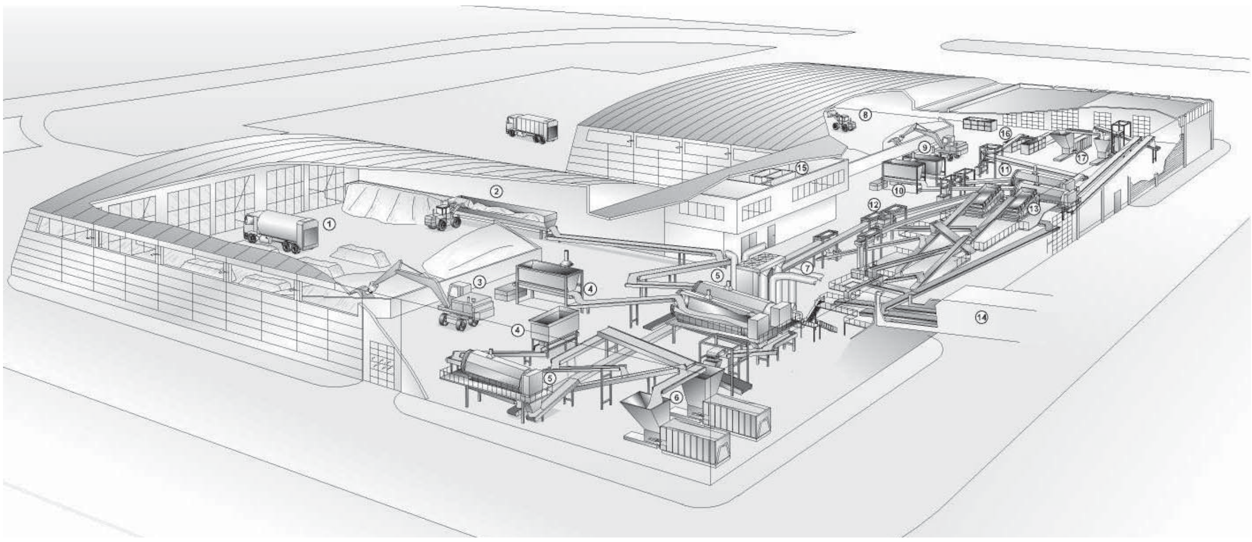

Bild 3: Mechanische Abfallaufbereitung

Seit 2006 ist diese Anlage um eine Trockenvergärungsanlage System Valorga mit Nachrotte als Wandermiete ergänzt worden und genügt damit den hohen Ansprüchen an eine ökologische Abfallverwertung.

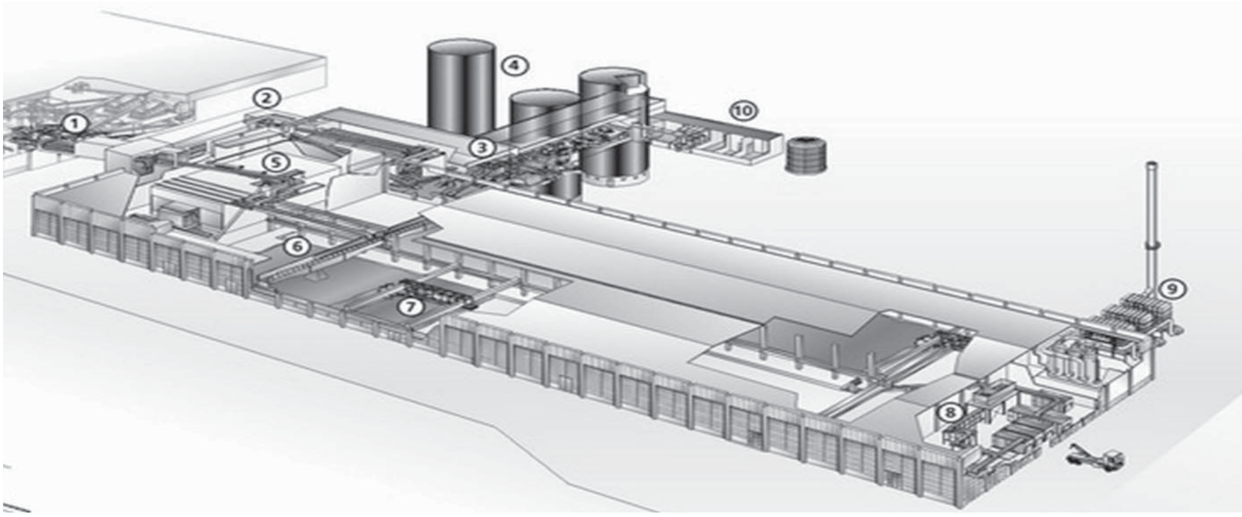

Bild 4: Biologische Aufbereitung MBA Hannover

In Bild 5 ist die Stoffstrombilanz für die MBA Hannover dargestellt.

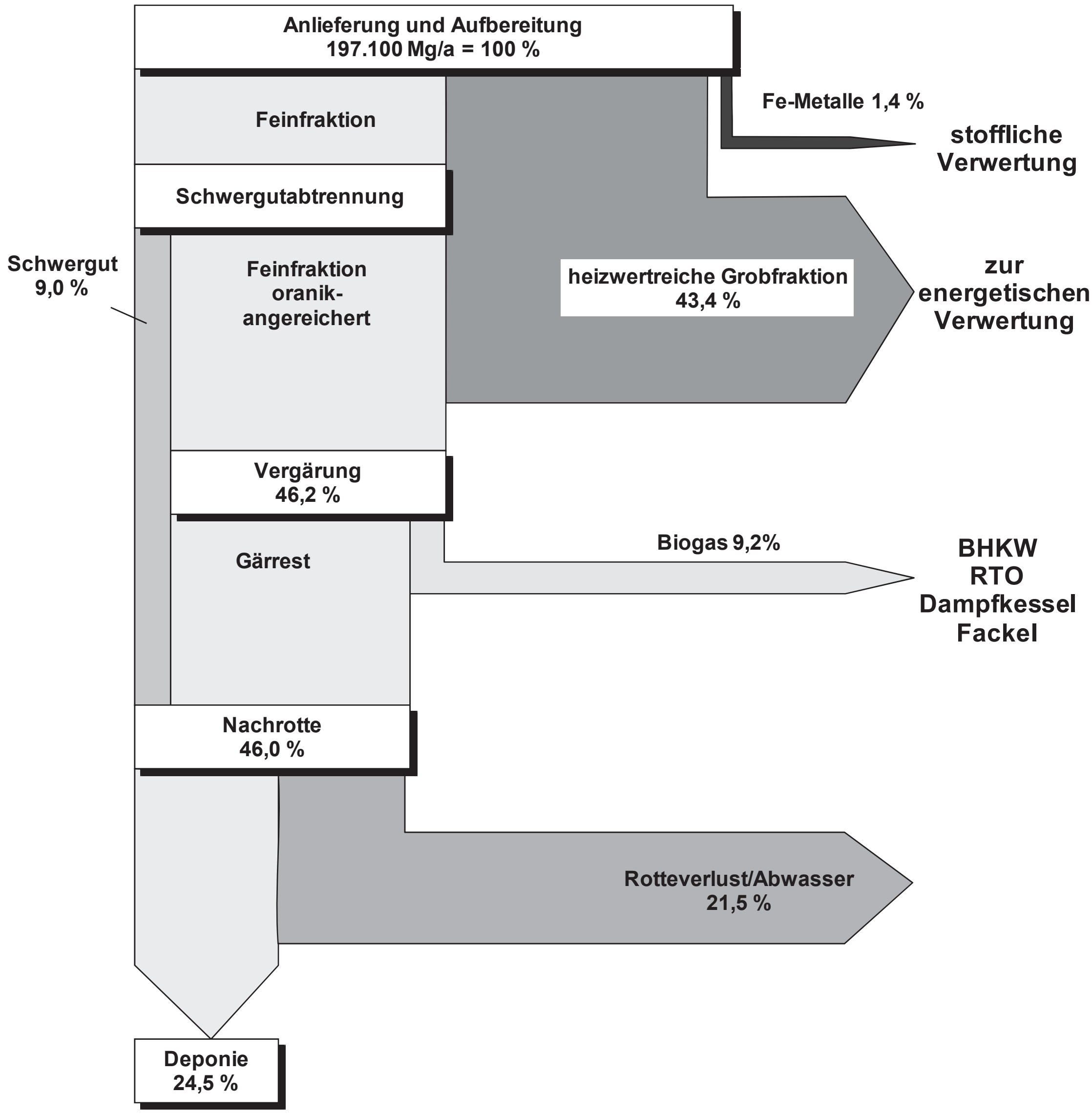

Bild 5: Stoffströme MBA Hannover 2012

2.1.1 Energieeffizienz

Die bereits erwähnten Einflussfaktoren Marktpreis sowie Ökobilanzierung im Rahmen einer Energieeffizienzanalyse führen dazu, die bestehende Anlage weiter zu entwickeln. Hierbei ist die Energieeffizienz ein wesentlicher Beurteilungsfaktor.) Dieser wird anhand des ASA-Bilanzmodells zur Ermittlung der Energieeffizienz und Klimabilanz von Abfallbehandlungsverfahren (Ketelsen, 2013) bestimmt. In Abhängigkeit von der nachgeschalteten energetischen Verwertung ergeben sich für die MBA Hannover dann unterschiedliche Ergebnisse bezogen auf die Energieffizienz (vgl. Tabelle 4). Von einer Energieffizienz von derzeit rund 18% könnte unter Optimierung der mit einer Biogasverwertung im BHKW und mit einer höherwertigen energetischen Verwertung einschließlich Dampferzeugung und Abgabe des Dampfes eine deutlich gesteigerte Energieeffizienz von bis zu % (Netto-Primär-Wirkungsgrad) erreicht werden. Bei Optimierung der heizwertreichen Fraktion zu einem Ersatzbrennstoff sowie biologischer Trocknung und weitergehender Aufbereitung der Feinfraktion aus der Vergärung mit Erzeugung einer zweiten Brennstoff-Fraktion (Biostabilat) ließe sich bei Verwertung der Brennstoff-Fraktionen in einem EBS-Kraftwerk der Netto-Primär-Wirkungsgrad sogar auf rund 50 % steigern.

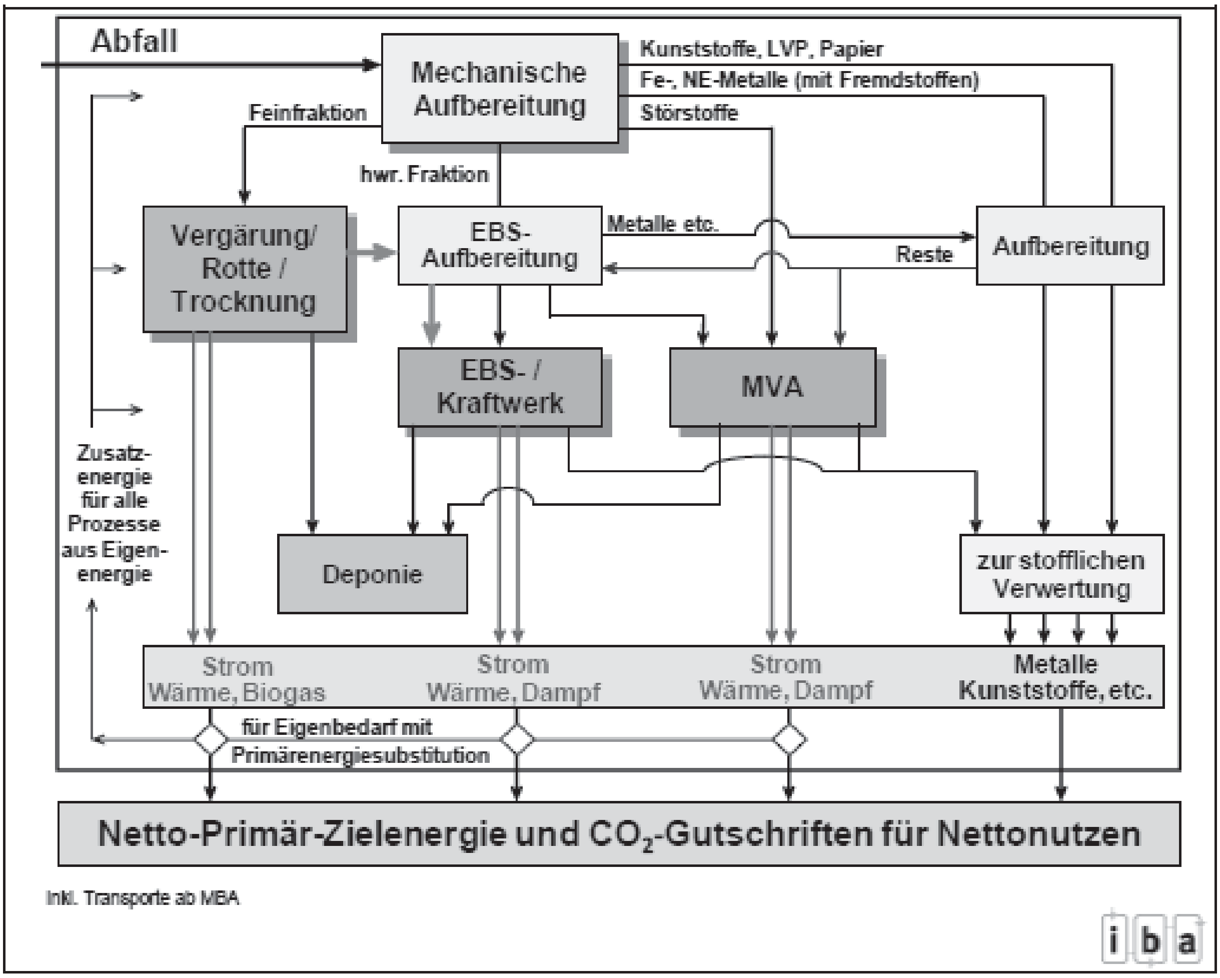

Bild 6: Energie- und Stoffströme MBA Hannover

Tabelle 4: Einfluss des Behandlungsverfahrens und der nachgeschalteten Verwertungsanlage auf Klimabilanzwert und Energieeffizienz der MBA Hannover

Bilanz/Szenario	**Klimabilanzwert**	**Energieeffizienz – Netto-Primär-Wirkungsgrade**		
	kg CO_2-Äquiv./Mg	**elektrisch - %**	**thermisch - %**	**gesamt - %**
IST 2012	-181	17,9	0,4	18,3
Basis 2012 mit opt. BHKW und opt. TEV	-327	13,9	30,7	44,6
Basis 2012 mit biolog. Trocknung der Feinfraktion und EBS-Kraftwerk	-271	9,5	40,1	49,6

2.1.2 Biostabilat

Ein vielversprechendes Feld zur Optimierung von MBA bildet die weitergehende Nutzung des erzeugten Rottegutes. In Bild 7 und Bild 8 sind hierzu Ergebnisse der durchgeführten Untersuchungen dargestellt.

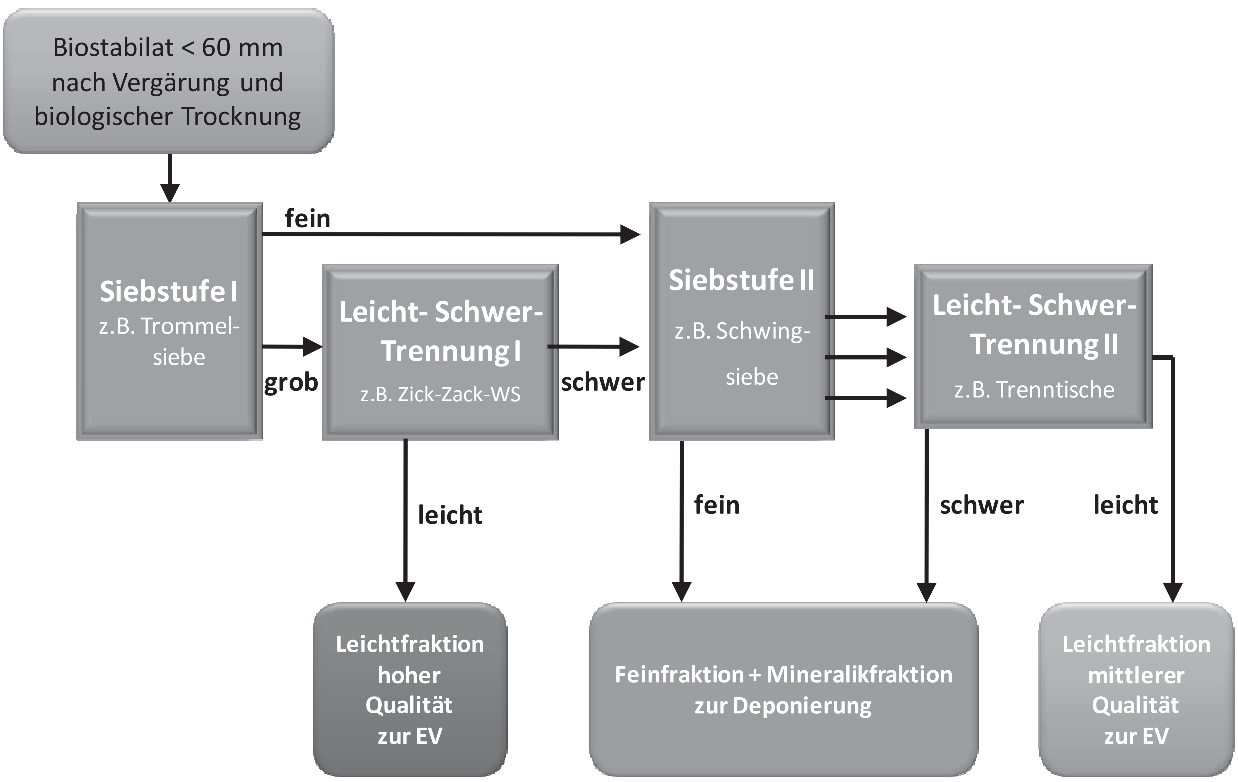

Bild 7: Weitergehende Aufbereitung von MBA Rottematerial

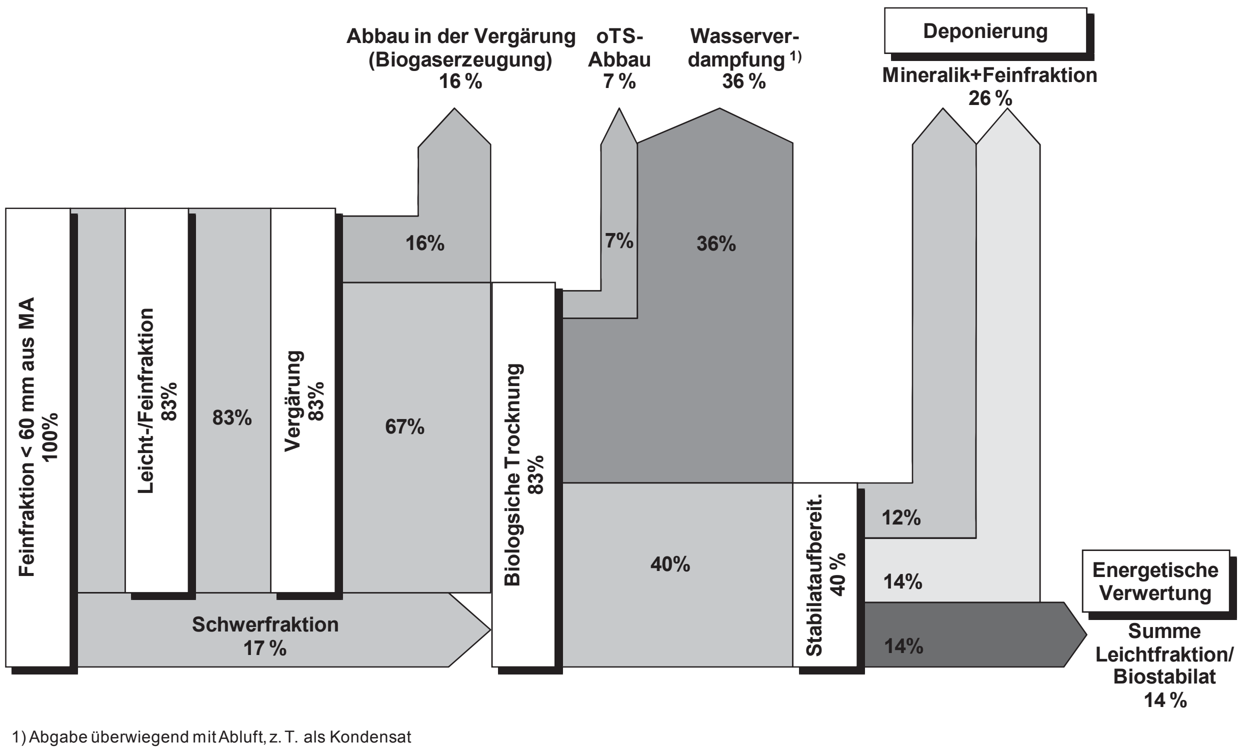

Bild 8: Stoffstromaufteilung der organikreichen Feinfraktion nach Vergärung, biolog. Trocknung und weitergehender Stabilat-Aufbereitung

Durch die weitergehende Aufbereitung werden Stoffströme generiert deren Marktsituation gegenüber der Deponierung deutlich günstiger ist. Hierdurch können die höheren Aufbereitungskosten weitgehend kompensiert bzw. je nach Marktlage zusätzliche Erlöse generiert werden.

3 Ausblick

Die Verwertung von Abfällen ist bereits mit einfachen Verfahren zu einem großen Prozentanteil möglich. Mit den zunehmenden Anforderungen an eine weitergehende Wertstofferfassung sowie unter Berücksichtigung ökobilanzieller Aspekte steigen die Kosten. Dabei sind den ökobilanziellen Zielen insbesondere unter Berücksichtigung der Marktlage und den jeweiligen Interessen der Anlagenbetreiber unter den gegebenen Voraussetzungen Grenzen gesetzt. Inwieweit hier der Gesetzgeber Maßstäbe setzen wird bleibt abzuwarten. Daneben hat in den letzten Jahren eine zunehmende Diversifizierung der Abfälle stattgefunden, die zu einem Kostenanstieg für die Aufbereitung führt. Dabei sind aus Sicht kommunaler Unternehmen für diese Stoffströme nur regionsübergreifende Konzepte mit entsprechenden zu behandelnden Mengen zielführend bzw. die Einbeziehung privatwirtschaftlicher Entsorgungsunternehmen.

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Stand und neue Entwicklungstendenzen / Perspektiven von MBA in Deutschland

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Status and new trends / perspectives of MBT in Germany

Abstract

Inhaltsangabe

Derzeit werden in Deutschland ca. 6-7 Mio. Mg Siedlungsabfall in Anlagen mit mechanischer und biologischer Technologie stoffspezifisch aufbereitet, das entspricht ca. 30 % der in 2012 angefallenen Rest-Siedlungsabfallmenge.

Vor dem Hintergrund der europäischen AbfRRL und deren Umsetzung in Deutschland durch das KrWG müssen sich die Betreiber mit veränderten Rahmenbedingungen in der Abfallwirtschaft auseinandersetzen. Diese werden u. a. zu rückläufigen Mengen an Rest-Siedlungsabfällen in Deutschland führen.

Gleichzeitig sind schon jetzt Überkapazitäten für die Behandlung von Rest-Siedlungsabfällen in Deutschland zu konstatieren.

Diese Mengenentwicklung wird neben einem Rückgang vorrangig auch zu einer Umnutzung der vorhandenen Anlagenkapazitäten und Umstellung der Verfahren führen. Die vorhandenen Konzepte zur stoffspezifischen Abfallbehandlung (MBA) stehen damit zukünftig im verschärften Wettbewerb. Die MBA-Anlagen sind dabei sich mit geeigneten Optimierungsstrategien an die veränderten Rahmenbedingungen anzupassen.

Auf Grund der Flexibilität der MBA-Technologie und einer Vielzahl von Entwicklungspotenzialen im Bereich der stofflichen und energetischen Verwertung verbunden mit signifikanten Vorteilen beim Klimaschutz wird die MBA ihre Position in der deutschen und europäischen Abfallwirtschaft behaupten, sofern es den Entscheidern mit der Umsetzung der fünfstufigen Abfallhierarchie ernst ist.

Keywords

MBA, MBS, MPS, Restabfall, Bioabfall, Wertstoffe, Vergärung, Biogas, EBS, MVA, Energieeffizienz, Klimaschutz, Abfallbehandlung, Kapazitäten

MBT, MBD, MPD, MSW, biowaste, recyclables, anaerobic digestion, biogas, RDF, MSWI, energy efficiency, climate protection, waste treatment, capacities

1 Einführung

Die Abfallwirtschaft muss sich zunehmend an den Vorgaben nachhaltiger Ressourcen- und Klimaschutzziele ausrichten. Nach aktuellen Studien kann die Abfallwirtschaft dazu auch weiterhin einen wesentlichen Beitrag durch eine stoffliche und energetische Verwertung von Abfällen leisten. In Europa führt die Umsetzung der AbfRRL in den Staaten der EU zu einer schwer abschätzbaren Veränderung des Abfallaufkommens hinsichtlich Menge, Qualität und Verbleib.

Im deutschen Entsorgungsmarkt sind mittlerweile deutliche Überkapazitäten in der Restabfallbehandlung zu konstatieren. Gleichzeitig wird in den Prognosen von stagnierenden Siedlungsabfallmengen bzw. vor dem Hintergrund des KrWG und der erwarteten Entwicklungen bei Wertstoffen und Bioabfällen, von leicht rückläufigen Restabfallmengen ausgegangen. Abfallimporte aus dem europäischen Ausland gleichen dies derzeit nur zu einem geringen Anteil aus. Die langfristigen Auswirkungen einer EU-weit angestrebten Reduzierung der Deponierung auf die Höhe von Abfallimporten nach Deutschland sind wegen des gleichzeitig zu erwartenden Ausbaus der Behandlungskapazitäten in den EU-Staaten unklar.

Die MBA muss und wird sich dem daraus zunehmend erwachsenden Wettbewerb um Mengenströme und Qualitäten stellen. Die technischen Voraussetzungen und Entwicklungspotenziale sind dafür vorhanden. Erste Tendenzen zum praktischen Umgang mit Überkapazitäten sind in Deutschland bereits erkennbar.

Die stoffspezifische Abfallbehandlung mit einer Anlage mit MBA-Technologie als Schaltstelle einer Stoffstromtrennung mit energieeffizienter Behandlung und Verwertung der Teilströme bietet unter unterschiedlichsten Rahmenbedingungen eine gute Ausgangsposition im Wettbewerb. Die technische Ausführung der MBA-Technologie lässt sich dabei flexibel an die jeweiligen Anforderungen und Rahmenbedingungen anpassen. Die Stoffströme können qualitativ und quantitativ beeinflusst und so marktgerecht zur Verfügung gestellt werden. Dies gilt auch für Teilströme zur Deponierung, die auf die inerten Abfallbestandteile reduziert und so minimiert werden können.

Aktuelle Prognosen zur Kapazitätsentwicklung bei MBA in Deutschland weisen, der erwarteten Entwicklung bei den Restabfallmengen und dem wirtschaftlichen Druck folgend, entweder rückläufige oder auch, das Potenzial zur stofflichen und energetischen Verwertung gemäß neuer Abfallhierarchie hervorhebend, ansteigende Tendenzen aus. In allen Szenarien werden Verschiebungen bei den verfahrenstechnischen Konzepten erwartet.

2 Entwicklung und Stand der MBA in Deutschland

2.1 Entwicklung, Anzahl und Kapazitäten

Die mechanisch-biologische Abfallbehandlung wurde in Deutschland mit einfachen Verfahren schon vor 1990 betrieben (z. B. als Rottedeponie, Müllkompostwerk).

Mit der Diskussion um die TA Siedlungsabfall und dem damals angestrebten Deponierungsverbot ab 2005 wurden technischen Alternativen zur vorgesehenen Abfallverbrennung gesucht. Nach diversen wissenschaftlichen Forschungsvorhaben in Bund und Ländern und dem Bau von Demonstrationsanlagen, die einen technisch und emissionsseitig höheren Standard aufwiesen, wurden in 2001 mit der 30. BImSchV und AbfAblV die genehmigungsrechtlichen Anforderungen an den Bau und Betrieb von MBA nach dem 31.05.2005 definiert.

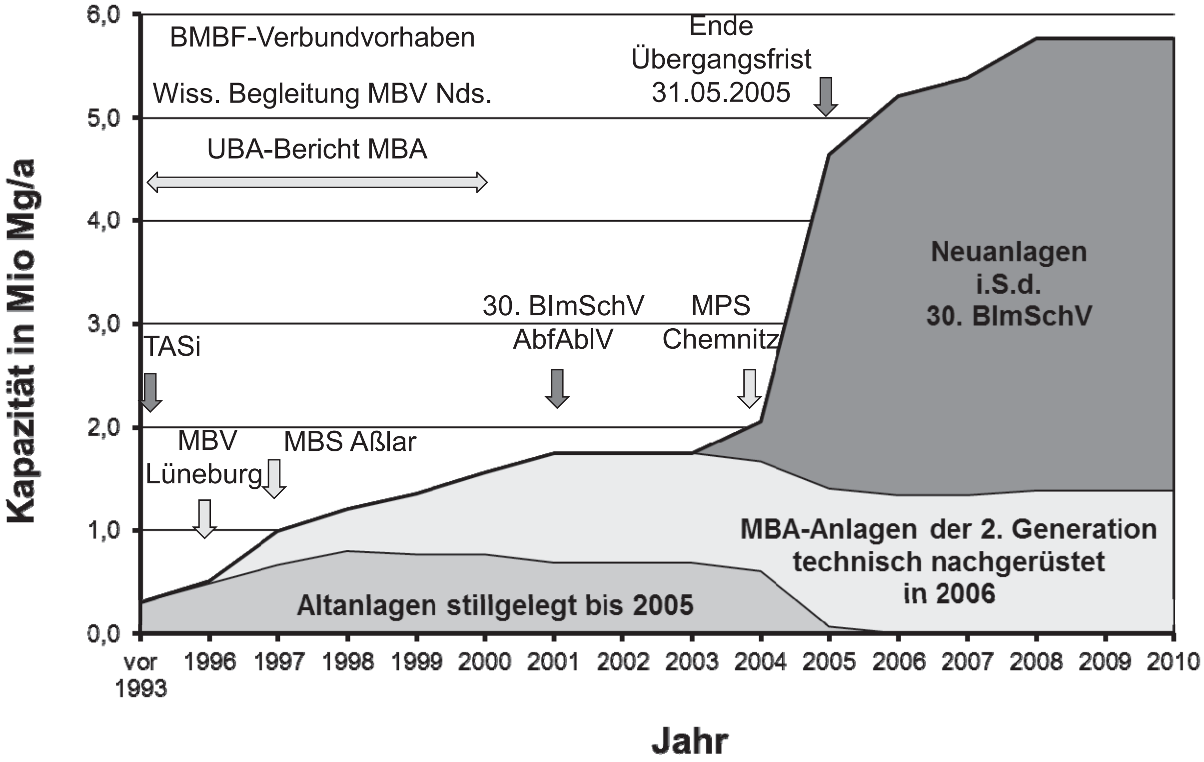


Abbildung 1 Entwicklung der Kapazitäten von MBA/MBS/MPS-Anlagen seit 1993

Die meisten der heute betriebenen neuen Anlagen mit MBA-Technologie wurden daher in den Jahren 2001 bis 2005 konzipiert. Für ihre Realisierung stand in der Regel ein vergleichsweise kurzer Zeitraum zur Verfügung. Bis 2006 wurden die nach 1996 in Betrieb gegangenen Anlagen technisch an den Standard der 30. BImSchV und AbfAblV angepasst. Altanlagen mit einfacher Technologie wurden in 2005 überwiegend stillgelegt. Die MBA-Kapazitäten wurden so in den Jahren 2004 bis 2008 um ca. 4 Mio. Mg gesteigert.

Seit nunmehr 10 Jahren müssen sich die MBA-Anlagen am Markt bewähren und die hohen Anforderungen der AbfAblV/DepV und der 30. BImSchV in der betrieblichen Praxis dauerhaft und sicher erfüllen. Vor diesem Hintergrund wurden und werden die Anlagen mit MBA-Technologie in den letzten 10 Jahren stetig optimiert und die Verfahrenskonzepte an die sich ständig verändernden Rahmenbedingungen im Abfallmarkt angepasst. Inzwischen haben sich die Anlagen mit MBA-Technologie zu einer wichtigen Säule in der Abfallwirtschaft etabliert.

2.2 Verfahrenskonzepte

In Anlagen mit MBA-Technologie werden Siedlungsabfälle mit dem Ziel einer stoffspezifi-schen Abfallbehandlung aufbereitet. Dies bedeutet, dass bei der Auswahl und Festle-gung von Behandlungsschritten für Siedlungsabfälle die unterschiedlichen stofflichen Eigenschaften der Abfallfraktionen maßgebend sind. Dieser Ansatz spiegelt sich in drei verfahrenstechnischen Konzepten wider:

- Mechanische Aufbereitung (MA-Verfahren, z. T. als Vorstufe vor einer MBA)
- Mechanisch-Biologische Abfallbehandlung (MBA-Verfahren, aerob/anaerob)
- Mechanisch-Biologische Stabilisierung (MBS-Verfahren)
- Mechanisch-Physikalische Stabilisierung (MPS-Verfahren)

Das derzeit noch am häufigsten verwendete Verfahren zur stoffspezifischen Abfallbehandlung ist die Mechanisch-Biologische Abfallbehandlung (sog. „Endrotteverfahren“). Hier werden die Stoffströme zur weiteren biologischen Behandlung sowie diejenigen zur stofflichen und energetischen Verwertung ausgeschleust. Die biologische Behandlung erfolgt in Rottesystemen (Tunnel, Zeilen oder Mieten) oder in Vergärungsstufen (Trocken- oder Nassvergärung). Als weiteres Endprodukt wird ein ablagerungsfähiges Material (Deponat) erzeugt.

Bei der Mechanisch-Biologischen Stabilisierung („Trockenstabilisierung“) erfolgt die biologische Trocknung des gesamten Abfallinputs zur Gewinnung heizwertreicher Abfälle bei Minimierung des abzulagernden Stoffstroms. Bei der Mechanisch-Physikalischen Stabilisierung werden heizwertreiche Abfallbestandteile aus Siedlungsabfällen nur über mechanische und physikalische Verfahren selektiert und im Rahmen eines mehrstufigen Behandlungsprozesses zu einem Ersatzbrennstoff aufbereitet. Dieser Aufbereitungsprozess umfasst z. B. eine Abtrennung der heizwertarmen Bestandteile und der Fe- und NE-Metalle sowie eine mehrstufige Zerkleinerung.

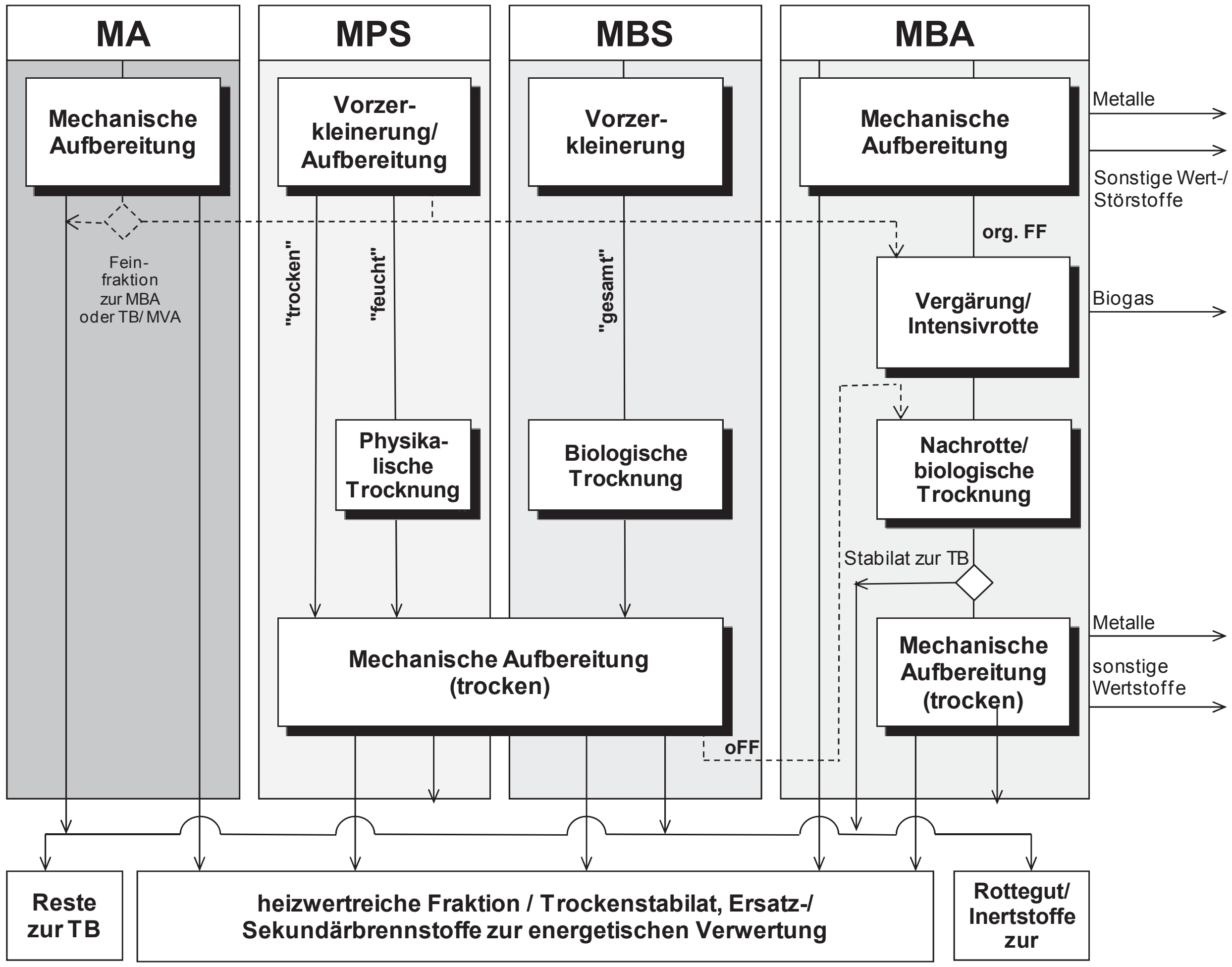


Abbildung 2 vereinfachte Darstellung der Anlagenkonzepte mit mechanischen und biologischen Verfahren

Während die klassische MBA i. d. R. auf Deponiestandorten realisiert worden ist, wurden die übrigen Anlagenkonzepte i. d. R. auf Standorten ohne Deponieanbindung errichtet. Demzufolge wurde mit der MBA nach Abtrennung von Metallen und den heizwertreichen Abfallbestandteilen auch das Ziel verfolgt, weiterhin eine ablagerungsfähige Fraktion zu erzeugen.

Im Gegensatz dazu lag bei den übrigen Verfahren der Schwerpunkt auf Minimierung der Abfallmasse durch physikalische oder biologische Trocknung und Erzeugung von Brennstoffen.

Im Zuge der wirtschaftlichen Optimierung und technischen Weiterentwicklung nimmt die Bedeutung der Deponie ab, die biologische Stufe in der MBA wird zunehmend zur Trocknung der organikhaltigen Feinfraktion oFF genutzt. Des Weiteren ist eine Kooperation zwischen den Anlagenkonzepten in dem Sinne festzustellen, dass Teilströme aus MA/MPS/MBS-Anlagen in MBA-Anlagen weiterbehandelt werden und umgekehrt.

2.3 Stoffbilanz und Verbleib der Stoffströme

Bei der Analyse der Stoffbilanz ist zu berücksichtigen, dass in MBA mit ca. 80 % überwiegend Hausmüll angeliefert und behandelt wird.

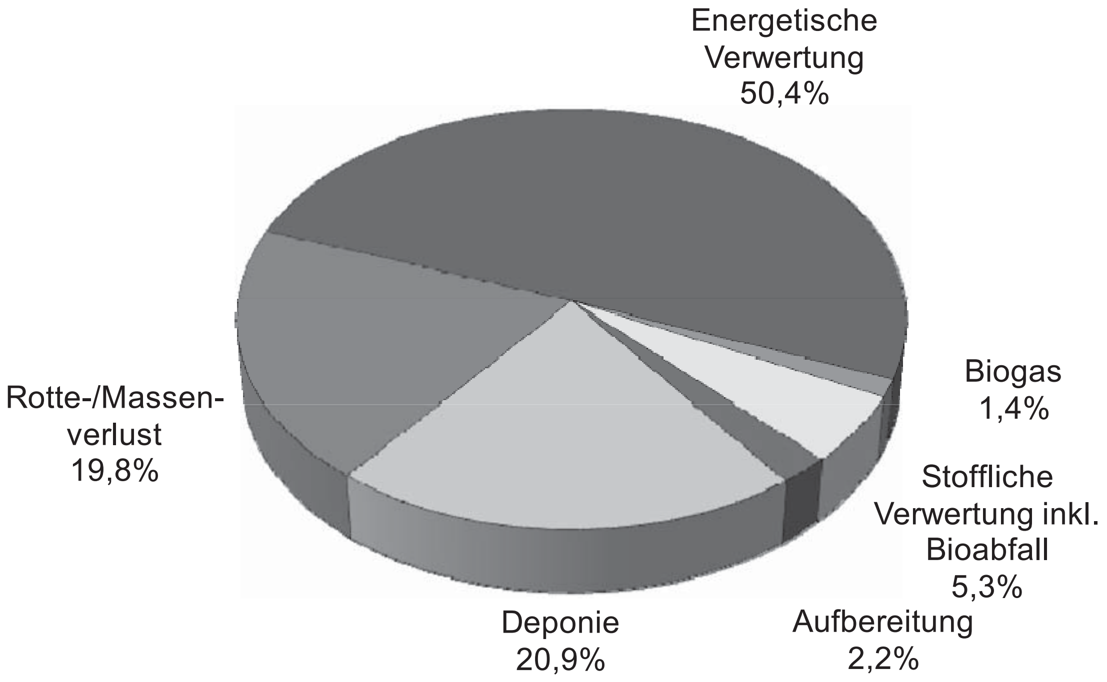
Gewerbe-, Sperr- und sonstige Abfälle spielen bei der überwiegenden Anzahl der MBA-Anlagen keine Rolle mehr, sondern werden in separaten Aufbereitungsanlagen angeliefert und behandelt. Ebenso werden vorgehaltene Kapazitätsreserven für Klärschlamm nicht in Anspruch genommen.

Die MBA-Anlagen wiesen 2012 eine mittlere Auslastung von ca. 80% auf. Die Teilauslastung geht u.a. auf Anlagen zurück, die bei hohen genehmigten Anlagenkapazitäten (insbes. der MA-Stufe) auf Grund fehlender bzw. umgelenkter Abfallströme die ursprünglich geplanten Durchsatzmengen nicht mehr erreichen können.

Von den aufbereiteten Abfällen wurden im Mittel ca. 50 % als EBS energetisch verwertet, nur ca. 21 % wurden noch deponiert (Abb. 3).

Dabei entstammten systembedingt die Deponatmengen überwiegend aus den MBA-Anlagen mit Rotte bzw. Vergärung. Mit Umstellung eines Teils dieser Anlagen auf biologische Trocknung wird sich auch hier der Deponieanteil deutlich reduzieren (Abb. 4).

Der höhere Massenverlust bei den MBS-/MPS-Anlagen trotz geringerem Organikabbau geht auf den höheren Wasseraustrag durch Trocknung der Gesamtabfälle zurück.



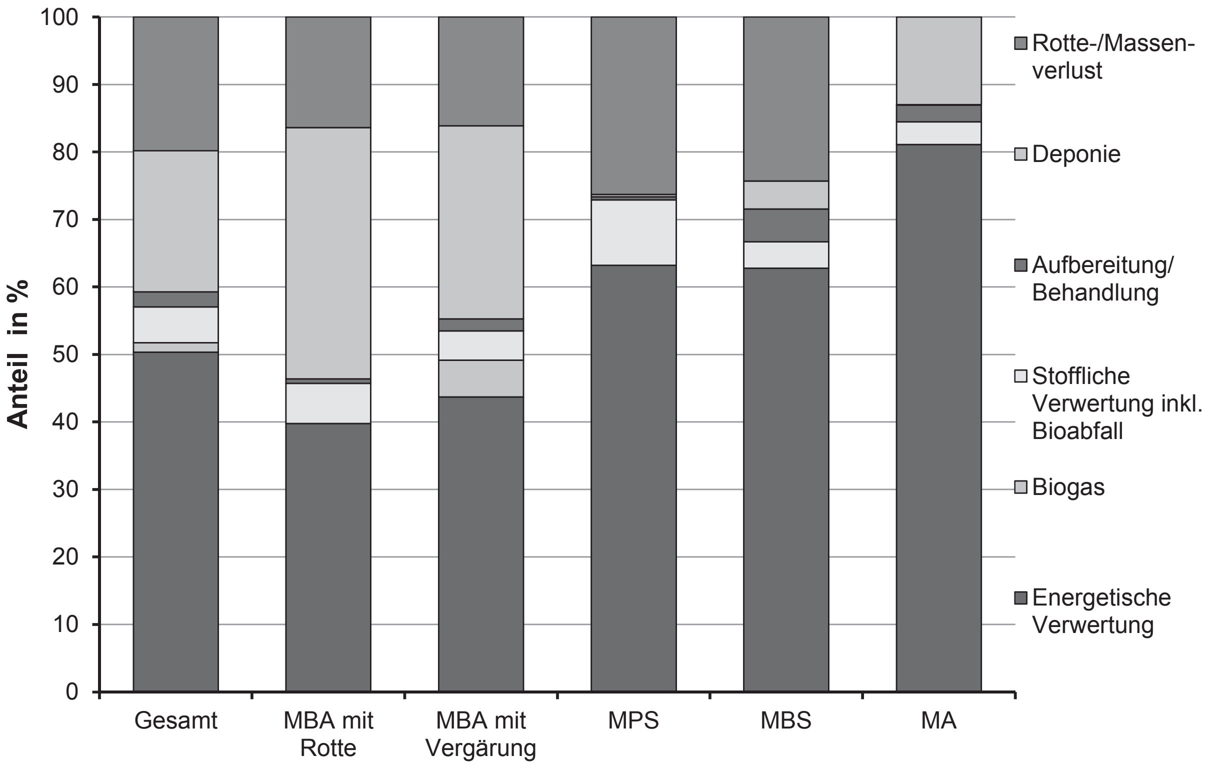
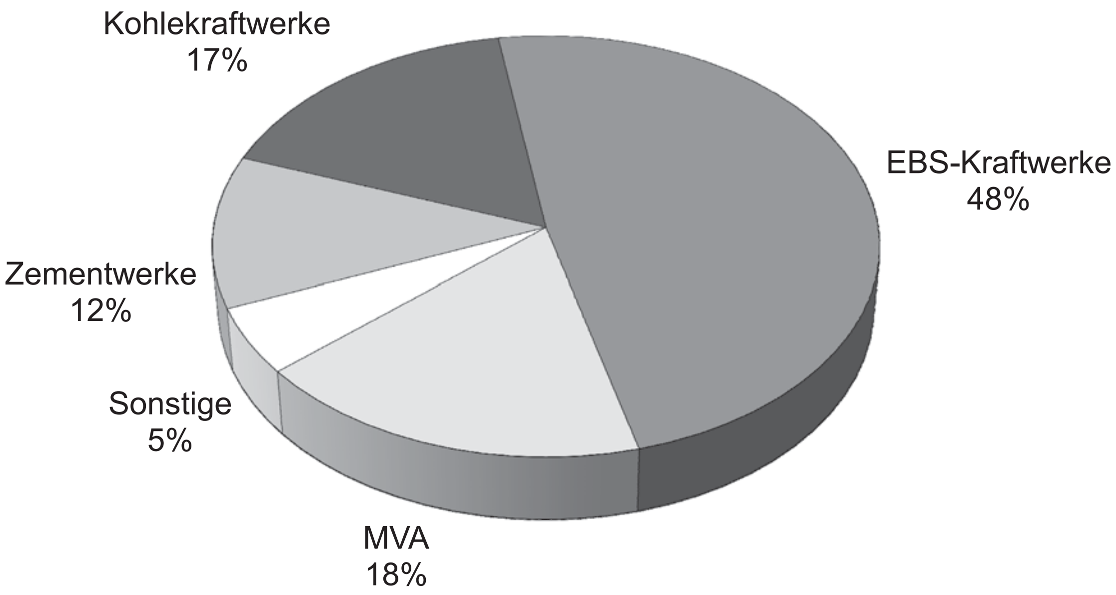


Abbildung 3 Aufteilung der Austragsmengen von MBA/MBS/MPS in 2012



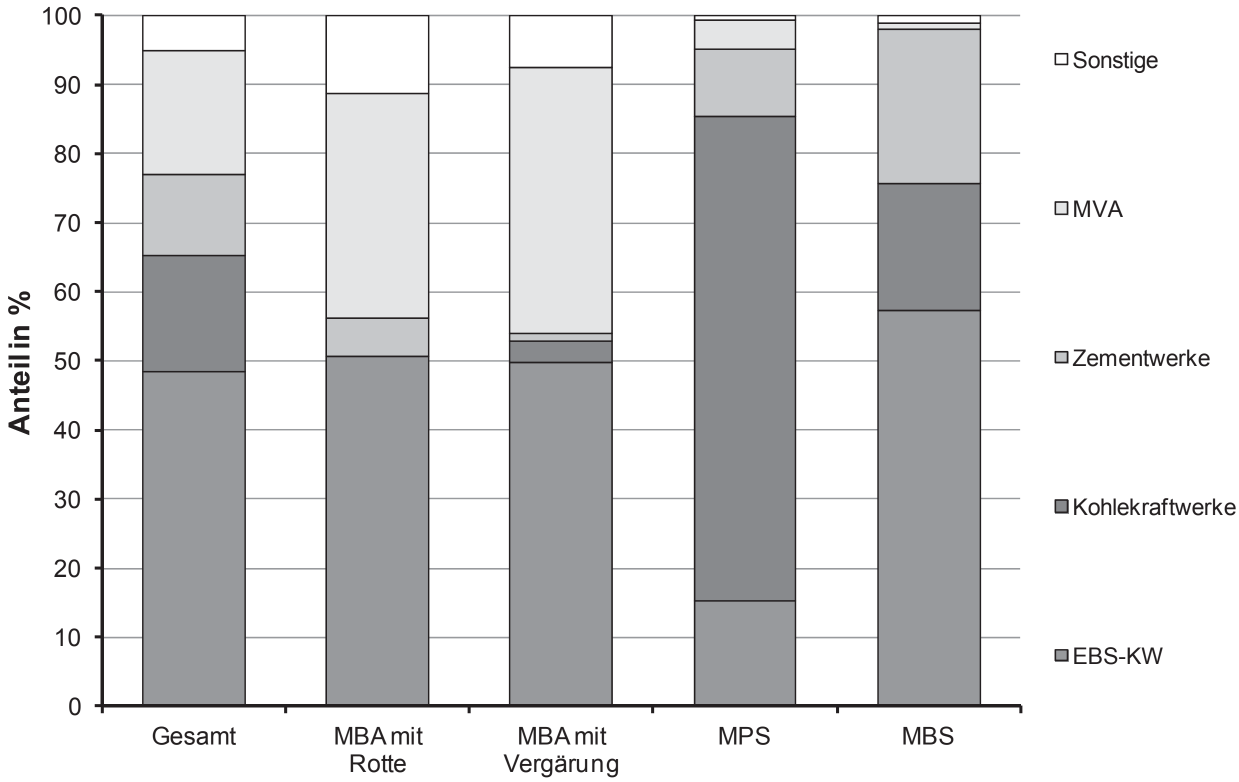


Abbildung 4 Verbleib der in MBA/MBS/MPS in 2012 erzeugten EBS-Mengen

Vor 2005 wurden noch Probleme bei der energetischen Verwertung der heizwertreichen Fraktion aus MBA prognostiziert. Dies lag zum einen daran, weil noch nicht genügend industrielle Verbrennungsanlagen als Abnehmer der produzierten Ersatzbrennstoffe zur Verfügung standen. Inzwischen steht eine Gesamtkapazität von 5-7 Mio. Mg/a zur Verfügung. Zum anderen ist die Qualitätssicherung der EBS in den vergangenen Jahren wesentlich verbessert worden, so dass inzwischen konstante und an das jeweilige EBS-Kraftwerk angepasste Brennstoffqualitäten geliefert werden können. Somit hat sich die Situation in der Praxis umgekehrt.

Bezogen auf die Gesamtheit der MBA wurden in 2012 knapp die Hälfte der erzeugten Ersatzbrennstoffe (EBS) in EBS-Kraftwerken energetisch verwertet.

Der höhere Anteil Kraftwerke und Zementwerke bei den MBS- und MPS-Verfahren liegt in der weitergehenden Aufbereitung der Trockenstabilate in diesen Anlagen (Stückigkeit, Feuchte, Inhaltsstoffe). Bei den MBA-Anlagen erfolgt von Ausnahmen abgesehen i. d. R. nur eine Vorzerkleinerung, Klassierung und Metallabscheidung der hwr. Fraktion. Im Rahmen öffentlicher Ausschreibungen gingen hierfür die wirtschaftlichsten Angebote von MVA oder EBS-Kraftwerken ein.

Die hohe Ausnutzung des Energiegehaltes der Abfälle mit MBA-Verfahren zeigt sich an der Höhe des in die Ersatzbrennstoffe überführten Heizwertfracht. Aus den MBA-Anlagen wurden im Mittel 84 % der Heizwertfracht des Rohabfalls über die EBS der energetischen Verwertung zugeführt (Tab. 1).

Bei den MBS-Anlagen verbleibt nach biologischer Trocknung ca. 95 % des Energiegehaltes der angelieferten Abfälle im Trockenstabilat. Bei den MPS-Anlagen wird durch Zuführung von externer Energie (Gas für Trommeltrockner) der nutzbare Energiegehalt im Stabilat sogar auf über 100 % erhöht.

Tabelle 1 Nutzbare Energieinhalte im EBS aus MBA im Verhältnis zum Heizwert im Rohabfall (Auswertung für 2012)

Energieinhalt	Hu Abfall	Massen-anteil EBS	Hu EBS	Energie im EBS absolut	Energie in EBS relativ
Fraktion zur EV/TB	GJ/Mg_{MBA}	% m/m	MJ/kg	GJ/Mg_{MBA}	% von Hu Abfall
Abfall zur MBA/MBS/MPS	7,8-9,2	100		-	-
EBS aus MBA Rotte	8,90	41,0	15,1	6,18	69
EBS aus MBA Vergärung	8,20	53,1	12,2	6,49	79
EBS aus MPS	7,80	61,0	13,8	8,43	108
EBS aus MBS	9,20	63,6	13,7	8,72	95
Mittel MBA/MBS/MPS	**8,60**	**52,9**	**13,7**	**7,25**	**84**

Selbst bei den klassischen MBA werden durch einfache Absiebung der heizwertreichen Abfallbestandteile 70-80 % des Energieinhaltes der Abfälle in die EBS-Fraktion überführt. Bei den Vergärungsanlagen wird zusätzlich ein hoher Anteil des in der biologischen Behandlung erforderlichen Energieaustrags über Biogas nutzbar gemacht.

Für die Gesamtheit der MBA-Anlagen besteht entsprechend dem aufgezeigten Konzept noch Optimierungspotenzial durch eine Erhöhung des Anteils an Abfällen, der mit Vergärungs- und/oder Stabilisierungsverfahren behandelt wird, bei gleichzeitiger Steigerung des EBS-Anteils, der in hocheffiziente Anlagen zur energetischen Verwertung geht. Eine Erhöhung des Massenanteils aus MBA zur energetischen Verwertung auf 60 % mit gleichzeitiger Steigerung des Energieanteils im EBS auf ca. 100 % erscheint mittelfristig realistisch (Abb. 5).

Ob langfristig relevante Teilmengen zur stofflichen Verwertung separiert werden können, hängt sowohl von der Entwicklung der Inputqualitäten als auch von der Qualität und Wirtschaftlichkeit der hierfür erforderlichen Separationstechnologien ab.

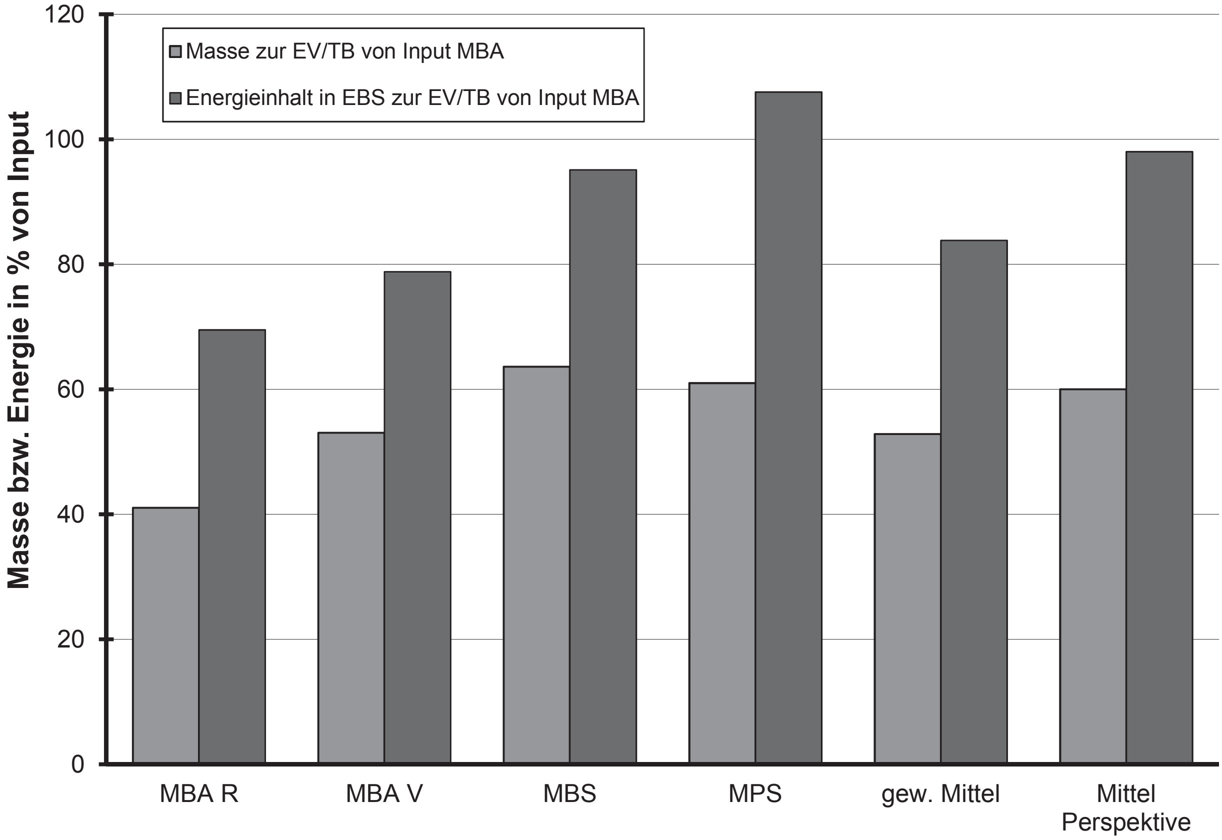


Abbildung 5 Masse und Energieinhalt in EBS aus MBA in 2012 und mittelfristige Zielperspektive

2.4 Betriebsverbräuche

Der für den Betrieb der MBA aufgewandte Energieverbrauch hängt neben dem Verfahren vorrangig vom Betrieb bzw. von der Aufbereitungstiefe in der jeweiligen Anlage ab.

Im Mittel wird in MBA mit Vergärung und in MBS/MPS-Anlagen um 20-30 kWh/Mg mehr Strom verbraucht als in MBA mit Rotte. Die größere Bandbreite der Stromverbräuche innerhalb jeder Verfahrensgruppe schränkt aus o. g. Gründen die Aussagekraft von Mittelwerten stark ein. Davon unbenommen werden in den Anlagen Energiemanagementsysteme und Verfahrensoptimierungen umgesetzt, mit deren Hilfe der spezifische Stromverbrauch weiter reduziert werden soll. Im Vergleich zu den genannten Werten der MBA liegt der Stromverbrauch einer MVA bei ca. 100-120 kWh/Mg.

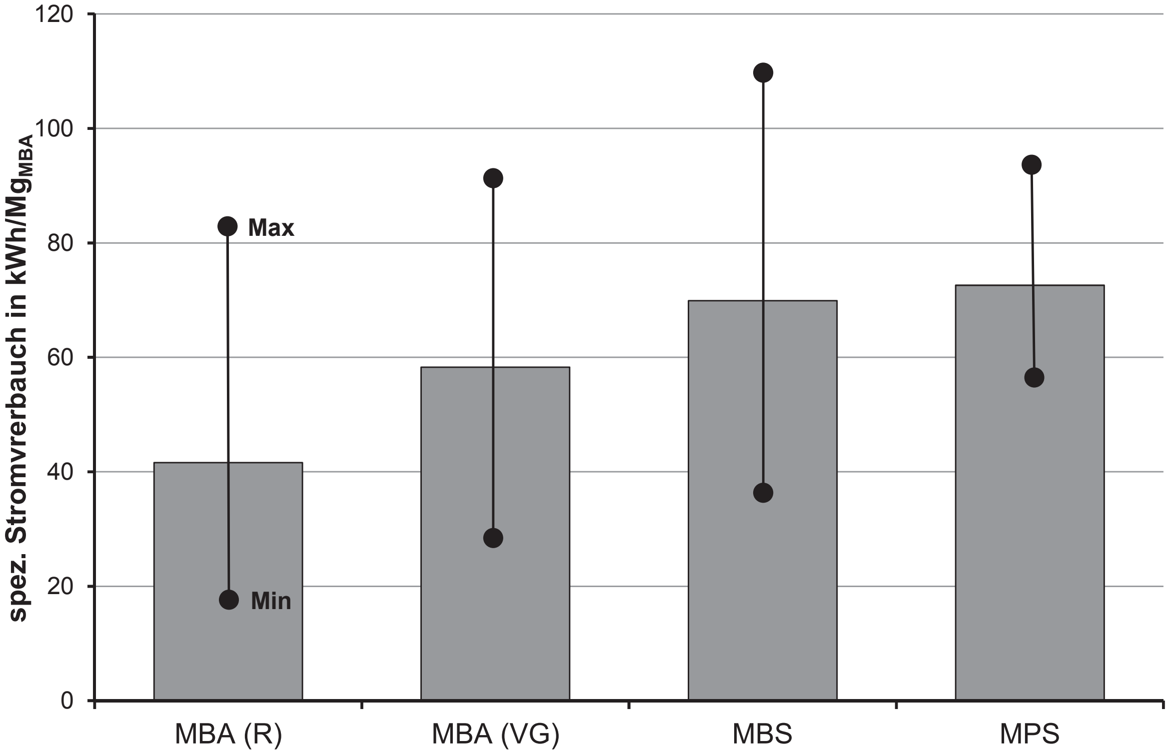


Abbildung 6 Spezifischer Stromverbrauch der untersuchten MBA/MBS/MPS in 2012

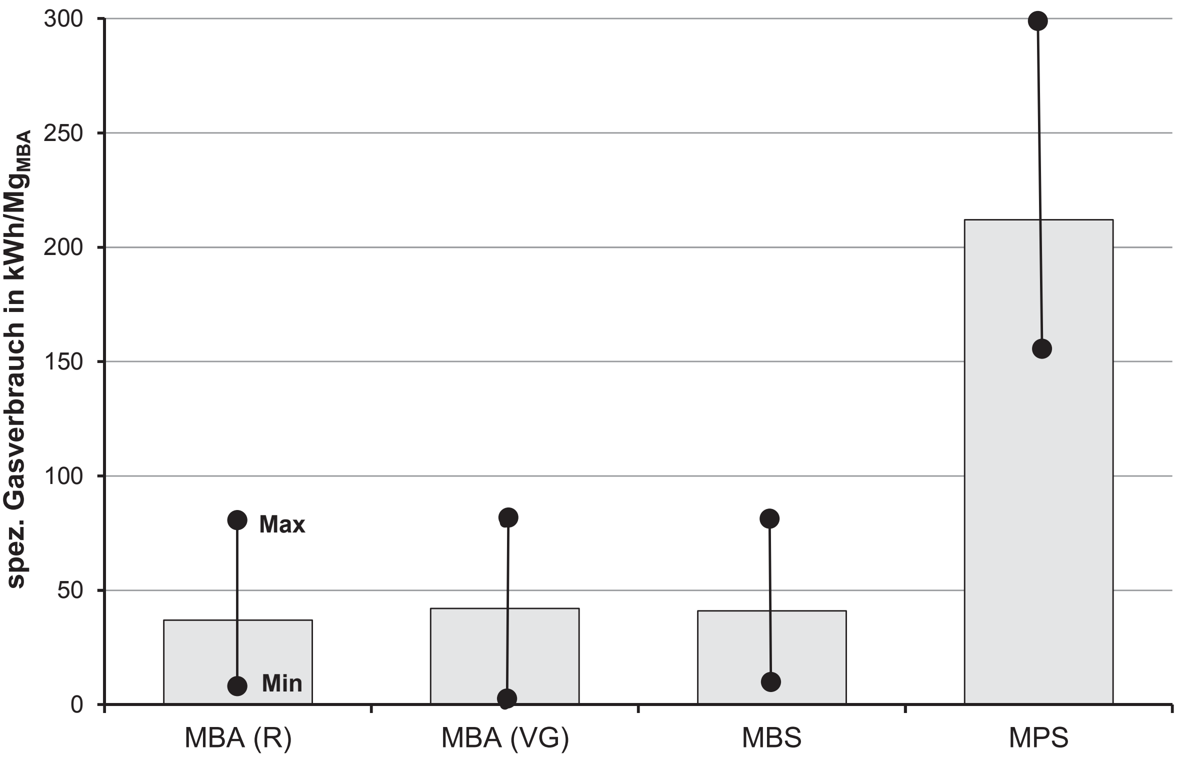


Abbildung 7 Spezifischer Gasverbrauch in MBA/MBS/MPS in 2012

Der Gasverbrauch bei MBA und MBS liegt im Mittel bei ca. 40 kWh/Mg (= 4 m³ Erdgas). Die großen Unterschiede innerhalb der Verfahrensgruppen resultieren aus unterschiedlichen Abluftkonzepten (Aufteilung Abluft auf RTO, Biofilter und Staubfilter, organische Belastung der Abluft zur RTO) und Betriebsführungen. Der Zusatzenergiebedarf bei den MBA mit Vergärung wird i. d. R. über das erzeugte Biogas gedeckt, wobei durch die Restausgasung der Gärreste in der Nachrotte die RTO autotherm gefahren werden konnte.

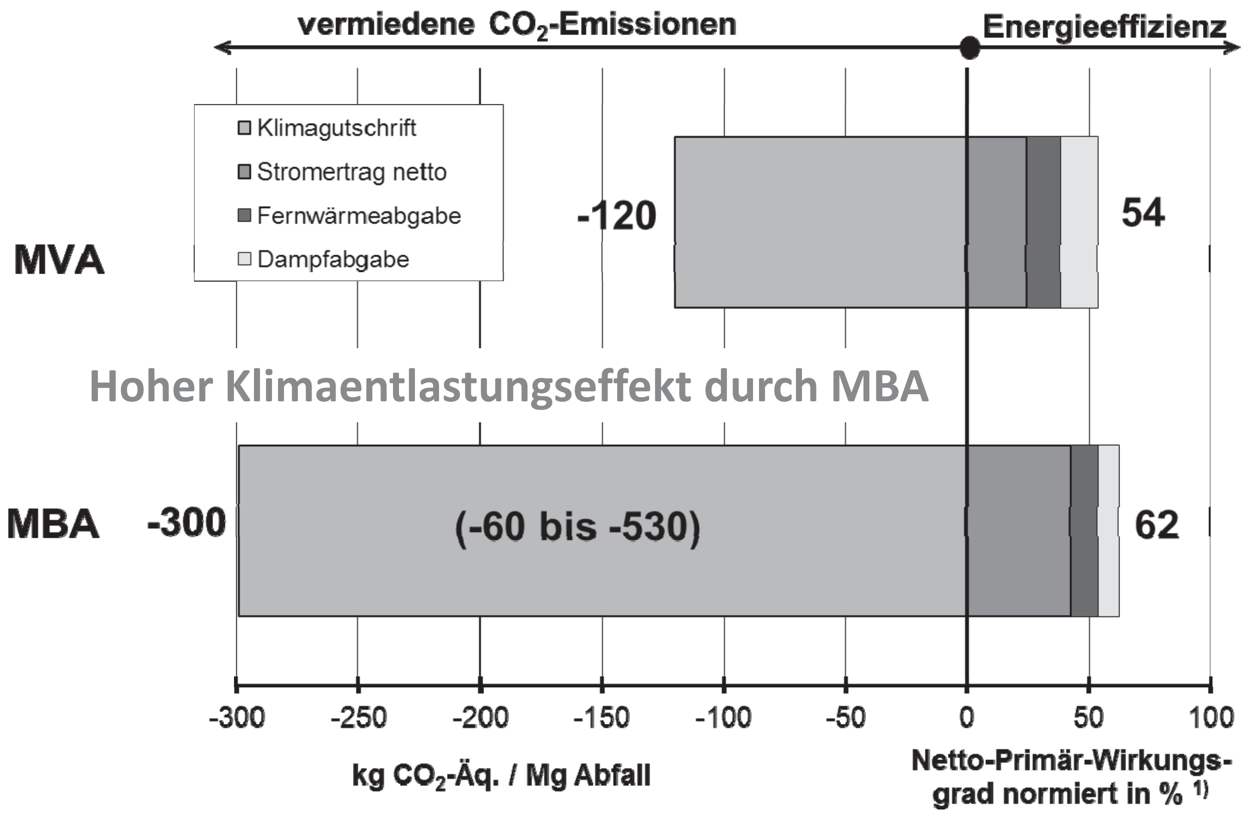
Der deutlich höhere Gasverbrauch in den MPS-Anlagen ist der thermischen Trocknung der Abfälle in den Trommeltrocknern geschuldet.

2.5 Energieeffizienz und Klimagasbilanz

Der ökologische Nutzen einer Abfallbehandlung mit MBA wird am Beispiel der Energieeffizienz und der Klimagasbilanz deutlich.

Die Energieeffizienz von Kombinationsverfahren mit Anlagen mit MBA-Technologie und energetischer Verwertung der heizwertreichen Fraktion wird maßgeblich von der Energieeffizienz der nachgelagerten Verfahren der energetischen Verwertung bestimmt. Der Energiebedarf für die Aufbereitung der Abfälle der MBA ist dagegen nachrangig. Bei weitgehender Abtrennung der heizwertreichen Abfallbestandteile und deren effektiver Verwertung in Kohlekraft- und Zementwerken lassen sich höhere Nettowirkungsgrade erzielen als mit der Verbrennung der Gesamtabfälle in einer MVA.

Dennoch lassen sich die Energieeffizienz des Gesamtverfahrens und damit der Beitrag zum Klimaschutz weiter steigern. Zu nennen sind hier u.a. die Integration von Vergärungsstufen, die Optimierung des Energieverbrauchs, die Erhöhung der Ausbeute und Qualität heizwertreicher Abfallbestandteile ggf. verbunden mit einer Trockenstabilisierung, die Optimierung der Abtrennung von Fe- und NE-Metallen sowie weiterer Teilfraktionen mit dem Ziel einer stofflichen Verwertung.



1) Normierung durch Multiplikation der elektr. Energie mit Faktor 2,6 und Wärmeenergie mit 1,1

Abbildung 8 Vergleich von Energieeffizienz und Klimagasbilanz von MBA 2012 und MVA (MVA ohne EBS-KW und ohne Gutschrift für Eigenbedarf Strom)

MBA erreichen schon heute mit einem (aus Vergleichbarkeitsgründen normierten) Netto-Primär-Wirkungsgrad von 62 % bezogen auf Primärenergie eine deutlich höhere Energieeffizienz als MVA. Der Klimaentlastungseffekt liegt mit im Mittel -300 CO_2-Äquiv./Mg Abfall bei MBA sogar 2- bis 3-mal so hoch wie bei MVA.

Aus der aufgezeigten Vielfalt von MBA auf der Ebene von Einzelanlagen und Verfahrenskonzepten und den zuvor beschriebenen Unterschieden in der Stoffstromteilung, den Verwertungswegen der erzeugten EBS und den betrieblichen Aufwendungen hierfür resultiert eine entsprechende Bandbreite hinsichtlich der Energieeffizienz und der Klimagasbilanzergebnisse (in 2012: -60 bis -530 kg CO_2-Äquiv./Mg Abfall). Die Stabilisierungsverfahren (insbesondere MBS) weisen hier Vorteile gegenüber den MBA-Verfahren auf, da erstere einen höheren Anteil der behandelten Abfälle zur Verwertung ausschleusen und auch die klimagasbilanzielle Wertigkeit der Verwertungswege derzeit höher ist. Mit entsprechend optimierten MBA-Konzepten werden sich zukünftig auch in der Breite Klimagutschriften in der Größenordnung von -500 kg CO_2-Äquiv./Mg Abfall erzielen lassen wie die Untersuchungen an den Praxisanlagen in Deutschland zeigen.

3 Perspektiven

3.1 Rechtliche und abfallwirtschaftliche Rahmenbedingungen

Mit der Umsetzung des Kreislaufwirtschaftgesetzes (KrWG, 5-stufige Abfallhierarchie, Verpflichtung zur Bioabfallsammlung), der anstehenden Novellierung der GewAbfV (Pflicht zur Getrennthaltung und Sortierung von Gewerbeabfall) und dem geplanten Wertstoffgesetz werden eine Reihe von Veränderungen hinsichtlich Aufkommen, Behandlung und Verbleib von Abfallströmen einhergehen.

Insbesondere ist von folgenden Entwicklungen auszugehen:

- Anstieg der Mengen in Anlagen zur stofflichen Verwertung mit R2-R12-Status
- Erhöhung der getrennt erfassten Bioabfallmengen und deren Vergärung, Kompostierung und Biomasseverbrennung, Mehrmengen werden dabei aber voraussichtlich nur zum geringeren Teil aus dem Restabfall stammen
- Rückgang der Erst-Anlieferung von primären gemischten Rest-Siedlungsabfällen (20 03 01) an MVA und MBA-Anlagen
- Verstärkte Erfassung und Sortierung/Aufbereitung von wertstoffhaltigen Abfallgemischen
- Anstieg von Sortier-/Aufbereitungsresten und EBS-Mengen (191210 und 191212 Sekundärabfälle)
- Bei künftig erhöhter Verpflichtung zur Vorsortierung/Vorbehandlung der primären Siedlungsabfälle wird die Anlieferung von 20er-Abfällen bei MVA stärker abnehmen als bei MBA

Bezogen auf den vorhandenen Anlagenbestand an MBA und MVA hat der Rückgang der Anlieferung von gemischten Siedlungsabfällen folgende Konsequenzen:

- Anlagenauslastung ist nur durch Annahme von Sekundärabfällen, ggf. auch durch verstärkte Abfallimporte sicherzustellen oder/und
- Kapazitätsabbau von Anlagen zur Behandlung von Rest-Siedlungsabfällen

Entscheidend für die Beurteilung der Situation und die zukünftige Entwicklung bei den Rest-Siedlungsabfällen ist deren Mengenentwicklung im Verhältnis zu den Behandlungskapazitäten. Dabei ist davon auszugehen, dass sich die erwarteten bundesweiten Entwicklungstrends regional unterschiedlich stark ausprägen.

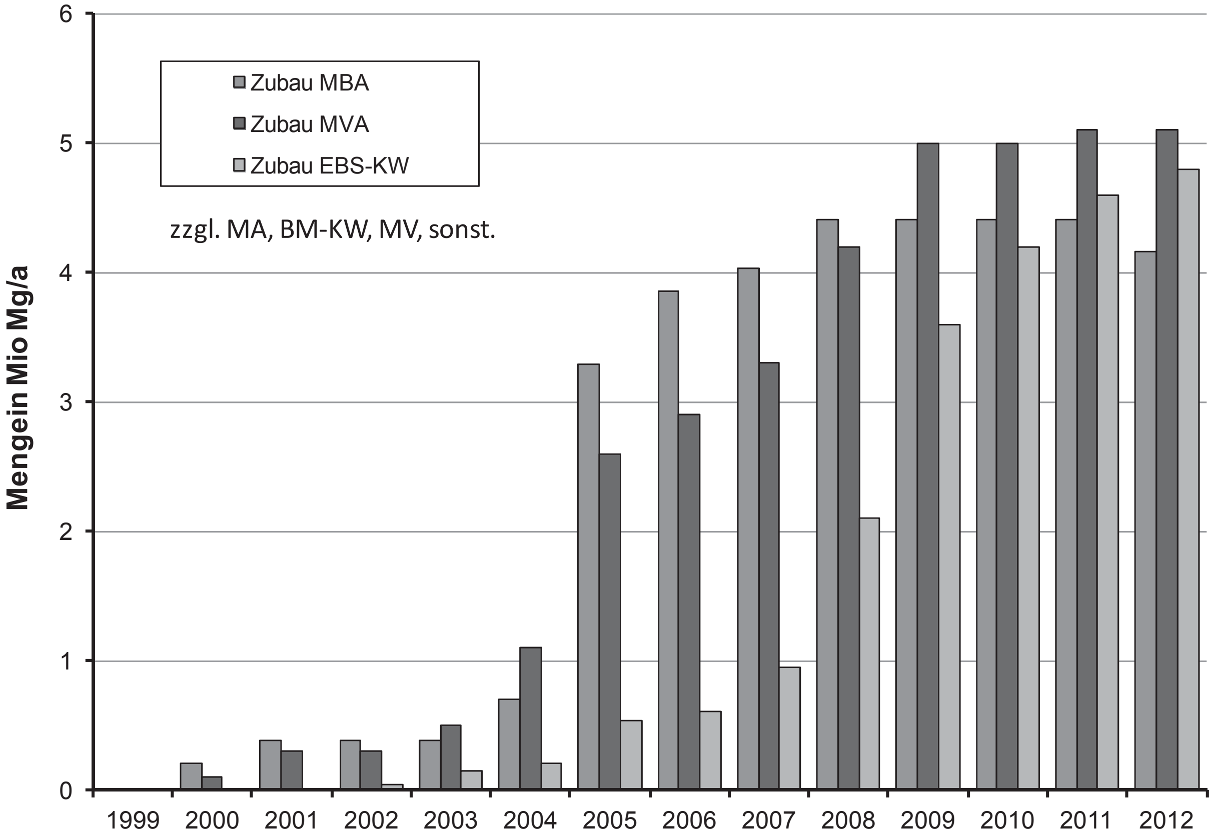


Abbildung 9 Zubau von Behandlungskapazitäten von MBA, MVA und EBS-KW seit 1999 in Deutschland (kumuliert; Bezug: EBS aus Siedlungs- und Gewerbeabfall, nach ASA, ITAD, Prognos, Thiel + eigene Abschätzung)

Durch den Anstieg der Behandlungskapazitäten von MBA, MVA und EBS-KW um ca. 12 Mio Mg/a in den letzten 10 Jahren stehen in Deutschland mittlerweile Vorbehandlungskapazitäten (MBA+MA) von 7,5-9,0 Mio. Mg/a sowie Verbrennungskapazitäten (MVA, EBS-KW, Biomasse-KW, Mitverbrennung) von 28-33 Mio. Mg/a zur Verfügung (Tab. 2, Abb. 9).

Tabelle 2 Gegenüberstellung von Siedlungsabfallaufkommen und Behandlungskapazitäten in Deutschland 2012

	Mio Mg/a	Anteil	Bemerkung
Abfallpotenzial	49,8	100 %	Siedlungsabfall gesamt
davon getrennt erfasst zur stofflichen Verwertung	**28,7**-(32,5)	58 %	(bzw. Menge zur stoffl. Verwertung in R2-R12 Anlagen n. Destatis)
Rest-Siedlungsabfall zur Behandlung	(17,3)-**21,1**	42 %	Primärabfälle zzgl. 19er Abfälle aus Behandlungsanlagen
Ziel KrWG 2020	< 17,5	≤ 35 %	bei effektiver RQ von 65%
Behandlungskapazitäten für Siedlungsabfall und EBS			
MBA	5,0-5,5		inkl. Behandlung von Bioabfall
MA	2,5-3,5		zzgl. Aufbereitungsanlagen für Sperrmüll und Straßenkehricht
Summe Vorbehandlung	**7,5-9,0**	~ 50%	von künftiger Restmenge
MVA	20,6-22		ohne 2,7 Mio. Mg EBS-KW in ITAD-Bilanz
EBS-Kraftwerke	4,8-6,3		nur EBS aus Siedlungs-/Gewerbeabfall
Biomasse-Kraftwerke	> 1 bis >2		Altholz aus Siedlungsabfall, z. B. aus Sperrmüll
Mitverbrennung (MV)	2-3		Kohlekraft- und Zementwerke
Summe Verbrennung	**28-33**	~ 180%	von künftiger Restmenge

Die Anlagenkapazität für MA wird nach einer Untersuchung der BGS e.V. auf 89 Anlagen mit bis zu 4,7 Mio. Mg/a abgeschätzt, Kühle-Weidemeier stellte für 2007 einen Anlagenbestand von 26 Anlagen mit einer Kapazität von 3,5 Mio. Mg/a fest. Die o.g. Kapazität beschränkt sich bei aller Unsicherheit über den aktuellen Anlagenbestand auf den Siedlungsabfall.

Diesen standen in 2012 Rest-Siedlungsabfälle zur Behandlung in einer Größenordnung von 17,3-21,1 Mio. Mg gegenüber. Das gesamte Aufkommen an Siedlungsabfall betrug 2012 ca. 49,8 Mio. Mg, davon wurden 58 % (28,7 Mio. Mg) mit dem Ziel einer stofflichen Verwertung getrennt erfasst. Zusätzlich wurden ca. 3,8 Mio. Mg an gemischten Siedlungsabfällen in Anlagen mit Verwerterstatus R2-R12 angeliefert. Daraus resultiert eine Rest-Siedlungsabfallmenge von 21,1 Mio. Mg (real und entscheidend für Anlagenbedarfsbetrachtung) bzw. 17,3 Mio. Mg (statistisch nach Destatis) (vgl. Ketelsen, 2012).

Allein die vorhandenen Verbrennungskapazitäten liegen schon derzeit deutlich über die verfügbaren Mengen an Rest-Siedlungsabfällen. Bei einer Steigerung der Recyclingquote auf reale 65 % entsprechend den Vorgaben des KrWG würde sich dieser Wert bis 2020 auf ca. 180 % erhöhen, sofern keine Kapazitäten aus dem Markt genommen werden. Rückläufige Mengen von primären Rest-Siedlungsabfällen werden also zunehmend zu Kapazitätsüberhängen bei den hierauf ausgelegten Behandlungsanlagen führen.

Eine Anlagenauslastung ist hierbei nur durch Erhöhung der Annahme von Sekundärabfällen (Abfälle aus Behandlungsanlagen), Abfallimporten oder Reduzierung der Anlagenkapazitäten zu erzielen.

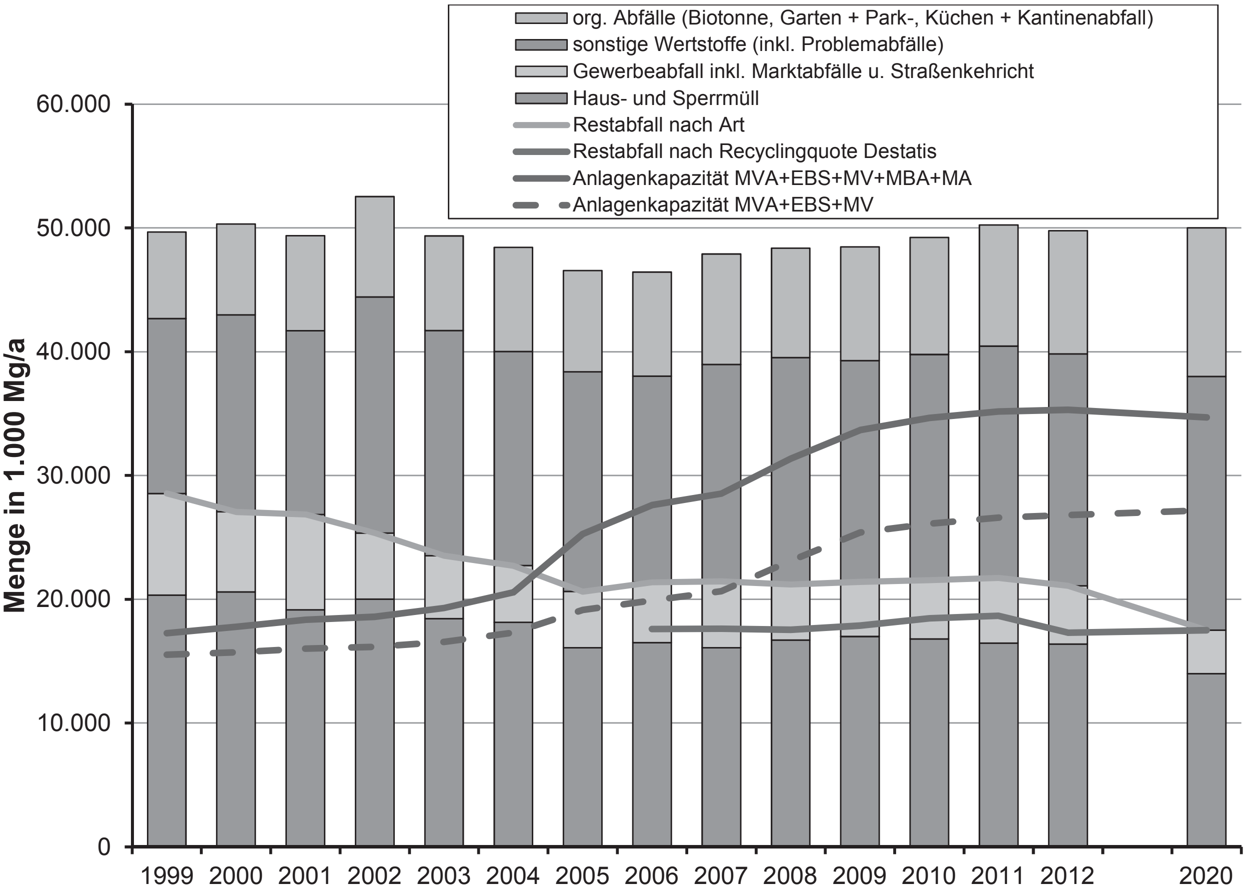


Abbildung 10 Entwicklung der Siedlungsabfallmengen nach Destatis sowie Abschätzung zu den Restabfallmengen und Behandlungskapazitäten

Die erwartete Entwicklung bei den Abfallströmen und die vorhandenen Überkapazitäten werden allgemein folgende Konsequenzen für Vorbehandlungs- und Verbrennungsanlagen haben:

- Abbau von Kapazitäten durch Stilllegung von Anlagen
- Verdrängung von MVA und MBA zu Gunsten von MA und EBS-Kraftwerken
- Ausnutzung freier Kapazitäten durch Abfallimporte
- Umnutzung von MVA und MBA (Umstellung auf Biomasse, Klärschlamm, Bioabfall etc.)

Inwieweit eine Zuweisung von ÖRE zu bestehenden Anlagen in der Region (Beispiel AWK NRW) und interkommunale Kooperationslösungen eine über die Region bzw. den Einzelfall hinausgehende langfristige Wirkung bei allgemein sinkenden Restabfallmengen haben werden, bleibt abzuwarten.

Die Optimierung der Wirtschaftlichkeit der Anlagen mit MBA-Technologie ist vor dem Hintergrund der aktuellen Rahmenbedingungen am Entsorgungsmarkt mit den Überkapazitäten im Bereich der thermischen Abfallbehandlung ein zentrales Thema. Die Überkapazitäten haben in den letzten Jahren zu einem erheblichen Preisverfall geführt. Diese Situation wird sich nur langsam entspannen. In diesem Spannungsfeld müssen sich auch die Anlagen mit MBA-Technologie behaupten.

Die spezifischen Behandlungskosten inklusive der Reststoffentsorgung der meisten Anlagen mit MBA-Technologie werden von der Auslastung der Anlage und maßgeblich von der Entwicklung der Kosten für die Stoffströme beeinflusst. Die Möglichkeiten zur Beeinflussung der Gesamtbehandlungskosten sind für jede Anlage mit MBA-Technologie anders und hängen von den jeweiligen spezifischen Rahmenbedingungen ab. Der Vorteil einer Anlage mit MBA-Technologie z. B. im Vergleich zu einer MVA liegt in der aktuellen Situation darin, dass die Anlagen mit MBA-Technologie die Stoffströme quantitativ und qualitativ beeinflussen können, was im Einzelfall auch zu einer verbesserten Wirtschaftlichkeit führt.

Für die Weiterentwicklung von MBA sind in Abhängigkeit von den jeweiligen Rahmenbedingungen an den Standorten insbesondere folgende Ziele von Bedeutung:

- Ressourcen- und klimaschonende Abfallbehandlung mit hoher Energieeffizienz
- Erhöhung der Energieeffizienz von MBA und der Gesamtverfahren
- Steigerung von Qualitäten und Mengen zur stofflichen Verwertung
- Qualitätserhöhung EBS mit Gütesicherung SBS
- Reduzierung der Deponierung auf inerte Abfallbestandteile
- Nutzung der Verfahrenskomponenten in der MBA für andere Abfälle

Die vorhandene Vielfalt der stoffspezifischen Abfallbehandlung wird sich dabei als Vorteil für die erforderlichen Anpassungen in der Abfallwirtschaft erweisen.

3.2 Prognosen und Entwicklungstendenzen

Auf Basis der erwarteten Entwicklung von Abfallmengen und weiteren Rahmenbedingungen wurden zuletzt mehrere Prognosen zum Anlagenbedarf in Deutschland nach 2020 erstellt.

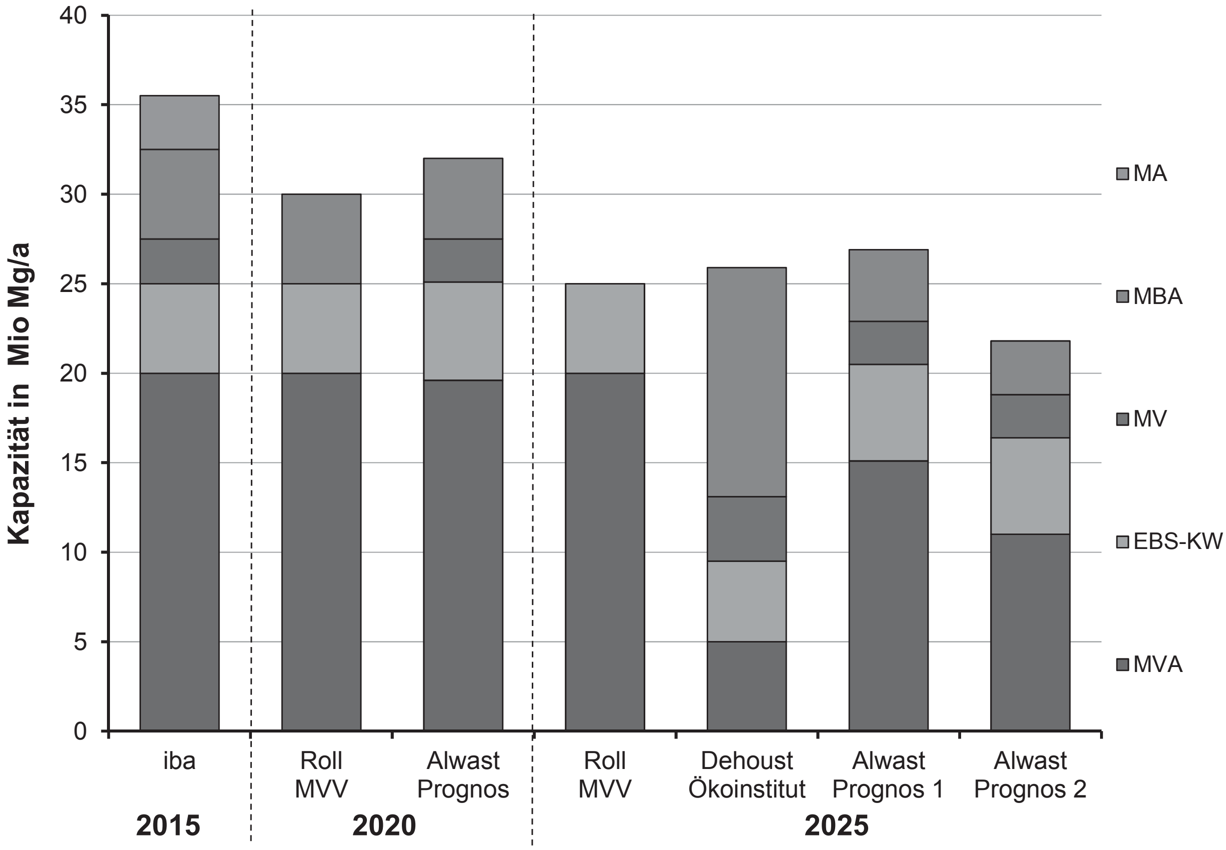


Abbildung 11 Prognosen zum Anlagenbedarf bzw. Anlagenbestand für die Behandlung von Siedlungsabfällen und EBS nach 2020

Gemeinsam sind den Prognosen eine mehr oder weniger starke Abnahme der Gesamtbehandlungskapazitäten sowie relativ stabilen Verhältnissen bei EBS-KW. Die prognostizierten Veränderungen bei MBA und MVA fallen je nach Sichtweise der Autoren jedoch höchst unterschiedlich aus. Für MVA reichen die Szenarien für 2025 von einem vollständigen Erhalt der Kapazitäten (100 %) bis zu einem Rückgang um ca. 15 Mio. Mg/a auf ca. 25 % der derzeit vorhandenen MVA-Kapazität. Die MBA-Kapazitäten könnten aus Sicht der verschiedenen Autoren auf 80, 60 oder 0 % zurückgehen oder auch um ca. 7,5 Mio Mg/a steigen.

Eigene Auswertungen der Tendenzen und Entwicklungen aus den letzten Jahren ergeben folgenden Ausblick auf die MBA-Kapazitäten in 2020:

Die klassischen MBA mit Rotte und Vergärung werden an Bedeutung verlieren. Dabei werden Verfahren ohne Vergärung von dem Rückgang wahrscheinlich stärker betroffen sein als Verfahren mit Vergärung. Mit dem Rückgang der klassischen MBA ist jedoch kein gleichartiger Rückgang von Anlagen und Behandlungskapazitäten verbunden. Wenn auch wenige Einzelanlagen bis 2020 stillgelegt werden, so wird bei den meisten MBA durch Umstellung des Betriebes auf biologische Trocknung, durch Reduzierung des Betriebs auf die mechanische Aufbereitung und durch Behandlung von Bioabfall die verfügbare Anlagenkapazität im MBA-Bereich nur geringfügig abnehmen. In Summe wird nach aktueller Kenntnislage für MBA bis 2020 von einem geringen Kapazitätsrückgang um 5-10 % ausgegangen. Für die Kapazitäten von MA Monoanlagen wird ein Rückgang in ähnlicher Größenordnung abgeschätzt.

Im Vergleich dazu gehen Alwast (2012 und 2014) und Dehoust et al., 2014 in ihren Prognosen davon aus, dass sich nach den Anforderungen des KrWG bei MBA über kurz oder lang die Stabilisierungsverfahren (MBS, MPS) durchsetzen und Verfahren mit Endrotte in Deutschland vollständig verschwinden werden.

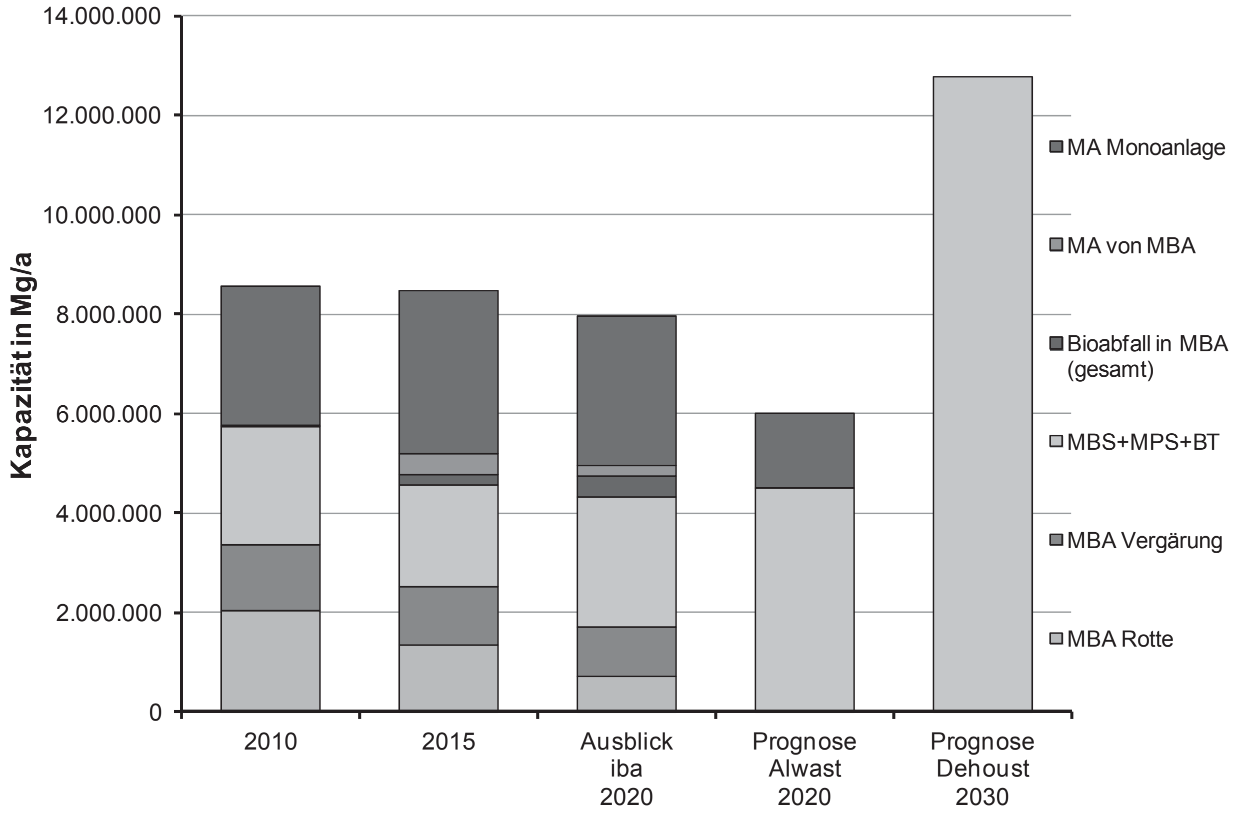


Abbildung 12 Erwartete Kapazitätsentwicklung bei MBA/MBS/MPS/MA in Deutschland

Den Extremszenarien anderer Autoren steht die bestehende Vielfalt und das Potenzial zur Optimierung, Weiterentwicklung und ggf. Umnutzung der bestehenden Verfahren u. a. mit folgenden Handlungsoptionen entgegen:

- Optimierung des Energiemanagements und Reduzierung des Energieverbrauchs
- Erhöhung der Fe- und NE-Auslese sowie Verbesserung der Qualität der Metallfraktionen
- Verstärkter Einsatz von sensorgestützter Sortiertechnik zur Abtrennung von Fraktionen zur stofflichen Verwertung, sofern der Nachweis der Verwertbarkeit gelingt

- Behandlung von „trockenem Restabfall“ oder Trocknung von Restabfall in der MBA
- Qualitätsverbesserung der EBS-Fraktionen (Heizwert, Wasser- und Aschegehalt) in Abhängigkeit von Anforderungen der Abnehmer (bisher nur Qualitätssicherung SBS)
- Erzeugung von Energie durch Vergärung und Biogasverstromung in BHKW
- Aufbereitung von Biogas zu Bioerdgas und Einspeisung ins Netz
- Verstärkte Einbindung abfallwirtschaftlicher Standorte in die Energieversorgung, z. B. durch Bereitstellung von Regelenergie über Biogas oder Biomasse
- Biologische Trocknung der organikhaltigen Feinfraktion und von Gärresten mit Erzeugung einer biogenen EBS-Fraktion
- Reduzierung der zu deponierenden Mengen auf den mineralischen Anteil (Sand, Steine, Scherben)
- Alternative Verwertung von Biomasse und EBS

In Verbindung mit einer offensiven Herangehensweise und vorausschauenden Planung bestehen somit gute Gründe und eine solide Basis für eine optimistische Prognose zur Entwicklung der stoffspezifischen Abfallbehandlung mit MBA.

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Energieeffizienz in MBS Anlagen

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Inhaltsangabe

Der Zweckverband Abfallbehandlung (ZAB) Nuthe-Spree betreibt am Standort Niederlehme im neunten Jahr eine Anlage zur Behandlung von Restabfällen nach dem Prinzip der mechanisch-biologischen Stabilisierung (MBS). Ziel der Aufbereitung ist die Herstellung unterschiedlich konfektionierter Brennstoffe durch eine Kombination von biologischer Trocknung und mechanischer Aufbereitung. Die MBS-Anlage verfügt über eine genehmigte Kapazität von 135.000 Mg/a.

Nach einer kurzen Vorstellung der MBS Anlage des ZAB werden die einzelnen Prozessstufen im Hinblick auf die Qualität der Outputstoffströme näher erläutert.

- Biologische Behandlung/Trocknung
- Mechanische Aufbereitung
- Abluftbehandlung
- Stoffströme

Weiterhin werden folgende Themenkomplexe näher behandelt:

- Energieeffizienz in MBS Anlagen
- Betriebserfahrungen einer Trockenstabilatanlage
- Erfüllung der Anforderungen der verschiedenen Verwerter (Wirbelschicht, Co-Verbrennung in Braunkohlekraftwerken, Rostfeuerung)
- Konfektionierung von SBS (Trocknung, Zerkleinerung, Pelletierung)

Abstract

The ZAB Nuthe Spree is located in Niederlehme about 40 Km from Berlin city center. In the plant municipal waste is processed in a mechanical biological stabilisation treatment.

The Aim of the treatment process is the production of different qualities RDF and minimising the material stream to landfill in a combination of biological drying process and mechanical treatment. The capacity of the plant is 135.000 ton/year.

Processing of The MBS plant:

- biological treatment/ drying process
- mechanical treatment
- air treatment
- mass balance

Further informations about the MBS process at the ZAB plant:

- Energy efficiency in MBS plants
- Operational plant experiences of the MBS process
- Meeting the requirements of different utilizing processes (fluidised bed incineration, utilization in lignite-fired power plants, grate incinerators)
- Tailoring-steps for RDF (drying, shredding, pelletizing)

Keywords
Energieeffizienz, Energiemanagement, biologische Trocknung, MBS

1 Die MBS Nuthe-Spree

1.1 Herkunft der Restabfälle

Der Zweckverband Abfallbehandlung (ZAB) Nuthe-Spree betreibt am Standort Niederlehme eine Anlage zur Behandlung von Restabfällen nach dem Prinzip der mechanisch-biologischen Stabilisierung (MBS). Die Anlage hat eine Behandlungskapazität von 150.000 Mg/a. Behandelt werden die Abfälle von rund 460.000 Einwohnern aus dem Verbandsgebiet (siehe Abbildung 1).

Abbildung 1 Verbandsgebiet des Zweckverbands Abfallbehandlung (ZAB) Nuthe-Spree

1.2 Verfahrensbeschreibung der MBS-Anlage des ZAB

Trockene Abfälle (Gewerbeabfall, Sperrmüll) werden in einem Flachbunker angeliefert, vorsortiert, zerkleinert und gelangen dann entweder in den Tiefbunker oder werden als EBS vermarktet. Die Anlieferung von Hausmüll und hausmüllähnlichen Abfällen erfolgt direkt in den Tiefbunker. Die Abbildung 3 zeigt den Tiefbunker mit dem automatischen Kransystem.

Der Abfall wird mit zwei automatisierten Kransystemen zunächst einer Zerkleinerung und dann der biologischen Trocknung in Rotteboxen zugeführt. Der Rotte- und Trocknungsprozess erstreckt sich in der Regel über sieben Tage in einem Temperaturbereich von 50 bis 60 °C. Die im Abfall enthaltene Feuchtigkeit geht dabei in den Luftstrom über, der das Rottegut ständig von unten nach oben durchströmt. Durch Kühlung mit Wärmetauschersystemen außerhalb der Rotteboxen kondensiert die Feuchtigkeit des Luftstroms. Das Kondensat wird biologisch-mechanisch gereinigt und als Kühl- und Prozesswasser wieder eingesetzt bzw. abgeleitet.

Die nachfolgende trockenmechanische Sortierung trennt den zuvor in verschiedene Korngrößenklassen aufgeteilten Abfall mittels Dichtetrenntechnik in leichte, brennbare und schwere, inerte Bestandteile auf. Zusätzlich werden aus allen relevanten Stoffströmen Eisen- und Nichteisenmetalle abgeschieden. Die Abbildung 2 zeigt vereinfacht die wesentlichen Aufbereitungsschritte.

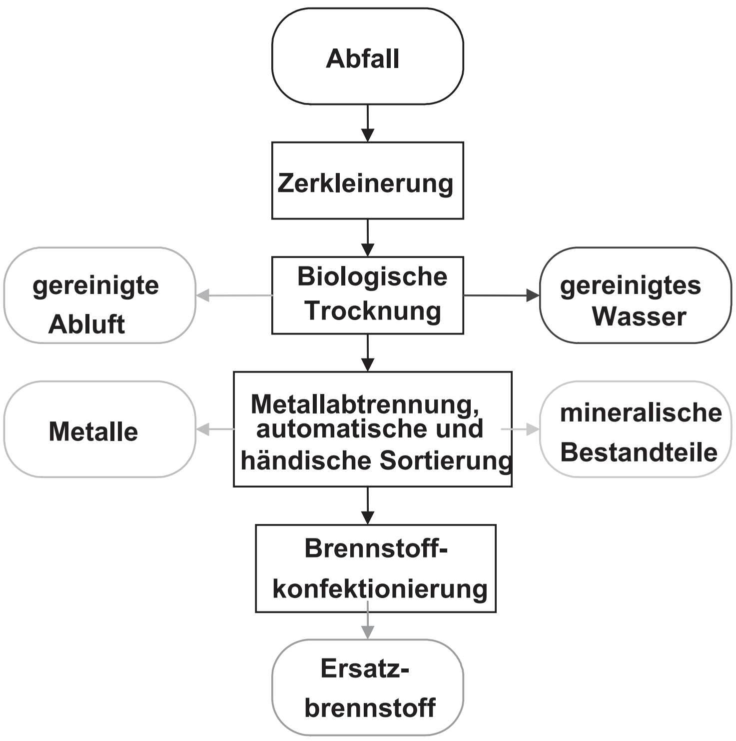

Abbildung 2 Wesentliche Aufbereitungsschritte der MBS-Anlage des ZAB

Die gewonnene Leichtfraktion (Ersatzbrennstoff) kann als loses Schüttgut verladen oder angekollert („Softpellet“) bzw. pelletiert („Hartpellet“) für die energetische Verwertung konfektioniert werden.

1.3 Produkte

Mit der installierten Anlagentechnik können Brennstoffqualitäten in einer relativ großen Bandbereite hergestellt werden:

- vorzerkleinerte Abfälle, maximale Korngröße 300 mm für den Einsatz in Industriekraftwerken
- Brennstoff aus Hausmüll, Sperrmüll, Gewerbemüll mit unterschiedlichen Heizwerten
- unterschiedlich konfektionierter Brennstoff

Die Tabelle 1 enthält eine Darstellung möglicher Brennstoffqualitäten (Korngröße und Schüttdichte).

Tabelle 1 Brennstoffqualitäten, Beispiele

Typ	Fluff	angekollerter Brennstoff	Softpellets	Hartpellets
Körnung (mm)	0 - 45	0 - 22	0 - 22	0 - 22
Schüttdichte (kg/m³)	130	250 - 300	350 - 450	650

1.4 Angepasste Aufbereitung der erzeugten Brennstoffe

Durch die Kombination von Flach- und Tiefbunker und eine an trockene und nasse Restabfälle angepasste Aufbereitungstechnik ist es möglich unterschiedliche Qualitäten an Ersatz- und Sekundärbrennstoffen zu produzieren. Die produzierten Brennstoffe unterscheiden sich dabei vor allem hinsichtlich der folgenden Eigenschaften:

- Stückgröße
- Schüttdichte
- Heizwert
- Aschegehalt
- Schadstoffgehalt

Die Abbildung zeigt die in der MBS-Anlage vorhandenen Möglichkeiten für eine angepasste Aufbereitung.

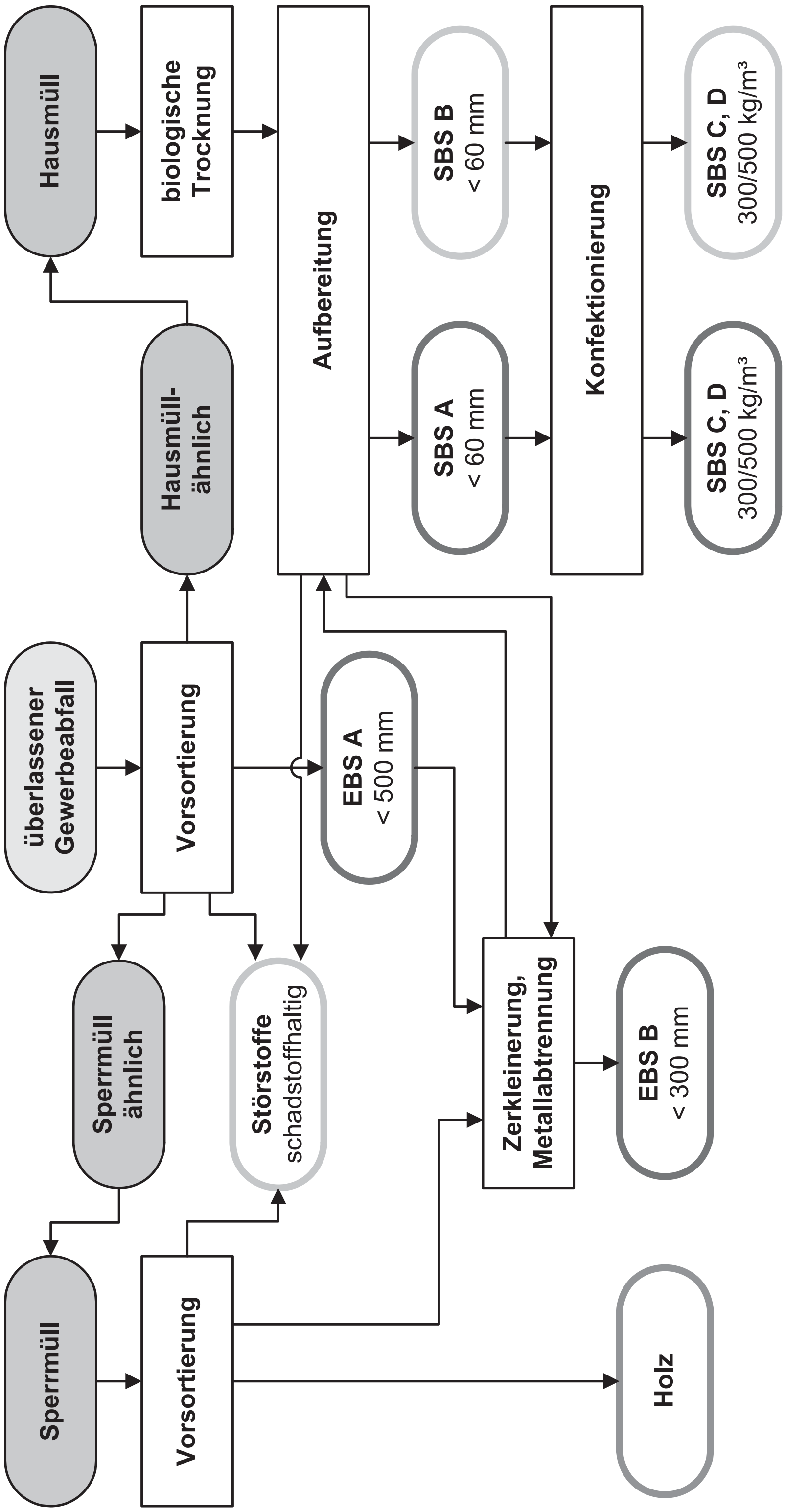

Abbildung 3 In der MBS-Anlage vorhandene Möglichkeiten für eine angepasste Aufbereitung

2 Energieeffizienz in MBS Anlagen

Die nachfolgende Abbildung zeigt die grundsätzliche Herangehensweise zur Erfassung bzw. Optimierung des gesamten Prozesses aus energetischer Sicht.

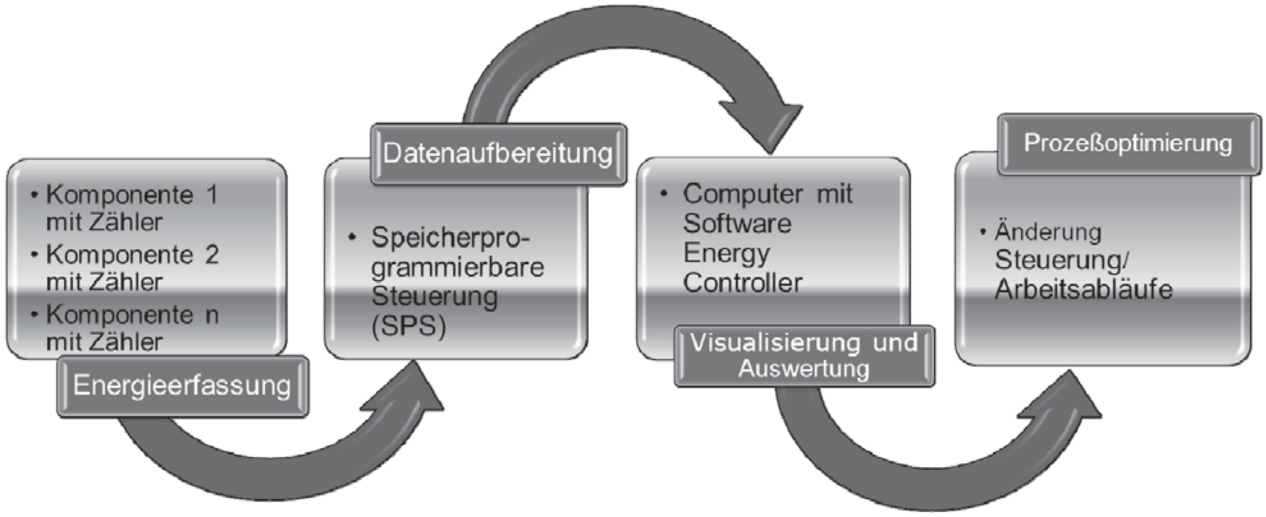

Abbildung 4 Prinzip der Energieerfassung/ Prozessoptimierung

Nachdem alle Hauptprozessstufen über Zähler aufgenommen worden sind, ist das Energieflussdiagramm die Grundlage für Ansätze zur energetischen Optimierung.

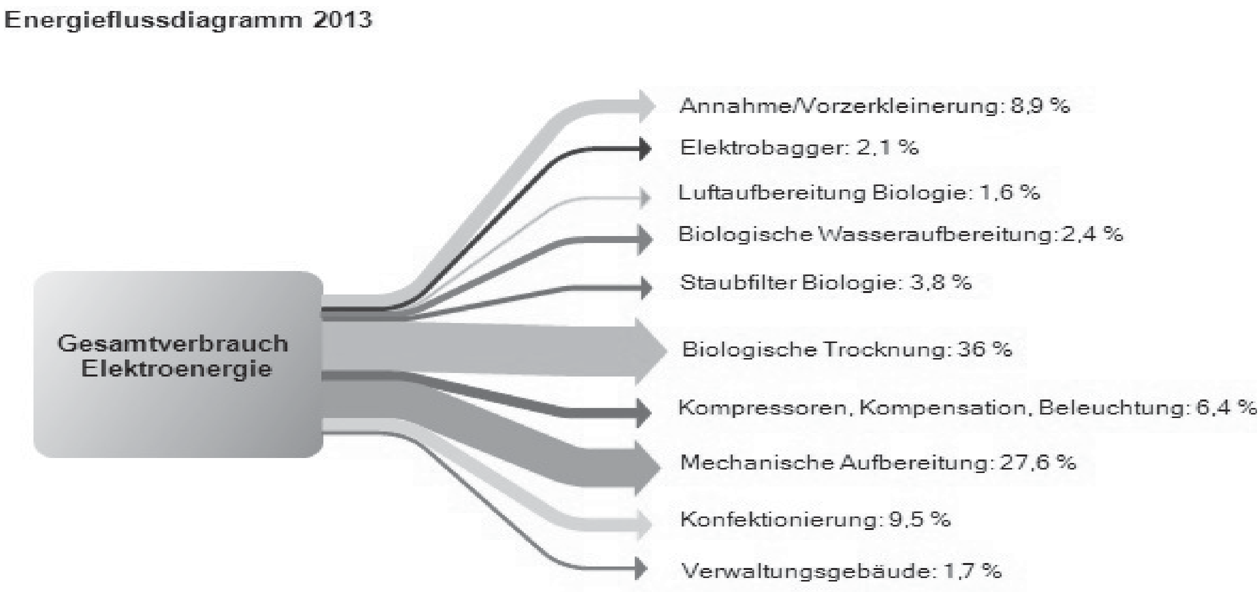

Abbildung 5 Energieflussdiagramm Elektroenergie

Nach der Visualisierung des Energieverbrauches konnte der Energieverbrauch zum Zeitpunkt der Einführung der Software innerhalb eines Jahres um 15 % gesenkt werden. Die Senkung des Energieverbrauches wurde ausschließlich durch Prozessoptimierungen, und Anpassung von Wartungszyklen im Bereich der Vorzerkleinerung, biologischen Trocknung, Nachzerkleinerung und Pelletierung erreicht.

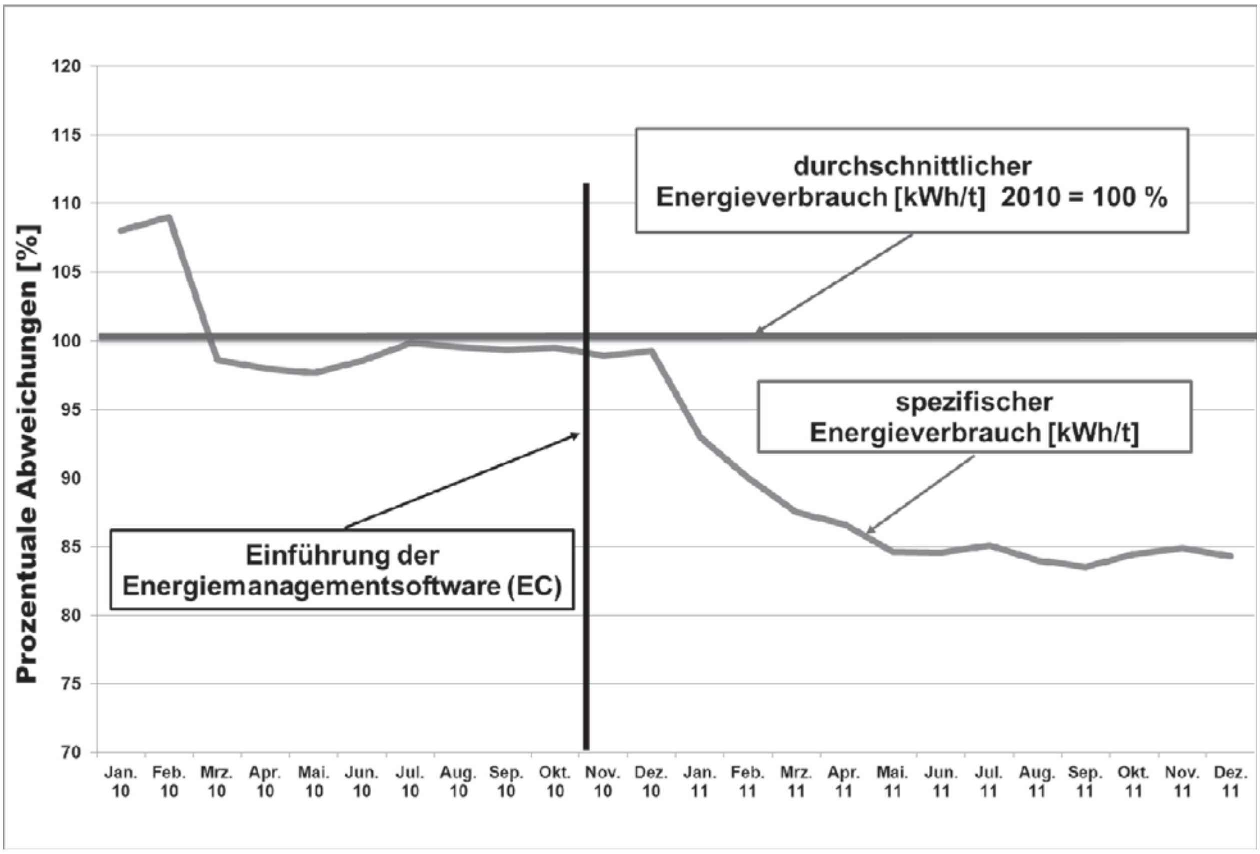

Abbildung 6 Senkung des Elektroenergieverbrauchs nach Einführung der Energiemanagementsoftware

Mittlerweile liegt der spezifische Elektroenergieverbrauch um ca. 25 % niedriger als vor der Einführung der Energiemanagementsoftware.

Nachfolgende Optimierungsmaßnahmen sind beispielhaft aufgeführt:

- Reduzierung der biologischen Trocknungszeit um 25%
- Verkürzung von Filterlaufzeiten für die biologische Trocknung
- Abluftbehandlungsmenge der biologischen Trocknung um 50 % reduziert
- Ultrafiltration der Wasseraufbereitung auf Intervallbetrieb umgestellt
- Anpassung des Reinigungszyklus für Wärmetauscher und Kühltürme
- Änderung der Siebe an der Vorzerkleinerung, Nachzerkleinerung, Pelletierung
- Einstellung der energetisch optimalen Feuchte für die mechanische Aufbereitung
- Feinkornabtrennung vor der Konfektionierung
- Minimierung der Leerlaufzeiten bzw. des Teillastbetriebes
- Optimierung der automatischen Filterreinigung
- ….

Nach der Installation zusätzlicher Gaszähler für die einzelnen RTO Linien konnte der direkte Zusammenhang zwischen Abluftmengen, Druckverlust und der Temperatur in der RTO- Brennkammer in Bezug zum Gasverbrauch ausgewertet und anschließend optimiert werden. Durch Änderung der Steuerung des Rotteprozesses und Senkung der Temperatur in der Brennkammer, bei gleichzeitiger Einhaltung der Emissionsgrenzwerte, konnte der Gasverbrauch drastisch reduziert werden.

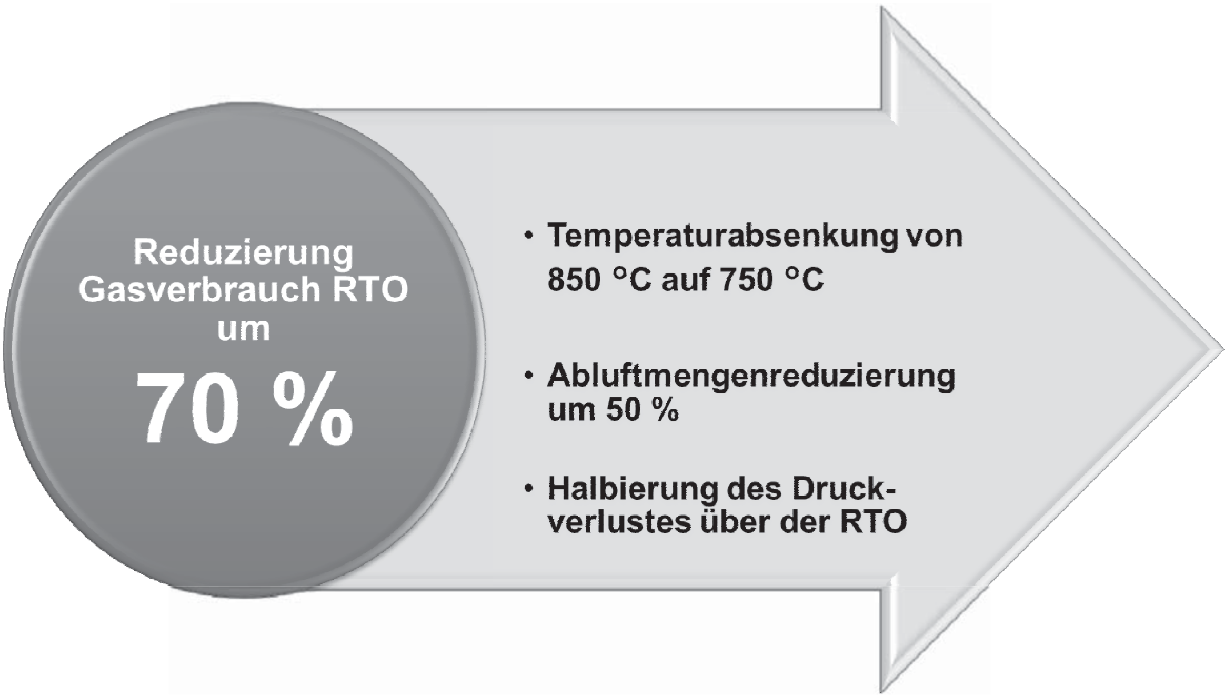

Abbildung 7 Senkung des Gasverbrauchs an der RTO

Der ZAB ist seit dem Jahr 2012 ISO 50001 zertifiziert und bildet seit der Einführung den Rahmen für alle Energieeinsparmaßnahmen.

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Optimierte biologische Trocknung für eine stabile EBS-Qualität – Erfahrungen aus der MBA Neumünster

Ralf Ketelhut

Stoffstromdesign Ralf Ketelhut, Sortierkontor, Neumünster

Optimized biological drying for a stable quality of RDF

Abstract

The municipal utilities of Neumünster run a MBT plant which produces an annual capacity of 150.000 Mg of RDF from around 150.000 Mg/a residual waste, 32.000 Mg/a bulky waste and around 60.000 Mg/a high calorific waste.

After the comminution of the household waste fraction to < 80 mm as well as parts of the bulky waste fraction < 50 mm, the substance undergoes biological drying in a static reactor. The goal is to reach a water content of 20 per cent by weight within a drying period of 21 days. Although the drying process and the quality of the RDF have been improved continuously, quality fluctuations concerning the materials' moisture content still occur.

Due to the intensive supervision of the air management during the process of drying for a period of four month, it is now possible to control the process of drying even in a static reactor by employing a targeted air management.

Inhaltsangabe

Die MBA Neumünster GmbH betreibt eine Mechanisch Biologische Abfallaufbereitungsanlage, in der aus einem Input von jährlich rund 150.000 Mg Hausmüll, ca. 32.000 Mg Sperrmüll und ca. 60.000 Mg heizwertreichen Abfällen eine Masse von ca.150.000 Mg Ersatzbrennstoff hergestellt wird.

Das aufgeschlossene Hausmüll-Unterkorn < 80 mm sowie Anteile des Sperrmülls < 50 mm werden einer biologischen Trocknung im statischen Reaktor unterzogen, bei der innerhalb eines Zeitraums von 21 Tagen ein Wassergehalt von 20 Masse% erreicht werden soll. Trotz kontinuierlicher Maßnahmen bei der Optimierung der Trocknung und nachweisbarer Erfolge bei der Verbesserung der Qualität des Ersatzbrennstoffes kommt es immer noch zu Qualitätsschwankungen hinsichtlich der Materialfeuchte.

Nachdem die Trocknungsprozesse im Hinblick auf das Luftmanagement über mehrere Monate intensiv begleitet worden sind, eröffnen sich nun Möglichkeiten, auch statische Trocknungsprozesse durch gezieltes Luftmanagement zu kontrollieren.

Keywords

MBA, biologische Trocknung, statischer Reaktor, Ersatzbrennstoff, Qualitätssicherung

MBT, biological drying, static reactor, RDF, quality management

1 Einleitung

Die MBA Neumünster GmbH betreibt in Neumünster eine Mechanisch-Biologische Abfallaufbereitungsanlage mit einer Gesamtkapazität von rund 250.000 Mg Input. Überschlägig werden folgende Inputmengen jährlich verarbeitet:

Tabelle 1 Überschlägige jährliche Inputmengen der MBA Neumünster

Material	Inputmenge [Mg/a]	Massenanteil [Masse%]
Hausmüll	150.000	62%
Sperrmüll	32.000	13%
Heizwertreiche Abfälle	60.000	25%

Für die heizwertreichen Abfälle steht eine separate Brennstoffaufbereitung zur Verfügung, die die Korngröße des Materials definiert sowie Wertstoffe (Metalle) und Störstoffe (Mineralik) abtrennt.

Der Hausmüll wird im ersten Schritt einer Zerkleinerung unterzogen und dann in einer Siebtrommel bei einem Trennkorn von 80 mm in ein heizwertreiches Überkorn und ein Unterkorn mit hohem Wassergehalt getrennt. Der Sperrmüll wird auf einer separaten Linie nach einer Zerkleinerung mit einem Trennkorn von 50 mm abgesiebt. Das Hausmüllunterkorn sowie fakultativ zumischbare Anteile des Sperrmüllunterkorns werden von magnetisierbaren Metallen gereinigt und dann in einem statischen Reaktor mit einer Grundfläche von 30 m * 6,5 m zu einer Füllhöhe von ca. 2,5 m aufgesetzt.

Abbildung 1 Statischer Trocknungsreaktor

Die Anlage ist als „BIODEGMA®"-Rottesystem in geschlossenen semipermeablen Zeltplanen gebaut worden, hat aber im Laufe des Betriebes seit 2005 verschiedene bauliche Veränderungen erfahren. Das nach wie vor gültige Grundprinzip der Trocknung beruht auf einer druckbelüfteten Rotte, bei der über vier in den Boden eingelassenen Zuluftstränge mittels Ventilatoren Luft in die Schüttung gepresst wird. Gleichzeitig wird der Luft oberhalb der Miete kontinuierlich abgesaugt. Der biologische Abbau des organischen Materials in der Miete erwärmt den Mietenkörper wie auch die durchströmende Luft, so dass mit der erwärmten Abluft Wasser ausgetragen und so eine Trocknung des Materials erreicht werden kann.

2 Vorliegende Messdaten

2.1 Wassergehalt

Aus kontinuierlichen Messungen des Wassergehaltes in Input und Output sind unter Berücksichtigung der zweifachen Standardabweichung folgende Messdaten bekannt:

- Wassergehalt im Input: 43,6% +/- 5,3% CV = 0,06
- Wassergehalt im Output: 18,5% +/- 7,4% CV = 0,20

Der Zielwassergehalt von 20 Masse% wird demnach im Mittel erreicht. Der Wassergehalt im Output schwankt jedoch mehr als drei Mal so stark wie im Input, so dass in 34,6% aller Prozesse der Wassergehalt oberhalb von 20% liegt.

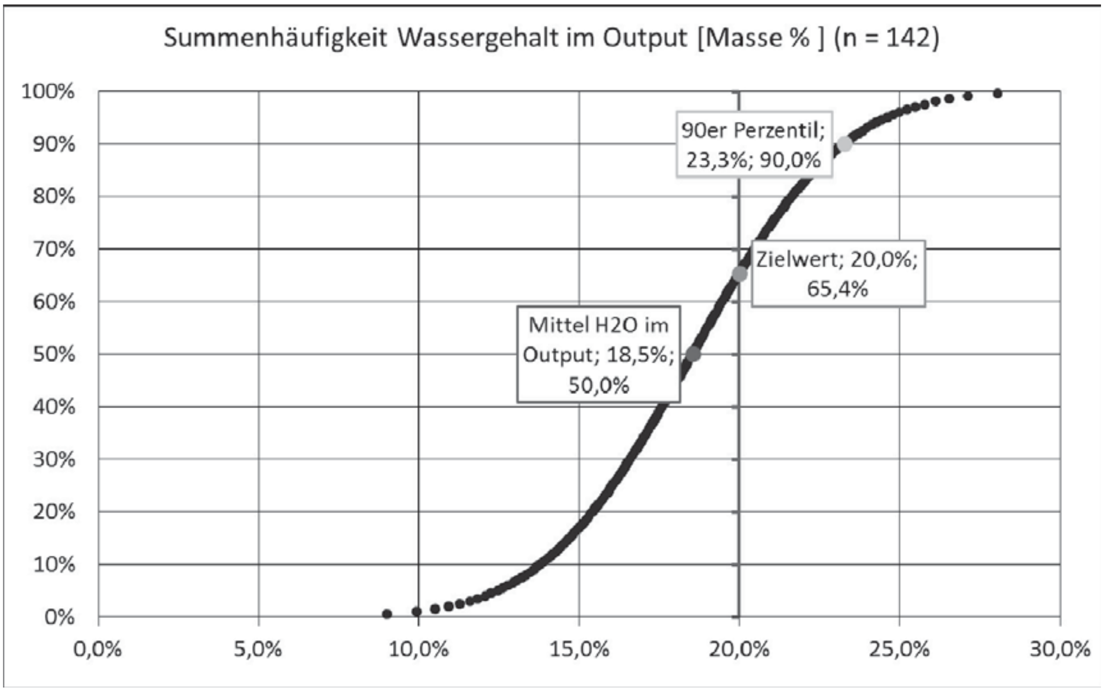

Abbildung 2 Summenhäufigkeit für den Wassergehalt im Trocknungsoutput [Masse%]

Trotz relativ stabiler Eintragsbedingungen gelingt es offensichtlich nicht, den Zielwert sicher zu erreichen, so dass jeder zehnte Trocknungsprozess auf Wassergehalte oberhalb von 23,3 Masse% führt. Hohe Wassergehalte im Output können sich nachteilig auf die nachgeschaltete Brennstoffaufbereitung und damit die EBS-Qualität auswirken.

2.2 Gütebewertung der Trocknungsprozesse

Über die Messung des Feuchtegehaltes hinaus erfolgt eine Gütebewertung der Trocknungsprozesse. Grundlage sind visuelle Eindrücke über das Material, die unter Radladerfahrern und Prozessverantwortlichem abgestimmt werden.

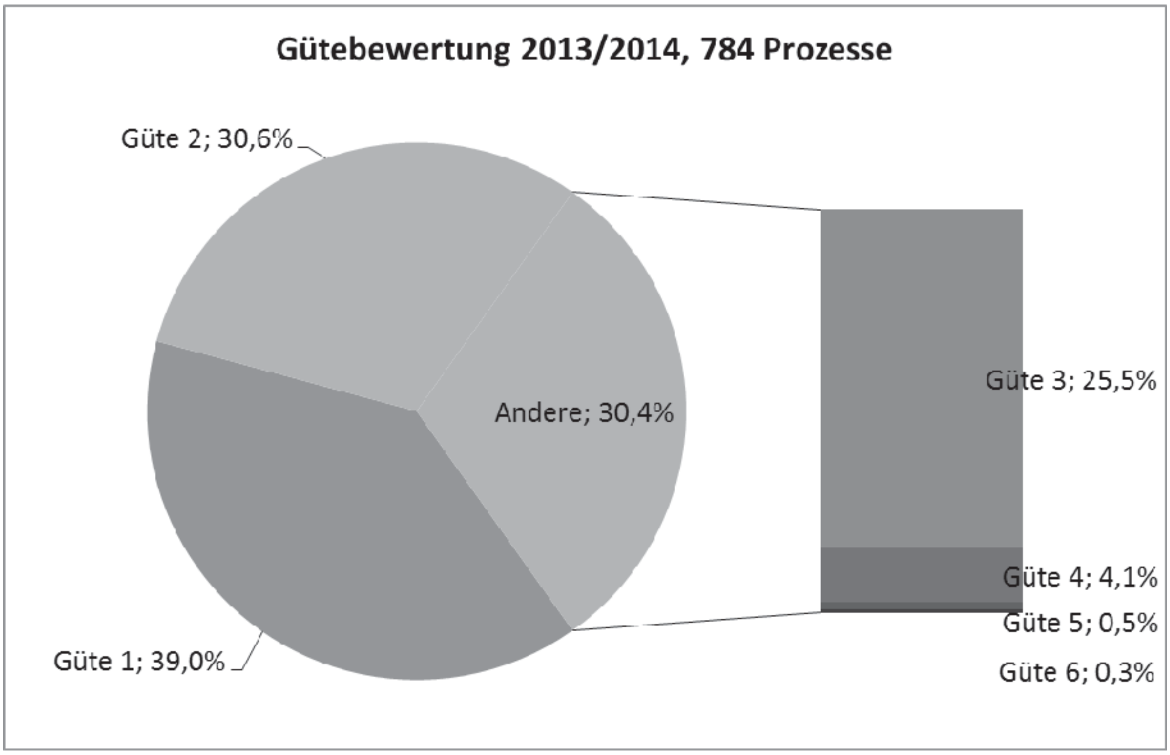

Abbildung 3 Gütebewertung von 784 Prozessen in Trocknungsreaktoren 2013 und 2014

Die Übersicht zeigt, dass weit überwiegend gute bis sehr gute Ergebnisse erreicht werden. Auch die Güte 3 wird als akzeptabel angesehen. Nur jeder 20. Prozess zeigt eine Güte, die schlechter ist als 3.

2.3 Einfluss der räumlichen Lage

Um Hinweise über einen möglichen Einfluss der räumlichen Lage der Reaktoren auf das Trocknungsergebnis zu prüfen, sind die Bewertungen von insgesamt 784 Trocknungsprozessen in 48 Reaktoren unter räumlichen Aspekten ausgewertet worden. Die nachfolgende Abbildung veranschaulicht die Lage der 10 „besten“ sowie der 10 „schlechtesten“ Reaktoren:

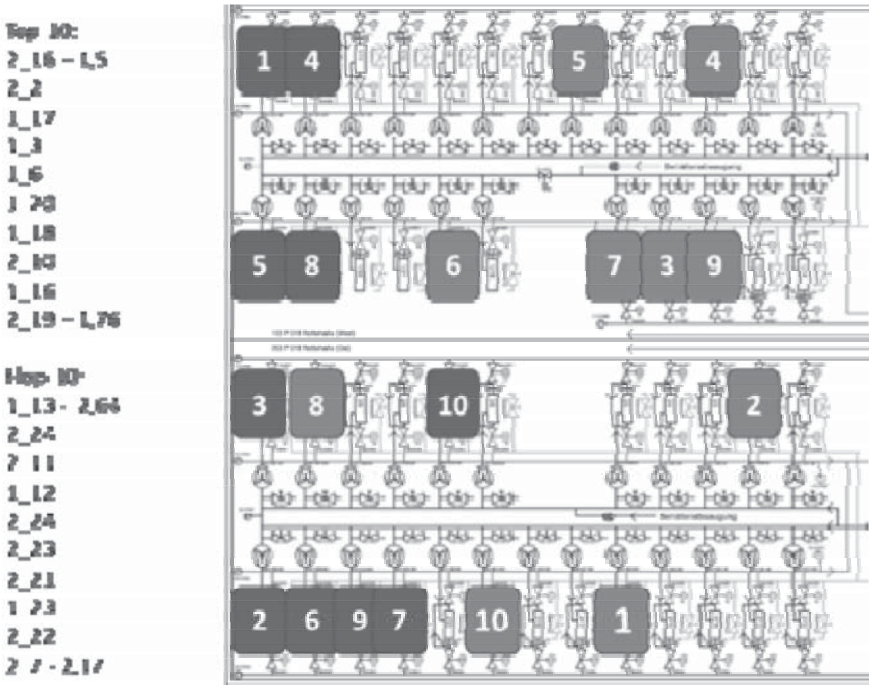

Abbildung 4 Lokalisierung der 10 „besten“ (grün) sowie der 10 „schlechtesten“ (rot) Trocknungsreaktoren 2013 und 2014

Die Abbildung erhärtet den Verdacht, dass das Trocknungsergebnis von der räumlichen Lage der Reaktoren abhängig ist. Die schlechteren Module liegen vornehmlich an den auf der linken Seite gelegenen Strangenden des Abluftsystems.

3 Prozessbilanz

Beim durchgeführten Prozess handelt es sich um eine biologische Trocknung im statischen Reaktor. Die Wärmeenergie aus dem aeroben Abbau leicht abbaubare Abfallbestandteile wird zur Trocknung des Materials eingesetzt. Der Prozess ist in Bezug auf das Wasser ambivalent, denn einerseits ist das Wasser zum biologischen Abbau notwendig, andererseits soll es bei der Trocknung ausgetrieben werden. Für die Bilanzierung derartiger Reaktoren steht mit der Dissertation von Bartha eine aussagekräftige Grundlage mit interessanten Modellrechnungen zur Verfügung (Bartha 2008). Die dort vorgestellten Bilanzierungen sollen hier in vereinfachter Form übertragen werden.

Ein durchschnittlich aufgesetztes Modul auf der MBA Neumünster umfasst ca. 260 Mg Materialeintrag. Für den Austrag ist ein mittleres Gewicht von 165 Mg ermittelt worden. Der Wassergehalt liegt 2014 im Mittel bei 43,6%. Die Standardabweichung beträgt 2,6%. Im Rahmen der zweifachen Standardabweichung muss daher mit einer eingetragenen Wasserfracht von 113 +/- 13 Mg pro Modul gerechnet werden. Im Austrag wird in 2014 ein Wassergehalt von 18,5% (+/- 20%) ermittelt. Überträgt man diese Daten in eine Prozessbilanz, so zeigt sich folgendes Bild:

Tabelle 2 Bilanz des mittleren Trocknungsprozesses

Mittlerer Prozess	Gewicht [Mg]	H_2O-Konz Mittel [%]	H_2O-Fracht Mittel [Mg]	TS Mittel [Mg]
Materialeintrag	260,0	43,6%	113,3	146,7
Materialaustrag	165,0	18,5%	30,6	134,4
Delta Trocknung	-95,0		-82,7	-12,3

Gemäß der Bilanz verliert das Material im Mittel ca. 95 Mg an Gewicht. Da aus dem Abbau der Biomasse ca. 600 g Wasser pro kg organischer Substanz entsteht, ist in Bezug auf das abzuführende Wasser davon auszugehen, dass während des Prozesses eine Gesamtwassermenge von ca. 90 Mg Wasser abgeführt werden muss. Dafür stehen der Luftweg oder aber der Wasserweg zur Verfügung. Der Wasserpfad hat sich bei durchgeführten Messungen jedoch als nahezu irrelevant erwiesen.

3.1 Wasseraustrag über den Luftpfad

Die Module werden von unten zwangsbelüftet. Unter idealen Bedingungen strömt von unten kalte und relativ trockene Luft ein, die auf dem Weg durch das Modul erwärmt wird und bis zur Sättigungsgrenze Wasser aufnimmt. Aus der Ablufttemperatur und dem entnommenen Volumenstrom kann daher auf die maximal abgeführte Wassermenge zurückgeschlossen werden.

Die Wassermenge in gesättigter Luft steht über Wasserdampftafeln und Berechnungsmodule zur Verfügung. TLV (TLV 2013) gibt für den Wassergehalt gesättigter Luft folgende Zusammenhänge an:

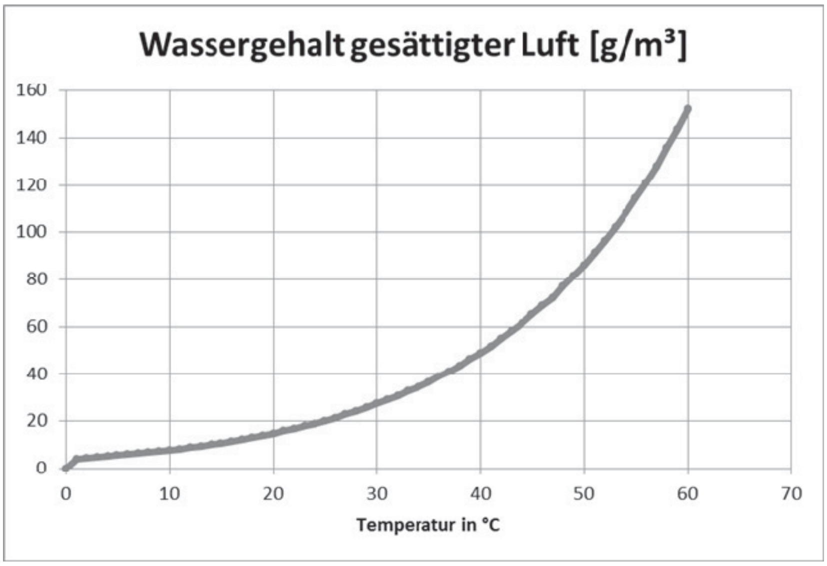

Abbildung 5 Wassergehalte gesättigter Luft [g/m³] Quelle TLV 2013, eigene Darstellung

Weiterhin ist zu berücksichtigen, dass die den Reaktoren zugeführte Luft aus einer Mischung von Maschinenhallenabluft anderer Betriebsbereiche und zurückgeführter Umluft aus den Modulen besteht, die bereits eine Primärbeladung an Wasser aufweist. Eine Wasserabfuhr kann daher nur im Rahmen der „Ladekapazität" der Luft vor dem Hintergrund der Temperaturbedingungen erfolgen. Die Temperatur der zugeführten Luft ist in Abhängigkeit von Produktionsbedingungen und Außentemperatur erheblichen Schwankungen unterworfen, die sich auf die Trocknungsleistung auswirken.

Die tatsächliche Trocknungsleistung eines einzelnen Reaktors bestimmt sich aus den Temperaturbedingungen, die sich auf Luftdichte und „Ladekapazität" für Wasser auswirken, sowie dem realisierten Abluftvolumenstrom.

4 Onlineparameter und Steuerungsmöglichkeiten

Nachdem die Trocknungsreaktoren von Hand verschlossen worden sind, werden die Prozesse von der Warte aus gesteuert. Die Belüftung der Reaktoren kann über drehzahlgeregelte Ventilatoren für jeden Reaktor separat geregelt werden. Hier hat sich aus Basiseinstellung und Erfahrungswerten ein über die Prozessdauer gesteuertes Programm eingespielt. Für die Prozesssteuerung stehen darüber hinaus verschiedene Parameter zur Verfügung, die in erster Linie die Lufttechnik betreffen.

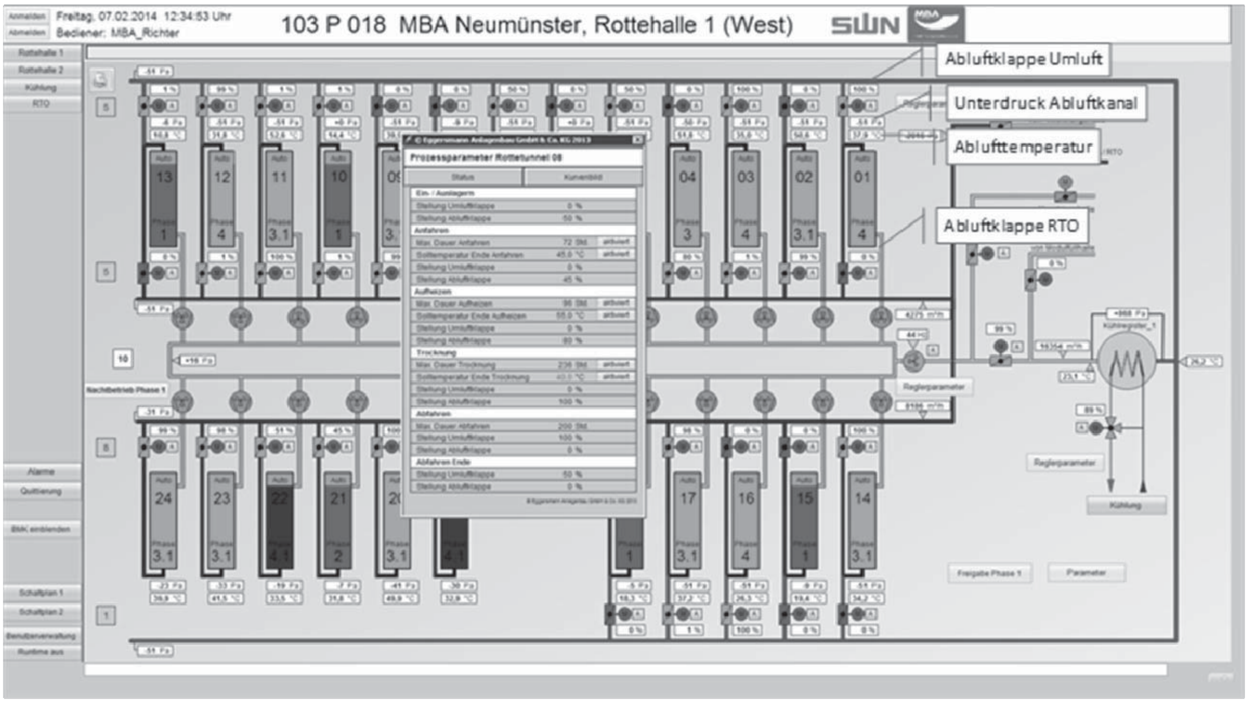

Abbildung 6 Steuerungsbildschirm Zuluft / Abluft

Die Reaktorabluft kann wahlweise zur Abgasreinigung mittels Regenerativ Thermischer Oxidation (RTO) abgesteuert werden oder aber im Umluftkreis gehalten werden. Im Umluftkreislauf erfolgt eine Wasserabscheidung im Kühlregister. Zur Prozessüberwachung stehen Onlinedaten zum Unterdruck in den Abluftkanälen der Reaktoren sowie zur Ablufttemperatur zur Verfügung. Die Volumenströme werden lediglich in den Sammelsträngen gemessen. Die Möglichkeiten zur Prozesssteuerung beschränken sich im Wesentlichen auf die Regulierung der Zuluftventilatoren sowie der Klappenöffnung der Module.

4.1 Auswertung der Prozessdaten

Die aus den Onlinemessungen zur Verfügung stehenden Prozessdaten sind über einen Zeitraum von 111 Tagen erfasst und evaluiert worden. In Bezug auf die einzelnen Reaktoren liefert dabei lediglich die Temperaturmessung aussagefähige Werte, da die Unterdruckmessung einen zu geringen Messbereich aufweist, der keine relevanten Zustandsänderungen offenbart. Messbar ist lediglich, ob ein Unterdruck < 50 Pa ansteht.

Aus den Ablufttemperaturmessungen können dagegen wertvolle Hinweise über den Prozessverlauf gewonnen werden. Die nachfolgende Abbildung zeigt die mittlere Ablufttemperatur der Reaktoren über den Prozesstag inklusive der einfachen Standardabweichung. Dargestellt sind die Verläufe vor (bis 23. Okt) und nach versuchter Optimierung der Prozesssteuerung (SSD):

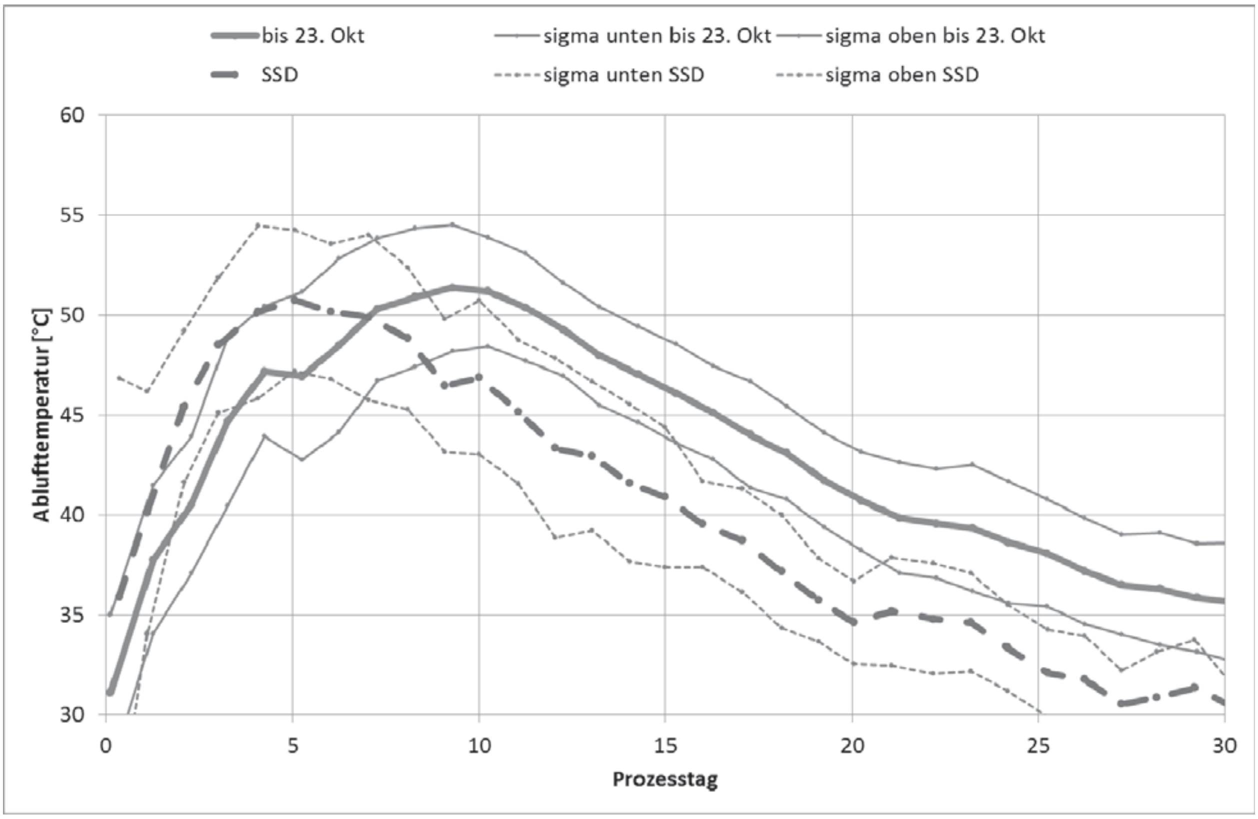

Abbildung 7 Mittlere Ablufttemperaturen über Prozesstag inklusive der einfachen Standardabweichung

Die Abbildung zeigt, dass Ablufttemperaturen oberhalb von 50°C, die eine hohe Trocknungsleistung bedeuten, nur über relativ kurze Zeiträume aufrechterhalten werden können. Die versuchte Optimierung der Prozesssteuerung führte zu einem schnelleren Aufheizen, war aber nicht in der Lage, hohe Ablufttemperaturen über längere Zeiträume zu gewährleisten. Als Hintergrund wird vermutet, dass sich die Zuluft in frühen Prozessstadien Wege durch den Schüttkörper sucht, die im Trocknungsverlauf beibehalten werden. Eine Trocknung von Bereichen abseits der Luftwege kann dann nur noch im Rahmen von Diffusionsprozessen erfolgen. Diese These wird von Kerntemperaturen untermauert, die deutliche Temperaturprofile in den Reaktoren ausweisen. Die Ablufttemperaturen korrespondieren mit den kühleren Bereichen.

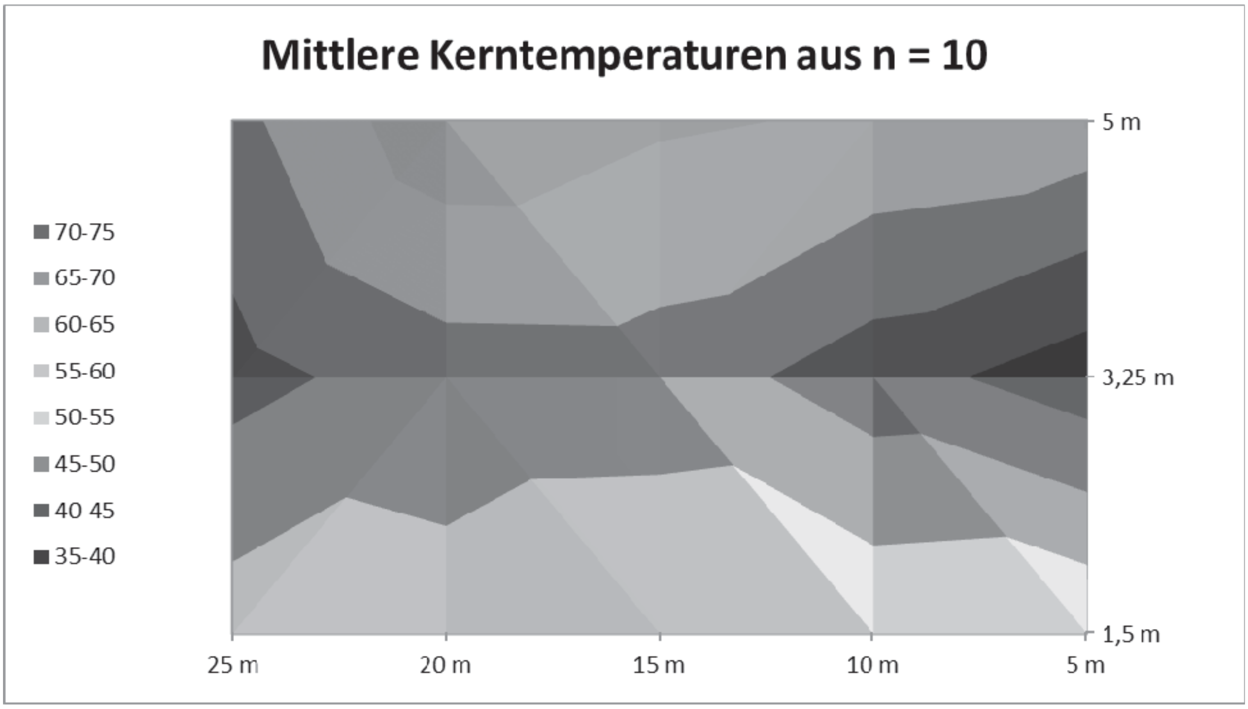

Abbildung 8 Mittlere Kerntemperaturen aus 10 Messungen im Trocknungsgut am 21. Prozesstag

4.2 Ergänzende Messungen im Abluftsystem

Um die in den Reaktoren realisierten Abluftvolumenströme definieren zu können, sind an mehreren Messtagen Bilanzmessungen durchgeführt worden, die jeweils in kompletten Abluftsträngen stattgefunden haben. Dabei zeigten sich gegenüber den auf der Basis der Inputvolumenströme berechneten Planmengen deutliche Abweichungen.

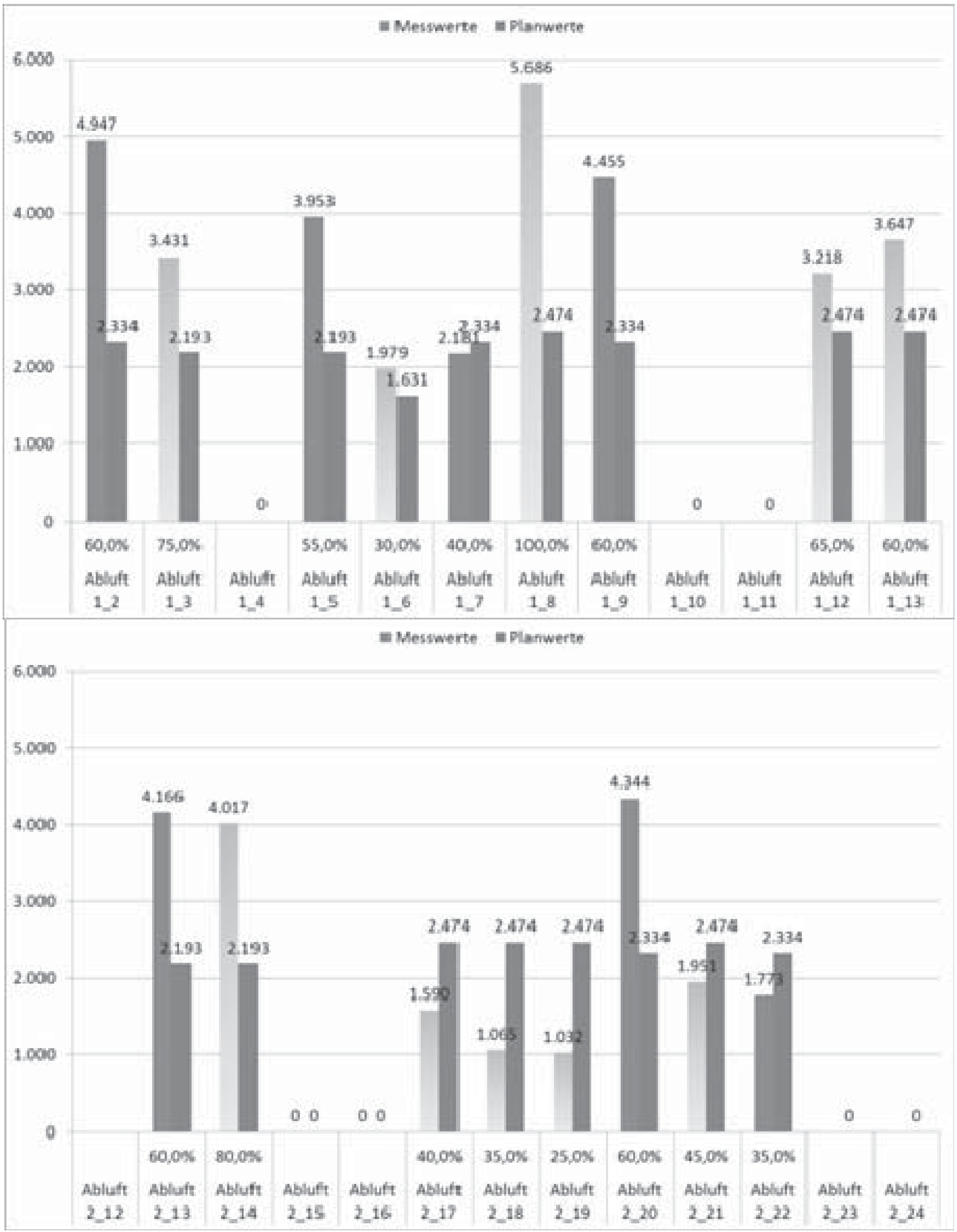

Abbildung 9 Realisierte Abluftvolumenströme und Planmengen

In einzelnen Reaktoren werden nur 40% der Planvolumina entsorgt, während sich in anderen Abluftkanälen mehr als die doppelten Planmengen wiederfinden. Die Differenzen treten sowohl in den RTO- als auch in den Umluftsträngen auf.

Da sich aus den Volumenstrom- bzw. Druckmessungen ein Zusammenhang zur Klappenstellung ableiten ließ, sind hier weitergehende Untersuchungen erfolgt. Dabei zeigte sich, dass die in den Abluftwegen anstehenden Unterdrücke und damit die realisierten Abluftvolumina in weit stärkerem Maße von der Stellung der Abluftklappen abhängen, als dies zu erwarten war. Darüber hinaus führt eine Vergleichmäßigung der Klappenstellungen zu einem Ausgleich im System und offenbart Steuerungsmöglichkeiten.

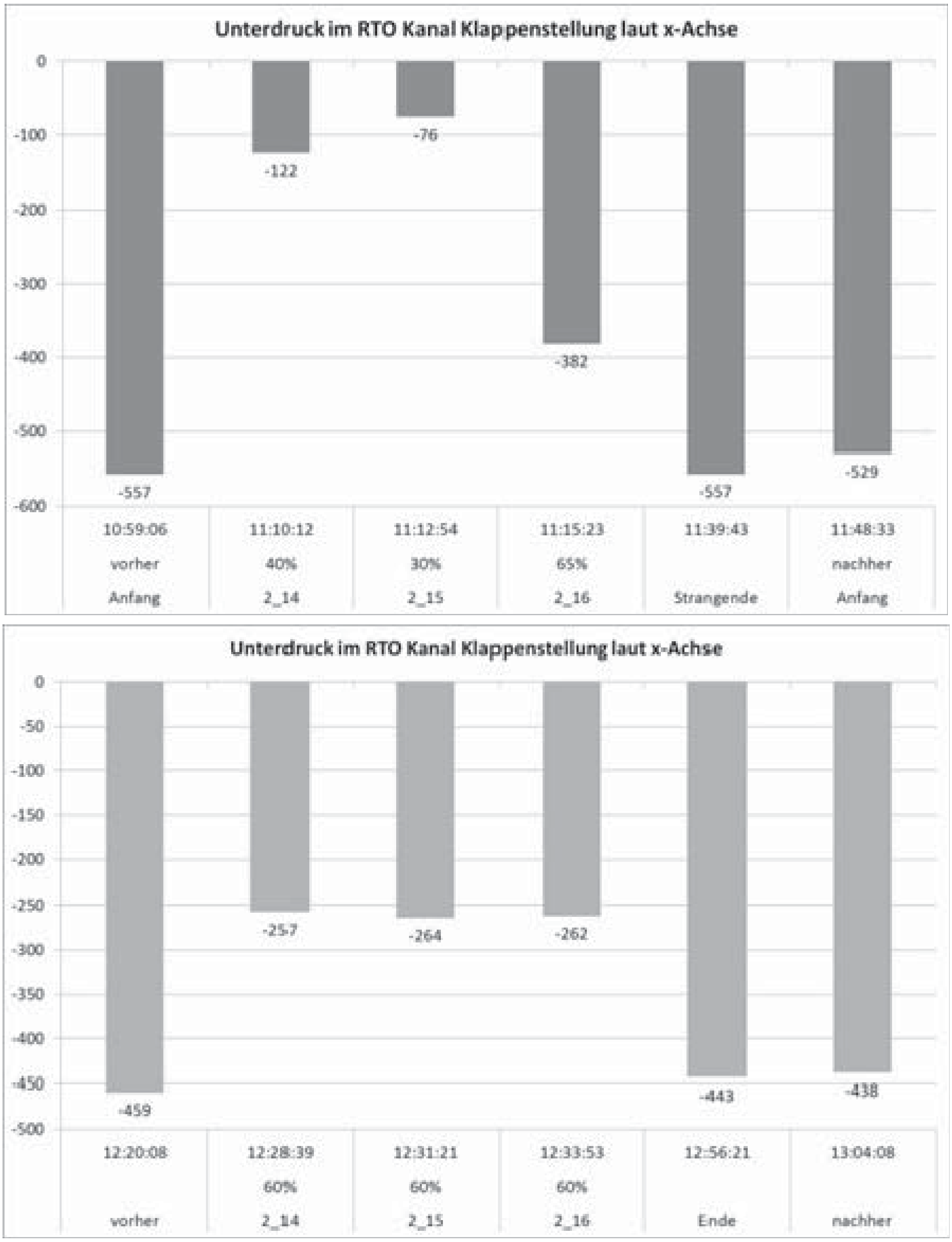

Abbildung 10 Unterdruck in Abluftkanälen vor und nach Vergleichmäßigung der Klappenstellungen

Die Steuerung der Abluftvolumina erscheint möglich, wenn die anstehenden Unterdrücke separat erfasst und mittels Abluftklappen strangweise geregelt werden.

5 Zusammenfassung

Die biologische Trocknung von Hausmüllunterkorn < 80 mm funktioniert auch im statischen Reaktor, der ohne Umsetzen des Materials arbeitet, weitgehend störungsfrei. Allerdings weisen die Austräge einzelner Reaktoren relativ hohe Feuchtegehalte auf, die sich nachteilig auf die Aufbereitung des Materials nach Trocknung und damit auch auf die Qualität des erzeugten Ersatzbrennstoffes auswirken können.

Im Zuge einer Begleitung der Trocknungsprozesse über einen Zeitraum von vier Monaten wurden Ansatzpunkte für Möglichkeiten zur Optimierung herausgearbeitet und vor allem versucht, leicht messbare und handhabbare Parameter zu identifizieren, die eine sichere Steuerung der Trocknungsprozesse in der Praxis ermöglichen.

Im Ergebnis zeigte sich, dass für eine sichere Prognose der Trocknungsleistung ggf. auf eine Bestimmung der einzelnen Abluftvolumenströme verzichtet werden kann, nicht jedoch auf die Erfassung der in den Abluftkanälen anstehenden Unterdrücke, die unmittelbar mit den realisierten Volumenströmen korrespondieren.

Die Anlage wird nun messtechnisch ertüchtigt, so dass die Aussicht besteht, in Zukunft den Austrag aller Prozesse sicher auf einen Wassergehalt von ≤ 20 Masse% zu bringen.

Der Dank des Autors gilt der Geschäftsleitung und den Mitarbeitern der MBA Neumünster GmbH für die hervorragende Unterstützung während der Arbeiten.

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Utilization of alternative fuels in substitute fuel, cement and coal-fired power plants in Germany

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Abstract

High costs for fossil fuels and climate protection cause a higher importance of co-incineration of alternative fuels in cement plants and coal-fired power plants. As alternative fuels various waste based materials are used, for example used wood, waste oil or (treated) industrial, trade and municipal wastes. The use is limited especially due to plant technology and legal emission standards. These aspects have a high influence on the markets for co-incineration in coal-fired power plants and cement plants. The following article will provide an overview of the status quo of the mentioned markets and its developments until 2020.

Content summary

Keywords

co-incineration, alternative fuels, waste, coal-fired power plants, emission, technology, substitute fuels, cement plants, markets

1 Introduction

High costs for fossil fuels and climate protection (e.g. emissions certificates) cause a higher importance of co-incineration of alternative fuels in cement plants and coal-fired power plants. Despite playing – compared to mono-incineration of wastes – a quantitative lesser role, the share of fuel use in cement plants already amounts to over 60%, with a small upward trend. Because of technical requirements this share is much smaller in coal-fired power plants. As alternative fuels in cement plants and coal-fired power plants various waste based materials are used, for example used wood, scrap tyres, waste oil, sewage sludge or (treated) industrial, trade and municipal wastes. The use is limited especially due to plant technology and legal emission standards, which the characteristics of the co-incinerated materials need to be consistent with.

The present article is primarily based on the results of the study „The market for co-incineration of alternative fuels in cement plants and coal-fired power plants in Europe until 2020“ published in 2013. Besides an overview of the current status quo concerning volume of waste, processing and use of alternative fuels in German cement plants and coal-fired power plants, a prognosis of the expected market trends until 2020 will be shown. In the scope of the potential study comprehensive research with intern and extern studies, data bases, press articles, internet and the like as well as about 60 expert interviews in the 12 researched countries (Germany, Estonia, Netherlands, Austria, Poland, Russia, Sweden, Czech Republic, Turkey, Ukraine, Hungary, United Kingdom) were carried out. The potentials of each market were calculated based on scenario and country specific assumptions, which led to differentiated results for each country. The future trends of the used quantity of substitute fuels and its prices in the cement plants and coal-fired power plants are shown in three scenarios. The reference scenario shows the most likely market trends, the other ones in contrast a more conservative or a more dynamic trend. Hereafter are shown the essential results for the German market.

2 Status quo

The volume of waste in Germany is on a relatively stable level since 1996. In 2012 were circa 381 million tons recorded, a part of this are with circa 50 million tons municipal waste and circa 54 million tons from the processing industries.

In Germany the whole municipal main waste is put into the waste treatment. Within the last decade the end of the implementation period of TASi on June 1., 2005 had a special influence on the development of the capacity of waste incineration, which forbid the landfilling of untreated biodegradable waste. At the same time the importance of thermal processing as well as the resulting energy (electricity and heat) in the utilization of waste rose. To create the needed disposal infrastructure, modern waste incineration plants (or expansion of capacity through new lines of incineration) as well as mechanical-biological waste treatment plants were built. Furthermore investments were made for the construction of refuse-derived fuel plants (RDF plant), which led to a new way of recycling especially for the high calorific value based group of treatment plants.

According to the German Federal Statistical Office (2014) circa 45 million tons of waste were thermally treated in Germany in 2012. For the first time in 2011 more waste was incinerated in thermal treatment plans than in classical waste incineration plants, triggered by the increase of RDF plants and biomass power plants.

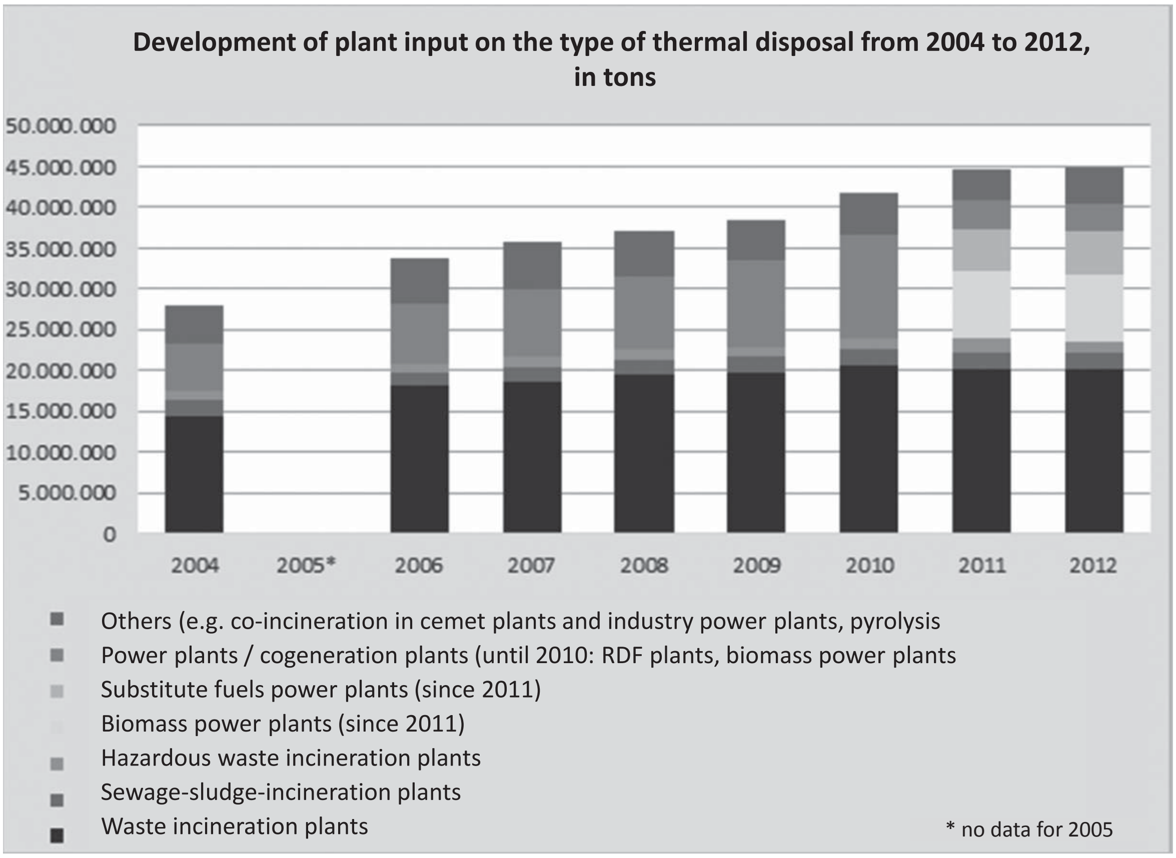

Figure 1: Development of plant input on the type of thermal disposal from 2004 to 2012, in tons (Source: trend:research, 2015 based on data from the German Federal Statistical Office, various years)

2.1 Processing of substitute fuels in waste incineration plants

Before the commencement of the prohibition of landfilling of untreated municipal waste on June 1., 2005 mechanical-biological treatment plants (MBA; German abbreviations are used) for the pre-treatment of residual waste became more important in waste management. Plants were built, which used different process setups and technical implementations.

Currently 39 MBA, MBS (mechanical-biological stabilization plant) and MPS (mechanical-physical stabilization plant) are operated in Germany with a capacity of circa 5.1 million tons per year (survey trend:research, 2014; note: combined plants are not listed as MBA but separately as MA (mechanical plant) and BA (biological plant), if they are independent plants). Around 3 million tons of these capacities consist of classic MBA, which are integrated in a landfill, a part of that are fermentation plants with circa 1 million tons and rotting plants with circa 2 million tons. Additional 2.2 million tons are installed as MBS or MPS.

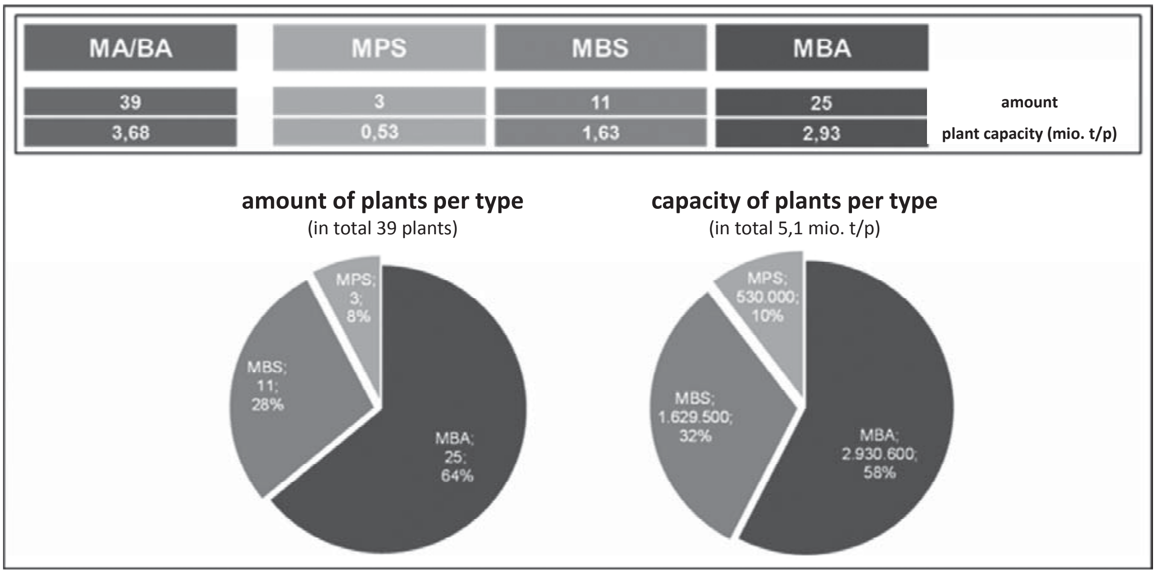

Figure 2: amount and capacity of waste treatment plants (source: trend:research, 2015, report "Future of MBA in German waste management")

The majority of todays installed MBA capacity was built from 2001 to 2005. During those years the installed capacity of MBA has increased tremendously, but after that increased only to a lesser extent. Since 2008 there were no new locations put into operation and also in the future the chances of new plants are slim. Modernization or reconstruction measures, like for example currently at the MBA Linkenbach in the county Neuwied (renewal of the intensive decomposition as well as retrofit of mechanical steps), are excluded.

In Germany MBA are mostly located at landfill sites or in close proximity and have a well-developed supply, disposal and traffic infrastructure. The production of substitute fuels is significantly affected by the respective operation site and purpose. The processing effort is always depending on the subsequent thermal process and its requirements on the fuels. Substitute fuels can generally be used in co-incineration plants (coal-fired power plants, cement plants) or in specific mono-incineration plants.

2.2 Use of alternative fuels in cement plants

In 2013 there were 22 companies with 54 plants, which produced around 31.3 million tons of cement and 23.1 million tons of clinker. The production of clinker is distributed among 34 locations, mainly located in the south of Germany and the Ruhr area. The other 20 locations are solely grinder. The necessary thermal energy demand in the cement production was sharply reduced in the last 50 years by technical progress and modernisation measures. The overall efficiency of rotary kiln reaches with over 80% a high energy efficiency. Fuels are used primarily in the burning process of cement clinker, in which the energy demand ranges between 3,500 and 3,900 kilojoule per kilogram clinker. Only a small part is used for the drying of resources or other components.

Due to the tense cost structure in the cement industry the share of substitute fuels is rising constantly to reduce costs for energy and emission certificates.

The applicable share of alternative fuels is based on the present plant technology. This concerns the roasting process itself, where by means of modern technology (e.g. calciner) a high turnover of substitute fuels can be reached, as well as the present flue gas cleaning, which dictates in compliance with legal limit values the usable amount and type of alternative fuels. In Germany the construction and operation of cement plants is regulated by the Federal Immission Control Act (BImSchG). The relevant emission limit values are set depending on the used fuels in the respective plants. The specific rules of the 17. Regulation in the Federal Immission Control Act (17. BImSchV) are applied to the use of substitute fuels. As a measuring method continuous or discontinuous methods in accordance with legally defined conditions (VDI-guideline and DIN-norms) are used. The first method is used mainly for measuring dust, NOx, SO_2 and Hg, the second for individual surveys concerning other important parameters of immission laws.

Besides technical factors the co-incineration is also affected by the availability of alternative fuels, which need to meet the quality requirements of the cement plants. These requirements are set by the plant operators and are based on the conditions of production (e.g. no effects on plant technology and product quality) as well as the legal emission limit values (Europe-wide the limit values of the Industrial Emissions Directive (IED) are significant), which possibly restrict the usable range of material. The treatment industry tries to develop uniform standards, like the RAL quality label 742 in Germany, which shall be used as a scale. According to the operators of cement plants high quality treated municipal and industry waste are easy to get in Germany.

On average, around 61% of primary fuels in Germany in 2013 were substituted (circa 3 million tons), whereas the use per plant significantly varies. Some cement plants reach over 90%, while others are significantly below the average. The used amount is determined by the demand of the construction industry, the need for cement and clinker in Germany are altogether declining.

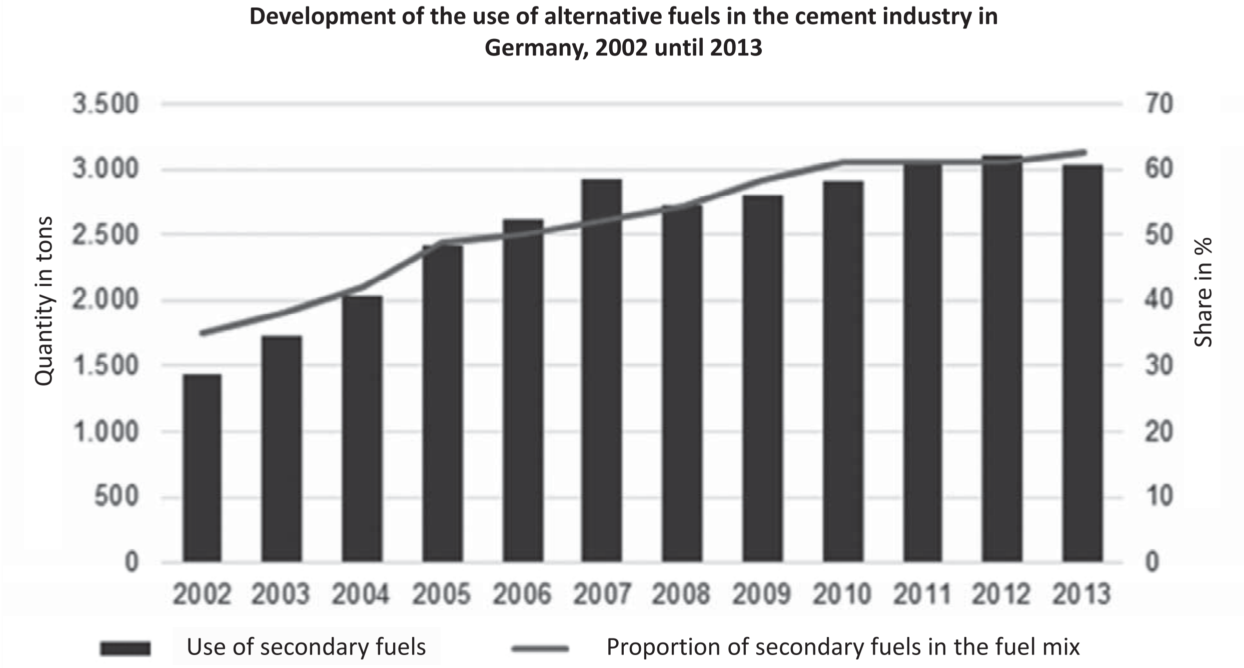

Figure 3: development of the use of alternative fuels in the cement industry in Germany, 2002 until 2013 (source: VDZ, various years)

2.3 Use of alternative fuels in coal-fired power plants

The amount of co-incineration of waste-derived materials is much smaller in coal-fired power plants. This refers both to the number of co-incinerating plants and to the share of alternative fuels on the energy use. Many coal-fired power plants forego alternative fuels, because of technical reasons (risk of corrosion) as well as the compliance of emission limit values, or they substitute only a small part of the primary fuels. Treated wastes are being used as substitutes for primary fuels in some coal power and lignite power stations, whereby the used amount constantly increased in the last years.

The main conditions for the use of substitute fuels in coal-fired power plants are financial benefits as well as a constant and uniform quality and demand meeting delivery. Substitute fuels must not impact the process inside the power station negatively, they may instead optimise the use of fuels. Concerning the co-incineration of substitute fuels coal-fired power plants are subjected to the regulations of the 17. BImSchV, which sets stricter emission limit values as those used in regular operation (then applies 13. BImSchV).

In 2010 11 German coal-fired power plants (of it 2 paper mills in Osnabrück and Oberkirch) reached together the current maximum of circa 800.000 tons of substitute fuels consisting of mixed municipal wastes and product specific industry wastes. About

78% were incinerated in lignite power stations, with the remaining 22%, incineration in coal power stations is considerably lower.

The used amount varies considerably. 91% of the used substitute fuels were incinerated in only five coal-fired power plants (Jänschwalde, Werne, Berrenrath, Flensburg and Schwarze Pumpe). The remaining 70,000 tons are divided between 6 locations. The highest amount of incinerated substitute fuels were processed by the lignite power station Jänschwalde. 8 of the 12 boiler are fired, next to the standard fuels, with substitute fuels (mainly treated municipal and industry wastes processed in MBS/MBA). Since the start of the continuous operation on average 390,000 tons were co-incinerated, the highest mark was reached in 2010 with 472,000 tons. Until 2009 there was a voluntary self-restraint of 400,000 tons per year. In middle-term it is targeted to reach 450,000 tons per year.

3 Future market trends until 2020

Germany is said to be one of the most developed countries in the area of waste management, because in the last 10 years they were successful to decouple the increase of economic performance from the waste volume. Furthermore the regulation in the EG-contract is put to use, which allows individual countries of the EU to set higher standards. Hereof benefits the domestic plant engineering industry, because they can appear on the international market as a frontrunner. The production of substitute fuels increased significantly since the implementation of the landfill ban on untreated waste in 2005. Especially in cement plants and lignite power stations alternative fuels are used to a great extent, whereas the share of substitution from primary fuels in cement plants is a lot higher than in lignite power stations.

3.1 Waste incineration plant

Because of the implementation period of TASi from 2001 to 2005 many existing MBA were extended and new ones were built to create enough treatment capacities. Since 2008 no new locations were put into operation and also in the future the prospects of a new plant construction are slim. With a regular operating time of 15 years for a lot of plants, regarding the operational reliability and disposal safety a decision needs to be made, if an investment should be made to renew the plant or to withdraw the capacity from the market. It needs to be taken into consideration that the utilization rate of some plants is heavily dependent on the available industry waste, which is often used to compensate missing municipal wastes, but at the same time subject to strong fluctuations. Over the next few years a slow decrease in municipal waste is expected, because next to the general population decline with a simultaneously increasing separating behaviour, measures were taken for waste prevention. Furthermore through introduction of the organic waste bin and the recycling bin additional volumes were brought into the utilization, therefore the amount of residual wastes could be reduced. Accordingly the capacities of MBA will decrease over the next few years, because in some plants adjustments will become necessary due to utilization reasons (e.g. closure of biological or mechanical lines).

On the output side, a substantial technical and financial effort for the production of (high-quality) substitute fuels in MBA needs to be made. Meanwhile in Germany substitute fuels are being offered in consistently good quality for different uses. Nevertheless a lot of MBA are in need of additional optimization to further improve the quality of treatment products and to enhance the efficiency of the treatment (reduction of energy consumption, wear, etc.). These measures need to be considered in light of the expected utilization.

3.2 Cement plants

Significant to the development of co-incineration in cement plants is the development of the cement market. The demand for cement and clinker in Germany is declining, which is why a lot of plant operators are dependent on either reducing capacities or lower costs of production. At this the increase of co-incineration will play an important role in the future.

In the reference scenario for future market trends co-incineration will steadily increase, the share of the primary energy use will reach over 90% in 2020. Due to the construction activity the overall produced amount of clinker will decline during the forecast horizon by 20% and the amount of used alternative fuels will therefore only rise to a lesser extent. There will be a break in 2018, because it is assumed, that a lot of plants will stop the clinker production due to not being able to meet the requirements concerning flue gas cleaning according to 17. BImSchV. The development of the NCR-catalyst for cement plants on an industrial scale will be assigned from 2 current pilot projects to other plants. However not all cement plants will make an investment, so that closure or reduction of use of alternative fuels in individual plants are expected. In contrast other plant operators will increase gradually the use of substitute fuels.

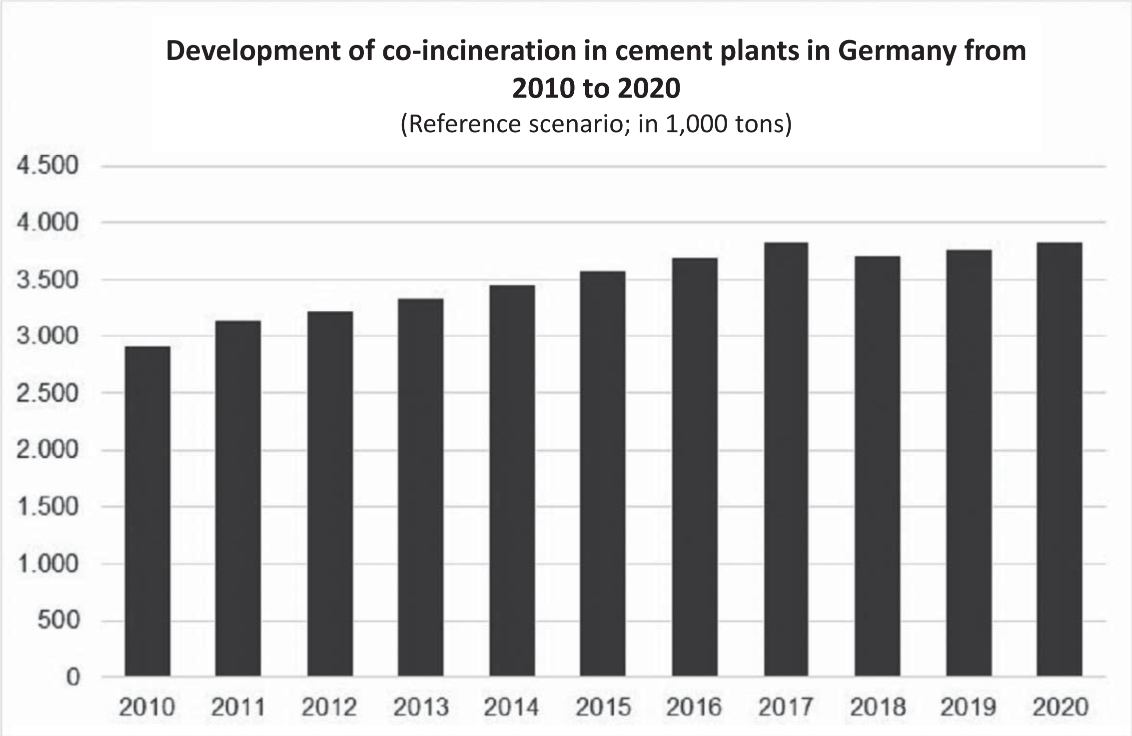

Figure 4: Development of co-incineration in cement plants in Germany from 2010 to 2020 (Source: trend:research, 2013)

3.3 Coal-fired power plants

The amount of co-incineration in coal-fired power plants will drop continuously. Due to the climate policy and the renewal of power plant parks, old coal-fired power plants, which are able to co-incinerate, will be gradually taken from the grid. In contrast new coal-fired power plants do not use substitute fuels or similar waste-derived substitute fuels for technical reasons. The reduction in Germany will be very significant, because lignite power stations substitute a comparatively high share of primary fuels. The reference scenario estimates with a strong decline of the volumes, in which a decrease of 50% until 2020 compared with 2010, which are 400,000 tons, is predicted.

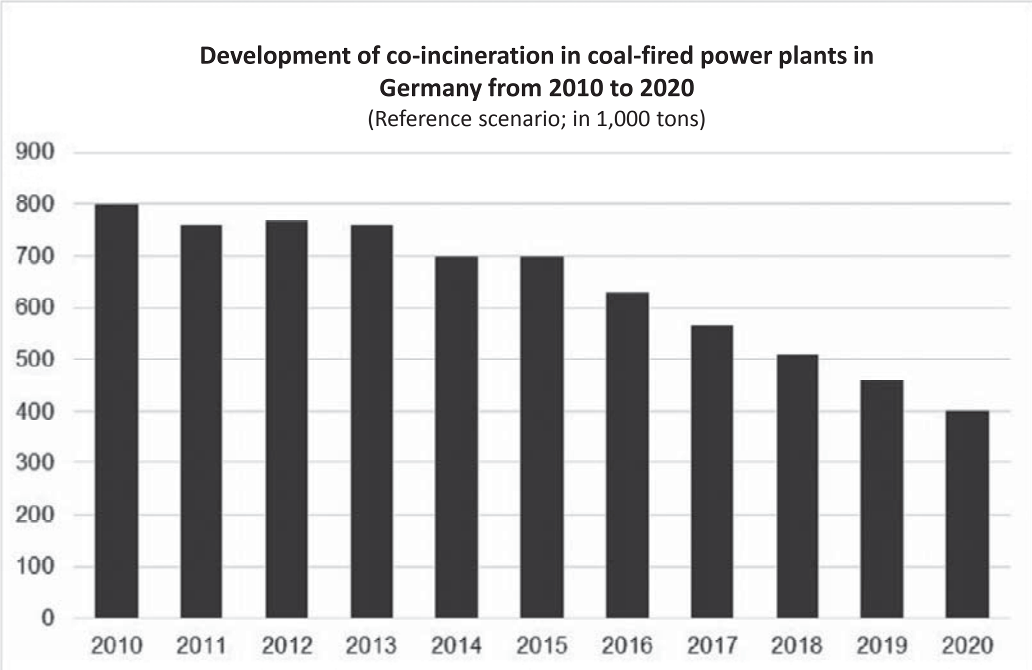

Figure 5: Development of co-incineration in coal-fired power plants in Germany from 2010 to 2020 (Source: trend:research 2013)

However co-incineration of biogenic fuels becomes more important. Concerning this, 4 coal-fired power plants are in the planning and/or testing phase. The used biogenic fuels are among others used wood and industrial residual wood. Less efficient and therefore rarely used are exotic fuels like rice husks or olive kernels.

4 Conclusion

To conclude, the markets for co-incineration in coal-fired power plants and cement plants are very different: Whereas in cement plants the use of co-incineration will increase due to price and competitive pressure, the use in coal-fired power plants in the reference scenario is declining. This is mainly because of the technology, which is not designed for the use of substitute fuels. Furthermore the use of substitute fuels or the amount of co-incineration is largely determined by the limit values of the Industrial Emissions Directive. This will, in the years ahead, lead to an upgrade of the flue gas cleaning (and therefore an increase of the co-incinerated amount), a restriction or termination of the co-incineration use or even plant closure (or in cement plants the termination of the clinker production).

5 About the Study

In the context of the study regulatory, political and economic frameworks for the co-incineration of alternative fuels in cement plants and coal-fired power plants in selected European countries are presented. Moreover the status quo is shown and the various used technologies are explained. Based on a structured survey of market experts as well as a transparent analysis a forecast is made for the future market trends until 2020. The study assists companies during strategic and operational decisions.

trend:research uses various field and desk research methods. In addition to wide-ranging intra and internet databank analysis (including journals, publications, conferences, business reports, etc.) the results of about 60 structured interviews flow into as well. The interviews with operators of cement plants, coal-fired power plants and waste treatment plants as well as with experts from associations, science and administration were conducted as part of the study.

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Use of SRF in cement plants

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Abstract

Over the last decades the German cement industry has gained lots of experience in the use of alternative fuels in the clinker burning process. The share of suitable alternative fuels could be increased continuously. In 2013 almost 62 % of the overall thermal energy demand of the German clinker kilns was substituted via alternative fuels. The recovery process of energy and material is carried out in an environmentally safe manner. This is proven by continuous and periodic control of the emissions of the major pollutants. Furthermore, the alternative fuels are subject to a quality assurance system if necessary. Untreated mixed municipal wastes are not a suitable material for the clinker burning process. The use of alternative fuels does not only lead to a preservation of natural resources. It also delivers a significant contribution to the reduction of fossil fuel related greenhouse gas emissions. In the meantime, the use of suitable alternative materials in the cement industry is also considered as Best Available Technique (BAT).

Keywords

alternative fuels, co-incineration, clinker burning

1 Decisive features for waste co-processing

As the essential constituent in concrete cement plays a key role for the development of a modern society. With cement clinker burning being the major step in the production chain cement manufacturing as such is an energy and resource intensive process. However, due to its specific characteristics, the clinker burning process offers excellent opportunities to environmentally beneficial waste-to-energy and material recycling applications which can significantly provide for energy and resource savings. The decisive major features for waste processing can be summarized as follows:

- maximum gas temperatures of 2,000 °C in the rotary kiln (main firing system)
- gas retention times of about 8 seconds at temperatures above 1,200 °C in the kilns
- oxidizing gas atmosphere in the rotary kilns
- sufficient gas retention times of more than 2 s at temperatures above 850 °C in the secondary firing
- uniform burnout conditions due to the high thermal capacity of the rotary kilns
- complete destruction of dioxins and furans due to the high temperatures
- sorption of gaseous components like HF, HCl, SO_2 on alkaline reactants
- high retention capacity for particle-borne heavy metals

- no de-novo-synthesis of dioxins and furans (PCDD/F)
- complete utilization of fuel ashes as clinker components and hence, simultaneous material recycling and energy recovery (co-processing)
- chemical-mineralogical incorporation of trace elements into the clinker matrix

2 Use of wastes as alternative fuels

The German cement industry uses primarily hard coal and lignite as conventional fuels. **Figure 1** shows some major key figures referring to the clinker production and the related fuel energy use.

▪ Clinker Production:	about 23 Mio t	
▪ Cement Production:	about 31 Mio t	
▪ Thermal Energy Demand:	90.5 Mio GJ/a	
↳ hard coal:	7.8 Mio GJ/a	
↳ lignite:	19.7 Mio GJ/a	
↳ petcoke:	3.2 Mio GJ/a	
↳ others:	3.1 Mio GJ/a	
		33.9 Mio GJ/a (hard coal, lignite, petcoke, others)
Alternative fuels:	56.6 Mio GJ/a	
Substitution of more than 2 Mio t of hard coal		

Figure 1 Key figures to the German cement industry

With respect to the recovery of alternative fuels the German cement manufacturers have a long lasting experience as shown in **Figure 2.**

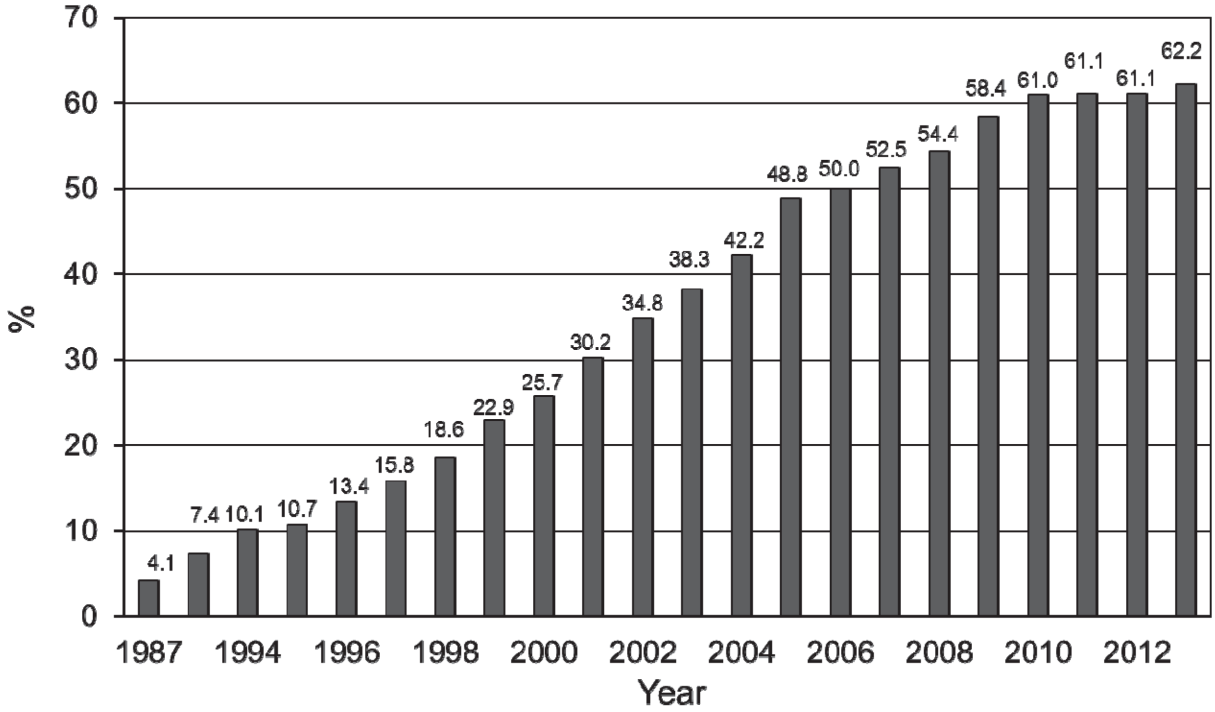

Figure 2 Alternative fuels in the German cement industry

As from 1987 on the statistics show a significant development that resulted in a substitution rate of 62 % up to the present. The corresponding fuel energy is equivalent to an annual saving of more than 2,000,000 t of coal. While these are figures for the industry as such it is clear that some substitution rates are higher, in individual cases exceeding 80 %.

Processed fractions from industrial wastes have been preeminent among the alternative fuels used for some years by now (**Figure 3**). In principle fractions from municipal wastes can also serve as a suitable fuel source for cement kilns if they comply with the required quality criteria. In Germany the growing amounts on the market of such processed fractions derived from municipal wastes is a direct consequence of the ban on landfilling of unprocessed waste which took effect on 1 June 2005. However, before these materials can be used as alternative fuel in cement kilns they have to be processed and pre-treated. Unprocessed mixed municipal waste as such is not a suitable material for the clinker manufacturing process for environmental reasons.

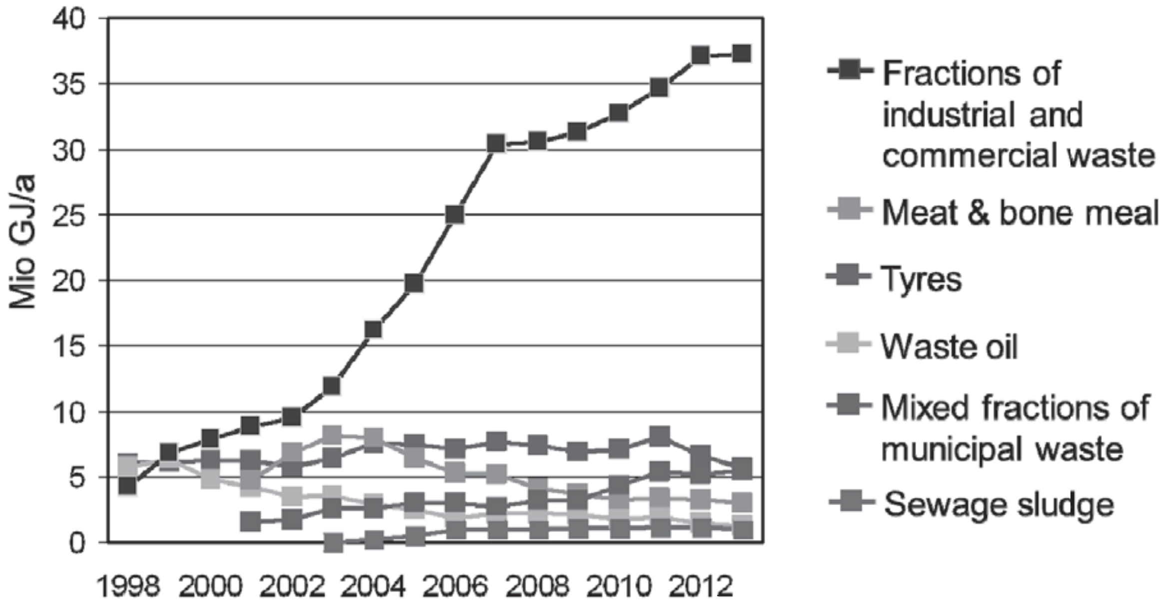

Figure 3 Important alternative fuels in Germany

3 Legal requirements

German cement works that utilise waste are subject to a national regulation which fully implements the requirements of Annex 6 of the European Directive 2010/75/EU on Industrial Emissions (IED). In principle, the co-incineration plants have to be operated according to the same environmental standards as dedicated incinerators.

According to the IED the emissions have to be monitored continuously (NO_x, SO_2, dust and TOC) or periodically by an independent third party laboratory (**Figure 4**). The results have to be published by the plant operator thus safeguarding sufficient transparency towards the neighbourhood.

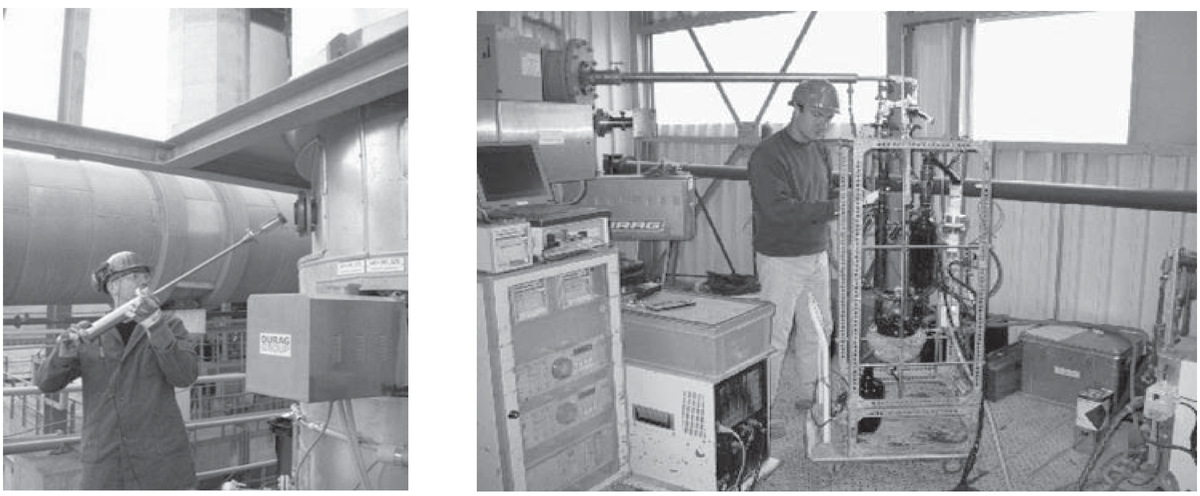

Figure 4 VDZ's emission monitoring team performing stack test which as required by European and German law

4 Selection and feeding of suitable fuels

As the energy recovery of alternative fuels in the clinker burning process is mainly targeted at the substitution of thermal energy the calorific value is a key parameter. Depending on the quality and the source of the alternative fuels for solid materials typical values are between 17 to 23 MJ/kg. For liquid alternative fuels such as used oil or solvents it can be even higher.

Referring to an undisturbed and even kiln operation the chlorine, sulphur und alkali content of the fuels have to be taken into consideration. These constituents may build up in the kiln system leading to accumulation, clogging and unstable kiln operation. From the environmental point of view the content of volatile heavy metals has to be assessed and controlled.

Depending on their composition, wastes are used either in the main firing system or in the secondary firing system. The actual feeding point should be selected according to the nature of the respective alternative fuel. If there are doubts about the feeding point selection in the individual case, reference measurements with and without waste processing should be performed.

5 Impacts on the emission behaviour

Dust emissions from the clinker burning process remain unaffected by the co-incineration of wastes.

Factors determining heavy metal emissions from the clinker production process are the behaviour of the individual heavy metals in the rotary kiln system, the input situation as well as the precipitation efficiency of the dust collector. The input situation is determined by the trace element concentrations in the raw materials and fuels processed. As the raw material/fuel mass ratio for clinker production is approx. 10 to 1, the raw material-related inputs are decisive for the emissions. In operating practice, the processing of wastes may result in a decreased or increased total input of individual elements into the kiln system.

Because of the high retention capacity for particle-borne heavy metals of the pre-heater and dust collector, the co-incineration of waste has only a minor influence on heavy metal emissions from the clinker burning process. Depending on the exhaust gas temperature, mercury is present in particle-borne and/or vapour form in the dust collector. To control mercury emissions, it may therefore become necessary to limit waste-related mercury inputs into the kiln system. When firing secondary fuels recovered from mixed waste fractions, a routine receiving analysis may be required for monitoring the heavy metals input.

The inorganic exhaust gas constituents NO_x, HCl and HF remain unaffected by the choice of the feedstock. According to current knowledge, the processing of wastes in the cement production process has no significant effects on these emissions. The same applies to the emission components SO_2, CO and TOC provided that the input of volatile sulphur compounds or volatile organic compounds via the raw meal path is not increased through the processing of waste.

Furthermore, the combustion conditions in rotary kiln systems ensure low emission concentrations of PCDD/F (dioxins and furans). Indications from comprehensive measurement programs are that in operating practice, PCDD/F emissions are well below the prescribed limit of 0.1 ng I-TEQ/m^3, regardless of the waste processed.

6 Impacts on product quality

The careful selection of suitable waste materials ensures that the product quality as such is not affected by the use of alternative materials. In principle, the use of wastes in the clinker burning process may slightly change the trace element concentrations in the cement. Depending on the total input via the raw materials and fuels, the concentration of individual elements in the product may increase or decrease as a result of waste processing. As cement is blended with aggregates (e.g. gravel, sand) for the production of concrete or mortar, it is the behaviour of the trace elements in the building material (concrete or mortar) which is ultimately decisive for evaluating the environmentally relevant impacts of waste recovery in the clinker burning process on the product quality.

Tests on mortar and concrete test cubes have shown that the heavy metal concentrations in the eluates are noticeably below those prescribed by the German Drinking Water Ordinance, for instance. Storage under different and partly extreme conditions has not led to any environmentally relevant releases. This also holds true when the sample material is crushed or comminuted prior to the leaching tests. Also from the environmental point of view the use of waste has no negative impact on the quality of the product. Cement can be used without restrictions for mortar and concrete production. The recyclability of these materials remains unaffected.

7 Alternative fuels and greenhouse gas emissions

The use of alternative fuels in the German cement industry leads to a substitution of about 2,000,000 t of coal equivalents. Based upon the IPCC 2006 figures for anthracite (net calorific value: 26.7 TJ/Gg, emission factor: 98.2 t CO_2/GJ) this represents a saving of more than 5,200,000 t of primary fossil fuel related CO_2 per year. Additionally, it has to be pointed out that especially the solid alternative fuels can contain a large proportion of biogenic carbon. Current investigations have shown that this biomass proportion can contribute between 20 % and 50 % of the carbon contained in the fuel. **Figure 5** shows the average share of fossil and biogenic carbon in different alternative fuels.

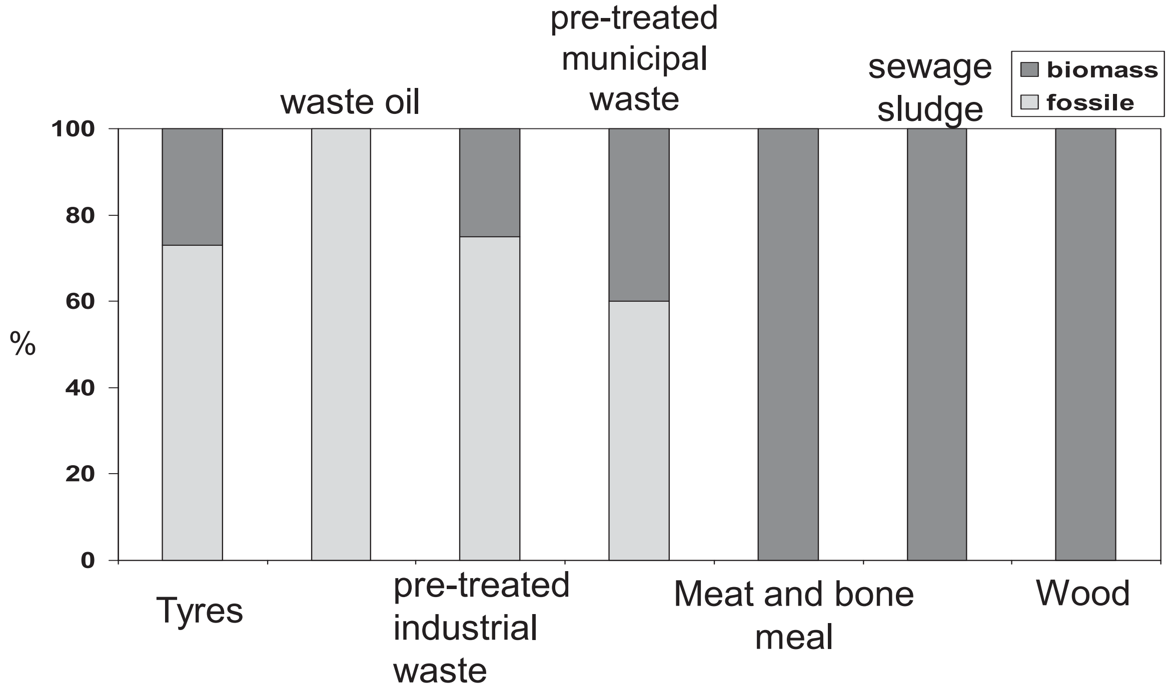

Figure 5 Average biomass content of alternative fuels

The figure also shows that even used tyres contain a remarkable amount of biomass carbon due to the content of natural rubber (caoutchouc). The German Emissions Trading authority (DEHSt) has accepted a share of 27 % of biogenic carbon as default value for used tyres.

Furthermore, it has to be pointed out that landfilling of waste has a highly detrimental effect from the climate protection point of view. The natural decomposition of organic waste materials leads not only to a release of CO_2. In the contrary, during the naturally occurring uncontrolled decomposition processes other gases with much higher greenhouse gas potentials (e.g. methane) are emitted leading to a greater potential damage to the environment.

8 An efficient solution for future challenges

The use of alternative fuels and the positive development of the respective substitution rates in Germany show the potential contribution of the cement industry to a modern and efficient recovery of alternative resources.

Due to its specific characteristics the clinker burning process offers an excellent option for an efficient use of alternative fuels. Simultaneously, the recovery of the alternative fuels leads to a direct and significant reduction of fossil fuel related greenhouse gas emissions. However, the cement companies use selected alternative fuels only, because these materials must suit the process and the final product from a technical and environmental point of view. This careful selection and - if necessary - pre-treatment of the secondary materials ensure that the co-incineration of wastes does not result in any harmful emissions to the environment. A quality control scheme and - whenever necessary - the limitation of trace elements in the wastes provide for a cement quality that is technically and environmentally not affected by the alternative materials being co-processed.

Based upon this overall positive impact the use of alternative fuels in the clinker burning process has lately been considered as being a Best Available Technique (BAT) for the cement industry in Europe.

The German cement industry will continue its efforts to further increase the share of suitable alternative fuels. By doing so and apart from all other advantages the industry can also deliver a valuable contribution to an environmentally sound waste management.

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Evaluation of the potential of different waste fractions for the preparation of Solid Recovered Fuels

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Abstract

Non-hazardous waste fractions which cannot be recycled can be profited as Solid Recovered Fuel (SRF), for its use as fuel/cofuel in the cement kilns or other fuel-intensive applications. In this work, three types of wastes were studied in two different periods of the year: End of life vehicles (ELV) waste, packaging and bulky wastes. According to European Rule EN 15359, these wastes were classified as SRF according to three parameters: lower heating value (LHV), chlorine content and mercury content. The lower heating value on a wet basis varies between 2277.9 kcal/kg and 10446.6 kcal/kg; the fine fraction of ELV wastes having the lowest calorific power. Most fractions have chlorine content below 1 % and meet the restrictions on heavy metals. A comparison among experimental Higher Heating Values and calorific power predictions from elemental analysis was carried out.

Keywords

Solid Recovered Fuel, Waste, Heating Value, Chlorine content, Mercury content, Modelling

1 Introduction

The European legislation about waste disposal has established a hierarchy, which consists of a series of options available for waste treatment or management: prevention, reuse, recycling, energy recovery and disposal (EUROPEAN COMISSION, 2008). Under EU policy, recycling of materials is preferable to energy recovery, and landfilling is the last possibility and should only be used when all the previous options have been excluded. In Spain, with 463 kg of waste generated per capita in 2012 (EUROSTAT, 2012), only 79 kg were recycled, whereas 44 kg were incinerated and 293 kg were deposited in landfill. These data point out the difficulties in the municipal solid waste (MSW) management. Since, although recyclable fractions such as paper, plastic and glass can be recycled, and the biodegradable fraction of MSW can be used as raw material of biological treatments, not all the waste material can be recycled. What is more, in waste treatment processes, a large amount of residues that may have high heating values and generally go to the landfill is generated (ARENA, 2014; NASRULLAH, 2014). This landfilling presents several drawbacks. These residues represent about 2/3 of the initial volume of waste. Firstly, the great volume of wastes accumulated, which could represent 2/3 of the initial volume of waste (MONTEJO, 2011), with the subsequent problem of space. Secondly, the potential environmental pollution caused either by the methane emissions generated by anaerobic degradation of organic wastes, or the heavy metals leached from the waste discharged in landfill (SÁNCHEZ, 2009). Among the possible alternatives, energy recovery could be an option to solve the problems of space and loss of material that could be a good fuel. In fact, once the recyclable materials have been recovered, the refuse derived fuel (RDF combustion is an alternative to be considered according to the flagship european initiative for a resource-efficient Europe under the Europe 2020 strategy, which aims the shift towards a resource-efficient, low-carbon economy to achieve sustainable growth. The use of part of this material as fuel could have several advantages as reducing emissions to landfill and partial substitution of fossil fuels with the corresponding decreasing of greenhouse gas emissions (BURNLEY, 2011).

The non-hazardous waste fractions can be used as fuel/co-fuel, for example, in the cement kilns provided that meet the requirements established in CEN standards (UNE-EN 15359, 2011) to be classified as solid recovered fuels (SRF). It is noteworthy that, in the cement industry, energy costs are 30-40 % of total production costs so this industry is one of the most beneficed by this type of fuels (TSILIYANNIS, 2012). The European Committee for Standardisation (CEN) has selected as key technical performance indicators of the SRF the lower heating value, the residual chlorine content and the mercury content. The concentration of chlorine in SRF is a critical parameter since elevated concentration could create both technical problems and environmental concerns, such as formation of polychlorinated dibenzodioxins (PCDDs) (VELIS, 2012).

In order to produce SRF, COGERSA, the public company for waste management in Asturias (1 million habitants in the North of Spain) selected a series of fractions of MSW to evaluate their suitability as SRF. Considering those fractions of waste with higher rates of generation in absence of seasonality and, with higher heating values, three types of wastes were selected: fragmentation waste of end-of-life vehicles (ELV waste), the refuses from milling process of bulky waste (bulky waste) and the refuses of a sorting plant of packaging waste (packaging waste). The main purpose of this work is to assess the suitability of the aforementioned different waste fractions for producing SRF. For this, both chemical and calorimetric analyses were carried out in order to classify the different wastes as SFR according to the parameters established by EN 15359 (EN 15359, 2011) shown in Table 1.

Table 1 Waste classification criteria as SRF

Parameter	Statistical Measure	Unit	Class				
			1	2	3	4	5
Lower Heating Value	Medium Value	MJ/kg	≥25	≥20	≥15	≥10	≥3
Chlorine content	Medium Value	% (w/w)	≤0.2	≤0.6	≤1.0	≤1.5	≤3
Mercury content	Medium Value	mg/MJ	≤0.02	≤0.03	≤0.08	≤0.15	≤0.50

2 Experimental

2.1 Materials

The collection of materials was carried out in COGERSA facilities. These materials were diverted from the non-hazardous waste landfill and were milled twice in an industrial milling to ensure a particle size below 100 mm, required for use as fuel in cement kilns.

As regards the content of these residues, bulky waste includes different types of furniture as couches, recliners, tables, etc. Packaging waste refers to the reject fraction that cannot be recovered in the sorting plant for light packaging waste, and ELV waste involves non-metallic part of global ELV waste.

2.2 Preparation of laboratory samples

After the process of industrial milling, wastes (packaging, bulky and ELV wastes) were submitted to the laboratory in bags of 5 kg each one, except fine ELV waste, submitted in a 2 kg bag. These samples were delivered in sealed plastic packaging high density.

Once samples were received, sub-sampling process was carried out due to the heterogeneity of the samples and the large size of some of them following a procedure similar to that suggested by EN 15413 (EN 15413, 2011).

According to this rule, the intervention procedure for obtaining test samples is:

1. Separation into fractions. Due to the heterogeneity of the samples, first, each one was separated manually in different macroscopic fractions which were analyzed separately. The separation improves the subsequent processes of downsizing and subsampling achieving greater uniformity.
2. Drying. To calculate the moisture content, data necessary for obtaining LHV.
3. Particle size reduction. The particle size reduction was carried out in order to achieve a uniform and representative portion and, on the other hand, to improve

subsequent analysis where particle sizes as small as possible are needed. Different techniques of particle size reduction as mechanical milling, freeze grinding and manual cut were carried out depending on the physical characteristics of the different materials.

2.3 Methods

2.3.1 Determination of Lower Heating Value (LHV)

According to EN 15400 (EN 15400, 2011) the determination of heating value was carried out using an adiabatic calorimeter IKA C4000. Firstly, the calorific capacity of the device was determined by combustion of benzoic acid tablets known calorific value. For the analysis of the samples, a portion (ca. 1 g) of each fraction of waste was taken and pelleted using a hydraulic press and the combustion of the pellets was carried out. Determinations were performed by duplicate using the following equations for calculating Higher Heating Values (HHV) and Lower Heating Values (LHV).

$$H_i = \frac{C\ \Delta T_i - Q_F}{m_i} \tag{1}$$

H_i: HHV for the i-sample in wet basis, J/g.

C: calorific capacity of calorimeter, J/K.

ΔT_i: temperature variation during the combustion, K.

Q_F: sum of the contribution of all those heat sources outside the combustion of the sample, J.

m_i: mass of the i-sample, g.

$$LHV_{wet} = \left[H_i - 2442\left(\frac{W}{100} + 9\ \frac{H_{dry}}{100}\right)\right]\left(1 - \frac{W}{100}\right) \tag{2}$$

LHV_{wet}: Lower Heating Value in wet basis, kJ/kg.

2442 is the heat of vaporization of water, kJ/kg.

H_{dry}: the percentage of hydrogen in dry basis.

9 refers to the water produced in the combustion in relation to the initial content of hydrogen, which is nine times this amount of water produced.

W: moisture content in percentage.

2.3.2 Elemental analysis

The determination of carbon, hydrogen, nitrogen and sulphur was performed according to the guidelines in the EN 15407 (UNE-EN 15407, 2011). An elemental analyser Elemental Vario EL was employed for the determinations using 0.1-0.2 g samples of each fraction. These analyses were carried out by duplicate.

2.3.3 Heavy metals content

The determination of heavy metals was carried out for samples of each waste, instead of samples of each fraction, so four representative samples (ELV fine fraction, ELV thick fraction, packaging and bulky wastes) were analysed. These samples of waste were artificially made based on the percentages of each fraction obtained in the sample preparation process.

The procedure was carried out following the indications given by the EN 15411 (EN 15411, 2011) and the samples were analysed using ICP-MS. The trace element analysis was carried out by triplicate.

2.3.4 Chlorine content

EN 15408 (EN 15408, 2011) recommends to perform the analysis of chlorine using ion chromatography technique. However, after comparing results obtained for three prepared samples of known concentrations and by triplicate with a chloride-selective electrode (Crison 96 52) results, the last technique was used. Combustion of the samples was carried out by a similar method than the calorific value determination. For each measurement, within bomb calorimeter, 10 mL of an absorbent liquid was introduced, where the chlorides released during the combustion were retained. After the combustion, the remaining liquid into bomb calorimeter was extracted and the chlorine concentration measured.

3 Results and discussion

Table 2 summarized the average composition of each prepared fraction obtained from the wastes. Mass percentage data obtained for each fraction were obtained by triplicate. The fine fraction of ELV waste is an independent fraction of global ELV waste.

Table 2 Fractional composition of different wastes

Waste	Fraction	Composition (%)
ELV	Fine	100.00
	Plastics	60.78
	Foams	18.55
	Textile	20.66
Packaging	Packaging	56.88
	Soft plastics	17.47
	Cellulosic (paper)	16.61
	Textile	9.04
Bulky	Foams	17.34
	Cellulosic (wood)	55.30
	Textile	27.35

3.1 Heating Value

Table 3 summarized the Higher and Lower heating values for each fraction and the global waste.

The plastic fractions (including packages) showed the Higher Heating Values followed by foams and cellulosic/textile fractions.

Table 3 HHV and LHV mean values for each fraction of waste

Waste	Fraction	HHV (kcal/dry kg)	LHV (kcal/dry kg)	Average LHV (kcal/dry kg)
ELV	Fine	2445.2	2277.9	2277.9
	Plastics	8479.0	7886.2	6708.4
	Foams	6408.2	5864.5	
	Textile	4340.9	4004.1	
Packaging	Packaging	7130.2	6289.1	6133.5
	Soft plastics	9646.9	8946.0	
	Cellulosic (paper)	3963.4	3279.5	
	Textile	5284.9	4962.9	
Bulky	Foams	6448.5	5885.9	4576.8
	Cellulosic (wood)	4455.5	3726.4	
	Textile	5831.9	5466.6	

3.2 Elemental analysis and chlorine content

Table 4 shows the elemental composition of each fraction of waste.

Table 4 Elemental analysis, chlorine, ash and moisture content for wastes received (%)

Waste	Fraction	C	N	H	O	Cl	S	Ash cont.	W
ELV	Fine	8.30	0.32	1.07	19.08	0.12	0.72	70.51	3.76
	Plastics	71.20	0.45	14.80	13.00	0.07	0.51	6.04	0.38
	Foams	52.78	3.92	7.15	8.95	0.23	0.44	26.76	2.54
	Textile	54.57	2.36	4.13	2.39	2.65	0.41	36.14	2.55
ELV Global	Average Value	64.34	1.49	11.18	10.05	0.63	0.48	16.10	1.23
Packaging	Packaging	72.19	0.21	8.67	12.58	0.08	0.28	6.07	5.33
	Soft plastics	72.09	1.18	10.76	8.60	0.12	0.84	6.53	1.40
	Cellulosic	37.37	0.59	5.14	30.28	0.14	0.96	25.66	9.21
	Textile	56.78	0.73	4.03	32.49	0.08	0.51	5.46	1.95
Packaging Global	Average Value	65.00	0.49	8.03	16.62	0.10	0.51	9.35	4.98
Bulky	Foams	58.13	5.85	8.55	24.83	0.05	0.45	2.21	1.72
	Cellulosic (wood)	47.88	0.86	6.52	43.56	0.12	0.40	0.78	8.31
	Textile	53.21	2.41	4.52	33.71	0.06	0.36	5.79	2.07
Bulky Global	Average Value	51.11	2.15	6.32	37.93	0.09	0.40	2.09	5.46

Comparing elemental analysis data and heating values, it is noteworthy that those fractions which have high carbon and hydrogen contents also have higher calorific values. From the point of view of the cement industry, the chlorine content of the waste under study should be less than 1 % to avoid environmental problems due to the emission of dioxins and technical problems as furnace binding. Although the textile fraction of ELV waste has chlorine content over 2 % as shown in Table 4, the average chlorine content of each waste did not exceed 1 % in any case and, thus, from this point of view, all wastes would be suitable to be used as SRF.

3.3 Determination of heavy metals

Table 5 Concentration values of trace elements and concentration limits, ppm.

Metal	ELV fine	ELV	Packaging	Bulky	Conc. Limits
Cr	529.50	112.00	9.67	2721.33	200
Mn	582.30	133.67	35.33	65.67	200
Co	19.32	4.86	1.25	0.52	200
Ni	486.00	76.33	7.00	7.33	200
Cu	6713.19	603.47	20.91	24.31	200
Zn	2146.33	985.33	79.67	56.00	500
As	0.74	1.63	0.31	0.35	10
Cd	2.61	0.94	0.17	0.11	10
Sb	6.67	7.39	9.15	1.75	10
Hg	0.07	0.08	0.01	0.12	2
Tl	0.08	0.04	0.02	0.02	2
Pb	1103.00	838.33	33.00	42.67	200

Table 5 shows concentration values of the elements included in EN 15411 (EN 15411, 2011) for each type of waste, as well as their concentration limits in ppm. The limit concentrations are given by European Union for Responsible Incineration and Treatment of Special Waste (EURITS, 2003).

ELV fine fraction exceeds the maximun concentration for most metals. Such high concentrations may be due to the presence of trace metals from the metal content of this waste and disable this fraction to be used as SRF.

3.4 Waste classification

Table 6 shows the parameter values for classification of the different wastes as SRF.

Table 6 Global wastes classification as SRF

Parameter	ELV fine	ELV	Packaging	Bulky
LHV (MJ/kg)	9.52	28.04	25.64	19.13
Cl (%)	0.12	0.63	0.10	0.09
$Hg \cdot 10^3$ (mg/MJ)	7.62	2.76	0.39	6.22
Class	LHV 5; Cl 1; Hg 1	LHV 1; Cl 3; Hg 1	LHV 1; Cl 1; Hg 1	LHV 3; Cl 1; Hg 1

From the point of view of the heating value, the most important parameter for the classification of SRF, ELV waste is the waste for use as SRF, followed by packaging waste, bulky waste, and, finally, the fine fractions of the ELV. Therefore, this last waste was discarded for using as SRF.

3.5 Empirical modelling

Calorific values obtained experimentally were compared to predicted data from a series of theoretical models based on the prediction of the heating values depending on the elemental composition of the samples.

Model	Equation	Source
Dulong	HHV=81C+342.5 (H-0.125 O)+22.5S-6(9H-W)	KATHIRAVALE ET AL., 2003
Scheurer-Kestner	HHV=81(C-0.75 O)+342.5H+22.5S+57·0.75 O-6(9H-W)	KATHIRAVALE ET AL., 2003
Steuer	HHV=81(C-0.375O)+57·0.375O+345(H-0.1O)+25S-6(9H-W)	KATHIRAVALE ET AL., 2003
Chang	HHV=8561.11+179.72H-63.89S-111.17O-91.11Cl-66.94 N	KATHIRAVALE ET AL., 2003

where C, H, S, Cl, O, N, W are the carbon, hydrogen, sulphur, chlorine, oxygen, nitrogen and moisture contents, in mass percentage.

In all these equations, Scheurer-Kestner equation exhibits the best approximation to the experimental data (R^2=0.87), Fig. 1.

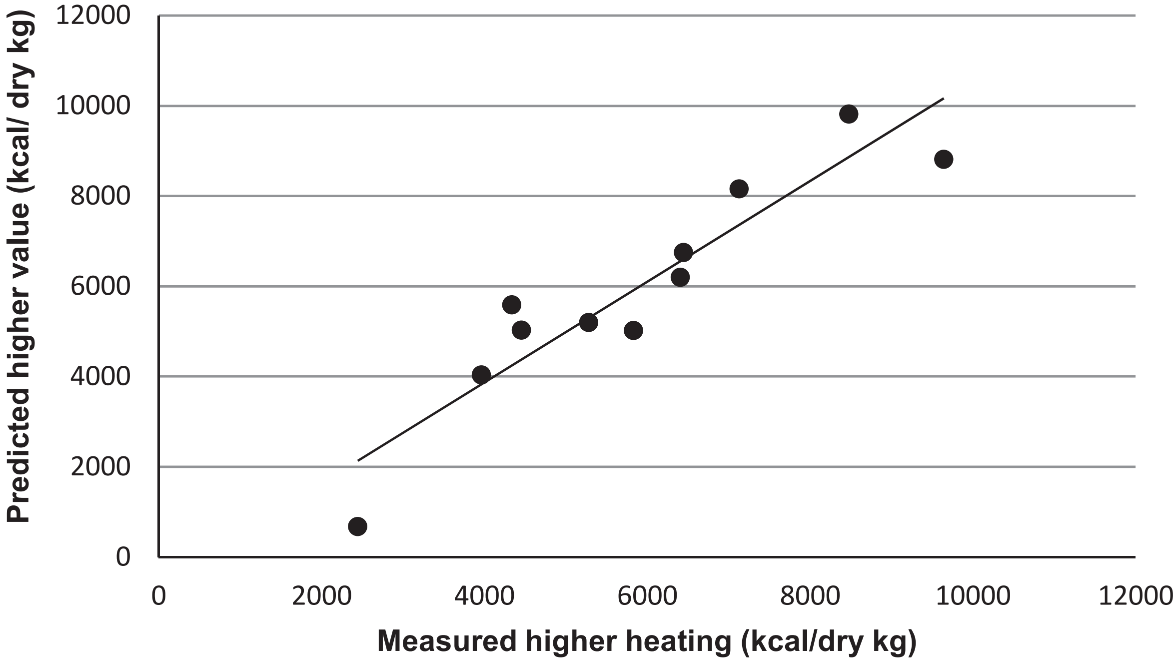

Figure 1 Comparative experimental HHV and Scheurer-Kestner HHV

Most fractions match the model, except the fine fraction of ELV waste. This fraction has high ash content so theoretical models do not predict adequately its heating value.

4 Conclusions

From the analysis were obtained the following conclusions:

- Fractions containing plastics (including light packaging wastes) and foams present the highest calorific values. Overall, the ELV waste has the largest LHV, following by packaging waste, with the fine fraction of ELV waste with the lower calorific value.
- All the considered residues are below the chlorine limit content of 1%, being bulky and packaging wastes those with lower chlorine content. Concerning the waste fractions, the textile fraction of ELV waste is the only one which exceeds the limit of 1% recommended by cement industry.
- From the point of view of heavy metal content, the fine fraction of ELV waste exceeds the recommendations set by EURITS for most metals, whereas the other wastes fit perfectly with the specifications. Add to this, its low LHV prevents the use of the fine fraction of ELV waste as SRF.
- From the theoretical models studied, Scheurer-Kestner equation is the most approximate to the experimental values.

- From the four kinds of studied wastes, three fractions (ELV waste, packaging waste and bulky waste) could be used as SRF due to their heating value, and chlorine and metals content. Thus, their use as SRF leads to a sustainable use in energy recovery units (such as cement kilns), instead of landfilling. This valuation would approach the waste management hierarchy established in the Directive 2008/98/EC.

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Vergleich von MBA's mit und ohne vorgeschalteter Vergärung in Bezug auf Feuchtigkeitsmanagement und Erreichung der Deponieablagerungskriterien

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Comparison of MBT plants with and without upstream fermentation in terms of moisture management and achievement of landfill disposal criteria

Inhaltsangabe

In der Abfallwirtschaft hat sich der Trend entwickelt, die anaerobe Vergärungstechnologie für die Behandlung von Hausabfällen einzusetzen. Deshalb wurden MBA's mit vorgeschalteter anaerober Vergärungsstufe gebaut.

Im Rahmen von Anlagenüberprüfungen und Versuchen wurde eine MBA mit und eine MBA ohne Vergärungsstufe untersucht und miteinander verglichen, um den Einfluss der Vergärungsstufe festzustellen. Dabei wurde besonderes Augenmerk auf den Anlagenbetrieb, insbesondere das Feuchtigkeitsmanagement, die Einhaltung der Deponieablagerungskriterien sowie die Wirtschaftlichkeit der MBA gerichtet.

Keywords

Gärrest, MBA-Material, Materialmischung, Bilanzierung, Feuchtigkeitsmanagement, Wirtschaftlichkeit, Abfallanalysen, Korngrößenverteilung, Abfallklumpen

1 Einleitung

1.1 Hintergrund

Der Betrieb von Vergärungsanlagen gewann in den letzten Jahrzehnten vor allem in der Landwirtschaft an Beliebtheit, in denen der nachwachsende Rohstoff (NaWaRo), dessen Qualität sehr konstant ist, verwertet wird. In der Abfallwirtschaft hat sich der Trend entwickelt, diese verbreitete Technologie der anaeroben Vergärung für die Behandlung von Hausabfällen, deren Abfallzusammensetzung sehr unterschiedlich sein kann, einzusetzen. Deshalb wurden MBA's mit vorgeschalteter anaerober Vergärungsstufe gebaut. Um den Einfluss der Vergärung auf den Anlagenbetrieb und die Wirtschaftlichkeit der MBA festzustellen, wurde eine MBA mit und eine MBA ohne Vergärungsstufe untersucht und miteinander verglichen.

1.2 Anlagen im Vergleich

Im Rahmen unserer Anlagenüberprüfungen wurden neben der Anlagenbetriebsweise auch die Materialeigenschaften der Abfallströme und die Wirtschaftlichkeit untersucht. Zur Erhebung der Materialeigenschaften wurden Korngrößenverteilungen (Sieblinien) durchgeführt. Im Rahmen dieses Vortrages werden folgende Anlagen verglichen:

Tabelle 1: Anlagendetails

	Anlage ohne Vergärung	Anlage mit Vergärung
Anlageninput	21.000 t/a	27.000 t/a
Fraktion	0/80 mm	0/60 mm
Aufteilung der Abfallströme Vergärung / statische Tunnelrotte	-	60 % / 40 %
Verweilzeit		
im Trockenfermenter	-	14-17 Tage
in der statischen Tunnelrotte	21 Tage	14 Tage
auf der Nachrottefläche	21 Tage belüftet	42 Tage unbelüftet
Gesamtbehandlungszeit	42 Tage	70-73 Tage
Umsetzen		
in der statischen Tunnelrotte	wöchentlich mit Radlader	wöchentlich mit Radlader
auf der Nachrottefläche	wöchentlich mit Umsetzer	wöchentlich mit Umsetzer

Abbildung 1: Statischer Rottetunnel

Abbildung 2: Blick in einen statischen Rottetunnel

2 Auswertung

2.1 Rechtliche Informationen

Grundsätzlich hat das Outputmaterial einer MBA die Deponieablagerungskriterien zu erfüllen, damit die behandelten Abfälle auf einer Deponie abgelagert werden dürfen. Gemäß Europäischer Deponierichtlinie ist die direkte Ablagerung von schlammigen oder pastösen Abfällen verboten (EUROPÄISCHER RAT, 1999). Abfälle, deren Ablagerung erlaubt ist, müssen gewisse Parameter erfüllen. Diese Parameter sind länderspezifisch und können u.a. sein:

- ✓ Atmungsaktivität des Materials (AT_4 und/oder GB_{21})
- ✓ maximaler Heizwert
- ✓ TOC (Total Organic Carbon)
- ✓ DOC (Diluted Organic Carbon)

Der Gärrest der untersuchten Anlage, der aus der Vergärungsstufe abgezogen wird, erfüllt nicht die in dem untersuchten Land vorgeschriebenen Ablagerungskriterien. Damit das Material trotzdem in einer Deponie abgelagert werden darf, muss es einer nachgeschalteten Behandlung unterzogen werden.

Aus diesem Grund ist die Vergärungsstufe nicht als alleinstehende Technologie anzusehen, sondern es ist immer eine Kombination mit einer Nachbehandlung erforderlich. Hierfür hat sich in der Praxis eine aerobe biologische Behandlung bewährt.

2.2 Anlagenbetrieb

2.2.1 Abfallmanagement

Für den optimalen Betrieb einer biologischen Abfallbehandlung sind gewisse Prozessbedingungen einzuhalten. Das Material hat für eine aerobe biologische Abfallbehandlung folgende Voraussetzungen zu erfüllen:

Optimale Bedingungen:

- ✓ Die Materialfeuchtigkeit hat zwischen 40 und 60 % zu liegen.
- ✓ Es muss genügend Porenvolumen vorhanden sein. Dies wird üblicherweise mit einer Materialdichte von max. 650 kg/m³ erreicht.
- ✓ Es muss genügend biologisch abbaubare organische Trockensubstanz zur Verdampfung des Wassers vorhanden sein.

Die Materialeigenschaften der untersuchten MBA‘s sind in Tabelle 2 gelistet.

Tabelle 2: Optimale und gemessene Materialeigenschaften

	SOLL	MBA-Material	Gärrest
Dichte	< 650 kg/m³	500-550 kg/m³	750-800 kg/m³
Trockensubstanz (TS)	40-60 %	57,7 %	47,7 %
Organische TS	40-60 %	52,7 %	44,7 %

Das MBA-Material wies nach der Aufbereitung mit einem Schredder und Sieb optimale Eigenschaften für die biologische Behandlung auf und konnte ohne weitere Arbeitsschritte verarbeitet werden. Die Materialeigenschaften des Gärrestes aus der Vergärungsstufe lagen aufgrund der hohen Materialdichte außerhalb des für die aerobe Nachbehandlung notwendigen optimalen Bereiches.

Zur Verbesserung der Materialeigenschaften des Gärrestes wurde ein Teil des aus der Aufbereitung anfallenden Abfallstroms als Teilabfallstrom abgezogen. Durch Mischung des Gärrestes mit dem Teilabfallstrom konnten die Materialeigenschaften insgesamt verbessert werden.

Für die Behandlung von Gärrest war immer eine Mischung mit einem Teilabfallstrom notwendig. Dieser Teilabfallstrom ist bei der Auslegung einer MBA mit Vergärungsstufe und der Wirtschaftlichkeitsberechnung zu berücksichtigen.

2.2.2 Materialmischung

In den Versuchen wurden der Gärrest und das MBA-Material im Mengenverhältnissen von 1:1 [v/v] gemischt. Für die Durchmischung der Abfälle wurde ein Radlader verwendet. In Abbildung 3 und Abbildung 4 wird dieser Durchmischungsvorgang dargestellt.

Abbildung 3 und Abbildung 4: Die Materialdurchmischung von Gärrest und MBA-Material mithilfe eines Radladers zeigte Schwächen in der Homogenität der Abfallmischung.

In den Versuchen wurde festgestellt, dass die vom Radlader hergestellte Materialmischung nicht vollständig homogen war. Während des Mischvorganges wurde mit dem Radlader teilweise über den Abfall gefahren, wodurch sich Klumpen bildeten.

Für eine optimale aerobe biologische Abfallbehandlung ist eine ausgewogene und homogene Mischung von Gärrest und MBA-Material Voraussetzung. Dies wird durch eine optimale Durchmischung und die Vermeidung von Verdichtungen gewährleistet.

Durch Schulung des Radladerfahrers konnte weitere Mischvorgänge und somit die Homogenität des Materials verbessert werden. In der Praxis hat sich aber der Einsatz eines Mietenumsetzers oder Mischaggregates bewährt.

2.2.3 Feuchtigkeitsmanagement

Bei der biologischen Abfallbehandlung wird Wasser während des Rotteprozesses verdampft. Voraussetzung dafür ist die Einhaltung der in Tabelle 2 gelisteten optimalen biologischen Prozessparameter. Tabelle 3 listet gemessene Werte von Wassergehalte.

Tabelle 3: Wassergehalte

	MBA ohne Vergärung	**MBA mit Vergärung (optimale Bedingungen)**	**MBA mit Vergärung (ungünstige Bedingungen)**
MBA-Material	39,1 %	42,3 %	46,7 %
Gärrest	-	52,3 %	55,2 %
Materialmischung MBA-Material / Gärrest	-	46,8 %	49,6 %
Aerobe Behandlungsdauer			
2 Wochen	32,0 %	43,1 %	-
6 Wochen	16,1 %	-	-
8 Wochen	-	16,4 %	38,1 %

Das Outputmaterial der MBA ohne Vergärung wies nach der 6-wöchigen aeroben Behandlung einen Feuchtigkeitsgehalt von 16 % auf. Annähernd gleiche Resultate erzielte die MBA mit Vergärungsstufe bei optimalen Bedingungen nach 8 Wochen aerober Behandlung. Bei ungünstigen Bedingungen zeigte das Outputmaterial nach 8 Wochen aerober Behandlung einen Feuchtigkeitsgehalt von ca. 38 % auf. Durch die

Klumpenbildung und die Inhomogenität des Materials fiel der Trocknungseffekt schlechter aus.

Neben der Verdampfung der Materialfeuchtigkeit ist für die internen Abwassermengen (z.B. aus der Abluftbehandlung oder der biologischen Abfallbehandlung) ebenfalls eine kostengünstige Behandlung notwendig. Grundsätzlich besteht während der aeroben biologischen Abfallbehandlung die Möglichkeit, diese Wassermengen als Bewässerungswasser einzusetzen. In Abbildung 5 ist exemplarisch ein Schema für eine Wasserbilanz dargestellt.

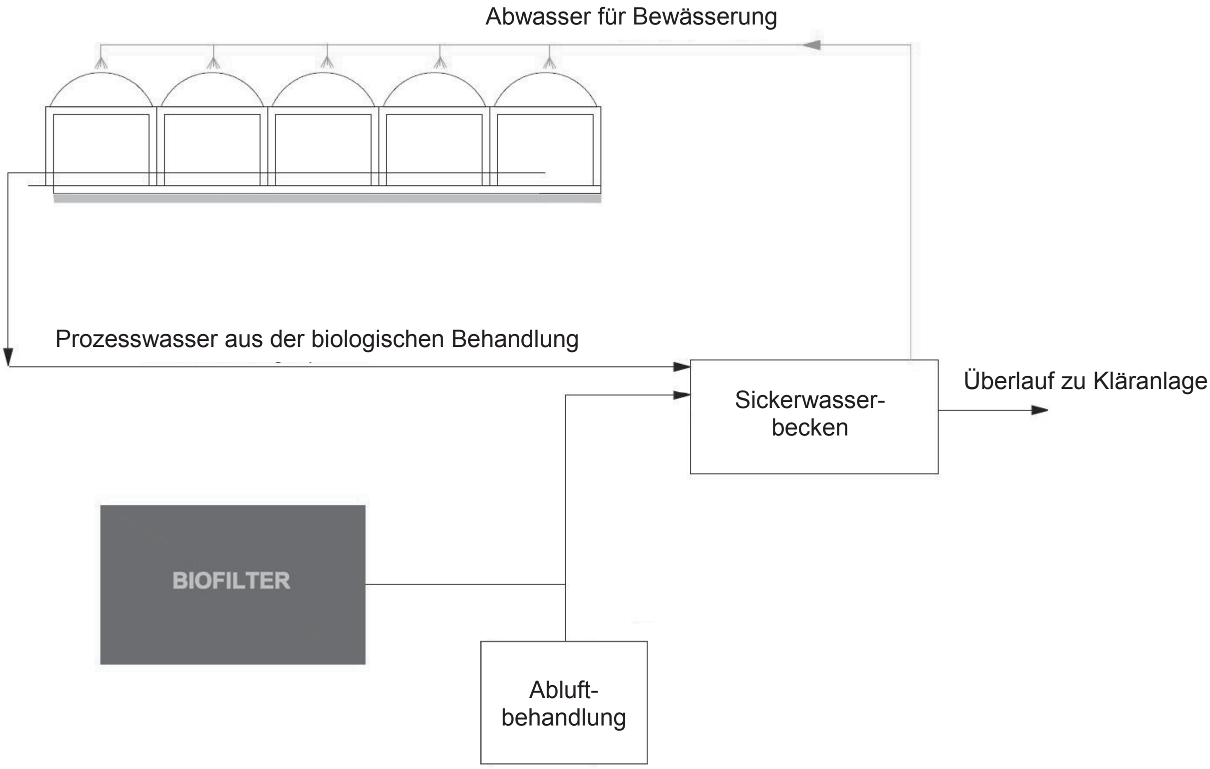

Abbildung 5: Schema für eine Wasserbilanz

In diesem Schema werden die anfallenden Abwässer aus biologischem Prozess und Abluftreinigung in einem Sickerwasserbecken gesammelt. Die mögliche verdampfbare Wassermenge wird in der statischen Tunnelrotte als Bewässerungswasser eingesetzt. Überschüssiges Abwasser wird in einer Kläranlage gereinigt.

Für die Kalkulation der Abwassermengen, die während der biologischen Behandlung verdampft werden können, sind detaillierte Massen- und Energiebilanzen notwendig, damit die Verdampfung des Schmutzwassers sicher gewährleistet werden kann.

Die Untersuchung der Abwässer zeigte einen hohen Gehalt an biologisch abbaubaren Stoffen (BSB_5), deren Werte bei einem BSB_5 größer 15.000 mg O_2/g TS lagen. Im Rahmen der biologischen Abfallbehandlung sind die biologisch abbaubaren Stoffe zu stabilisieren. Damit das bereits stabilisierte Material nicht mit frischem Material verunreinigt wird, wodurch die Einhaltung der Deponieablagerungskriterien gefährdet wäre, kann das Abwasser nur in der geschlossenen Tunnelrotte eingesetzt werden.

Des Weiteren kann die Anwendung von Schmutzwasser (das sehr geruchsintensiv sein kann) auf einer offenen Nachrotte zu Geruchsemissionen führen, die vor allem bei nahegelegenen Anrainern ein vermieden werden sollten.

2.2.4 Abfallanalysen

In machen Ländern ist es unter Einhaltung gewisser Kriterien erlaubt, die Feinfraktion (< 15 mm) des stabilisierten Abfalls als Deponiebegrünung einzusetzen, solange der Fremdstoffanteil einen maximalen Grenzwert nicht überschreitet. Diese Fraktion wird als CLO („Compost Like Output“) bezeichnet.

Ist die Verwendung von CLO gestattet, fallen keine Nachsorgekosten für das deponierte Material an. Deshalb ist es für MBA’s in diesen Ländern interessant, möglichst viel Masse dieser CLO-Fraktion zu erzeugen. Da der Störstoffgehalt gesetzlich limitiert ist, liegt das Augenmerk darin, dass möglichst viel organische Masse aus dem Grobkorn (> 15 mm) in diese Feinfraktion gelangt. Dadurch reduzieren sich die zu deponierende Masse und somit auch die Kosten für die Entsorgung.

Bei unseren Untersuchungen wurden Korngrößenverteilungen bei verschiedenen Zeitpunkten im Anlagenbetrieb durchgeführt, um den Einfluss der Betriebweise zu erheben. In Tabelle 4 sind die gewonnenen Analysedaten der Korngrößenverteilungen des Outputmaterials gelistet.

Tabelle 4: Korngrößenverteilung des Outputmaterials

		MBA ohne Vergärung	**MBA mit Vergärung (optimale Bedingungen)**	**MBA mit Vergärung (ungünstige Bedingungen)**
Output	**> 50 mm**	1 %	1%	6 %
	25-50 mm	16 %	11%	20 %
	15-25 mm	13 %	16%	43 %
	< 15 mm	70 %	72%	31 %

Eine Korngrößenverteilung des Outputmaterials einer MBA ohne Vergärung sowie einer MBA mit Vergärung bei optimalen und ungünstigen Bedingungen ist in Abbildung 6 dargestellt

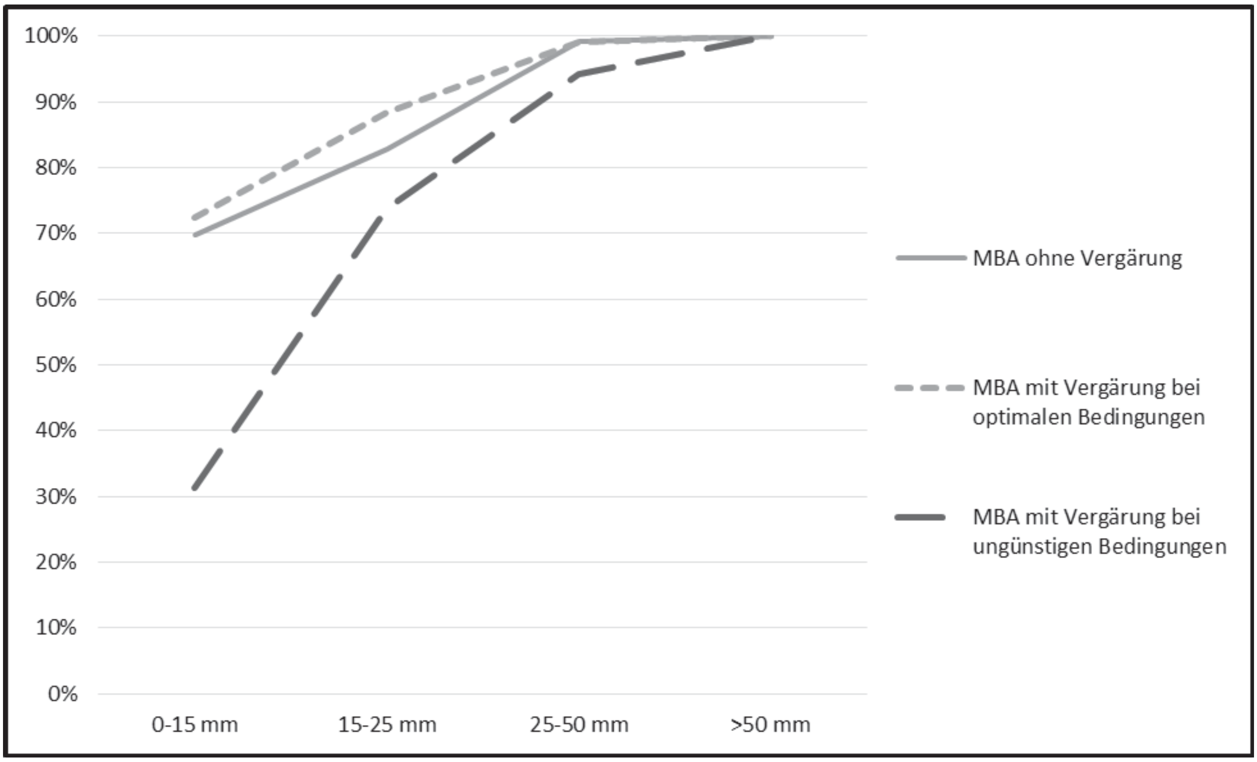

Abbildung 6: Korngrößenverteilungen der MBA ohne Vergärung sowie der MBT mit Vergärung bei optimalen und ungünstigen Bedingungen

Die Untersuchungen ergaben, dass die Korngrößenverteilung einer MBA mit Vergärung bei optimaler Abfallmischung der Korngrößenverteilung einer MBA ohne Vergärung glich. Bei guter Abfalldurchmischung verschob sich die Korngröße in Richtung CLO-Fraktion. Dies ergab, dass 70 % des Abfalloutputs nach der Siebung als CLO verwendet werden konnte und nur 30 % Masse als Deponiefraktion entsorgt werden musste.

Bei schlechter Durchmischung der Abfälle verblieb die Hälfte der organischen Masse, die ursprünglich in der CLO-Fraktion vorhanden war, durch Klumpenbildung in der Fraktion 15-25 mm. Die Folge war, dass eine schlechtere Siebleistung auftrat, wodurch nur 31 % der gesamten Outputmasse nach der Siebung in der CLO-Fraktion vorhanden waren. 69 % der Outputmasse mussten als Deponiefraktion entsorgt werden.

Die Herstellung einer homogenen Abfallmischung hat somit einen hohen Einfluss auf die Korngrößenverteilung des Outputmaterials. Für MBA's mit Vergärungsstufe, die die Möglichkeit der CLO-Produktion haben, ist die Herstellung einer ausgewogenen homogenen Mischung von Gärrest und MBA-Material sehr wichtig.

2.3 Wirtschaftlichkeit

Allgemein betrachtet sind für den ökonomischen Betrieb einer MBA folgende Bedingungen zu erfüllen:

- ✓ Die Betriebskosten der Anlage sollten möglichst gering sein
- ✓ Der Wassergehalt des zu deponierenden Materials sollte möglichst gering sein
- ✓ Deponieablagerungskriterien sind einzuhalten
- ✓ Falls CLO anerkannt ist, sollte möglichst viel organische Masse in der CLO-Fraktion (0-15 mm) enthalten sein

2.3.1 Deponieablagerungskriterien

Aus Sicht der Deponieablagerungskriterien kann gesagt werden, dass eine Vergärung aufgrund der Materialeigenschaften von Gärrest (siehe Punkt 2.2.1 Abfallmanagement) nicht als Stand-Alone-Technologie umgesetzt werden kann. Damit aus dem Gärrest ein ablagerungsfähiges Material wird, ist immer eine nachgeschaltete Behandlung notwendig. Eine kostengünstige Möglichkeit für die Nachbehandlung von Gärrest stellt hier die aerobe biologische Abfallbehandlung dar.

2.3.2 Anlagenbetrieb

Durch den Bau und Betrieb einer Vergärungsanlage entstehen zusätzliche Kosten. Diese Mehrkosten sollten für einen ökonomischen Betrieb durch den Stromertrag, den die Vergärung erzielt, gedeckt sein. Je nach Land ist der Einspeisetarif unterschiedlich hoch, deshalb ist eine länderspezifische Betrachtung der Wirtschaftlichkeit notwendig.

Für den Fall, dass die Vergärungsstufe für Wartungs- und Instandhaltungsarbeiten abgeschaltet werden muss, können trotzdem die gesamten Abfallmengen übernommen werden. In der Praxis hat sich gezeigt, dass in der nachgeschalteten aeroben biologischen Abfallbehandlung ausreichend Kapazitäten bestehen, den gesamten Abfall zu behandeln.

2.3.3 Wassermanagement

Bei der aeroben und anaeroben Abfallbehandlung entstehen Abwässer, die einer Behandlung unterzogen werden müssen. Um die Kosten möglichst gering zu halten, sollten die entstandenen Abwässer innerhalb der eigenen Anlage verwertet werden.

Grundsätzlich besteht bei der aeroben biologischen Abfallbehandlung die Möglichkeit, diese Abwässer anlagenintern als Bewässerungswasser einzusetzen. Für die Beurteilung, wie viel Abwasser verwertet werden kann, sind detaillierte Kalkulationen (Massen- und Energiebilanzen, Wasserbilanzen) notwendig, in denen die komplexe Struktur der Gesamtanlage (Vergärung + aerobe Nachbehandlung) betrachtet wird. Dabei ist auch zu berücksichtigen, dass der Wassergehalt des Outputmaterials niedrig bleibt. Eine Beispielrechnung für den Wassergehalt und dessen Einfluss auf die Kosten ist in Abbildung 7 dargestellt.

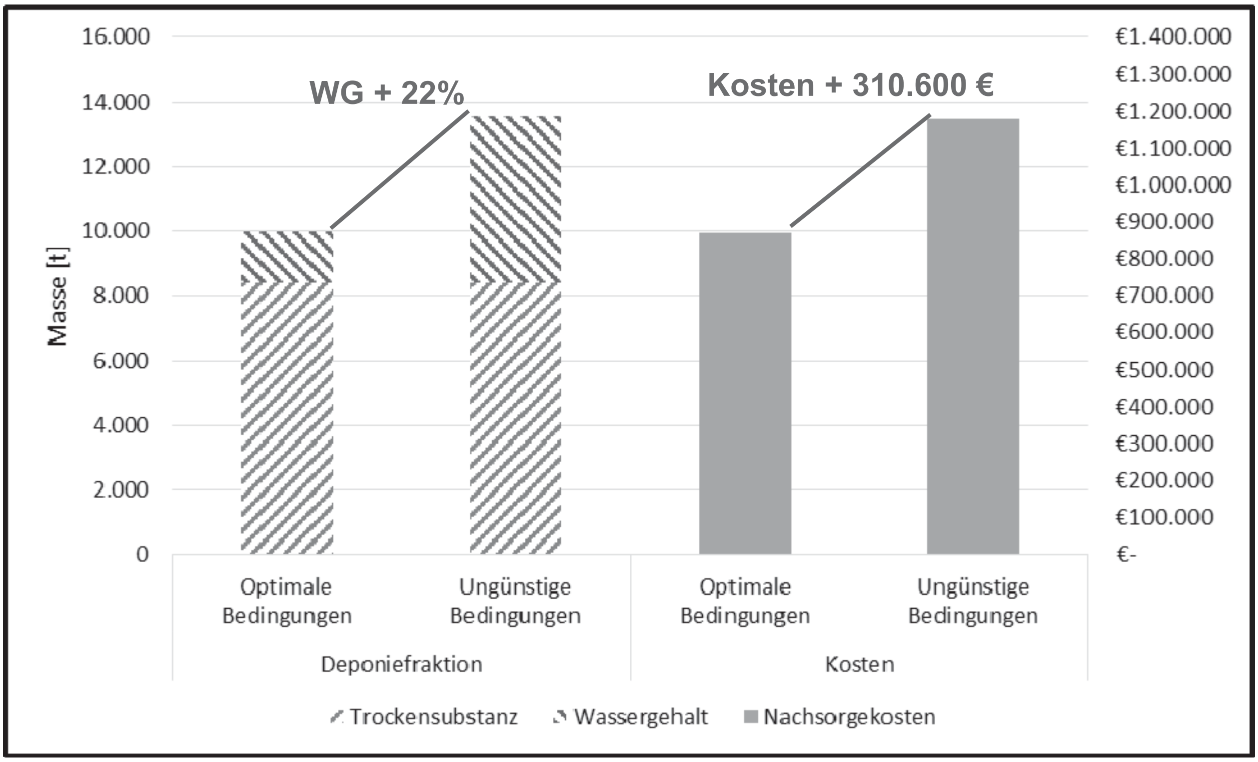

Abbildung 7: Beispielrechnung von Wassergehalt und Kosten

In diesem Beispiel weist die Deponiefraktion (gesamt 10.000 t/a) den Wassergehalt der optimalen Bedingungen von 15 % auf. Erhöht sich der Wassergehalt auf 38 % aufgrund ungünstiger Bedingungen, fallen zusätzlich 3.570 Tonnen Wasser pro Jahr an, die in die Deponie eingelagert werden. Bei einer Altlastensanierungsabgabe (kurz ALSAG) von € 87/t, die in Österreich für die Deponierung von Abfällen zu zahlen ist, fallen nur durch den höheren Wassergehalt zusätzliche Kosten von ca. € 310.600 an.

Somit gilt es, den Wassergehalt des Outputmaterials so gering wie möglich zu halten, weil sonst unnötige Kosten für die Ablagerung von „Wasser“ auf der Deponie entstehen.

2.3.4 CLO-Produktion

Die Korngrößenverteilung des Outputmaterials ist für MBA’s, die CLO für Deponiebegrünungszwecke produzieren, sehr interessant. In Abbildung 8 ist eine Verteilung des Outputmaterials (aufgeteilt in CLO [< 15 mm] und Deponiefraktion [> 15 mm]) bei optimalen sowie ungünstigen Bedingungen dargestellt.

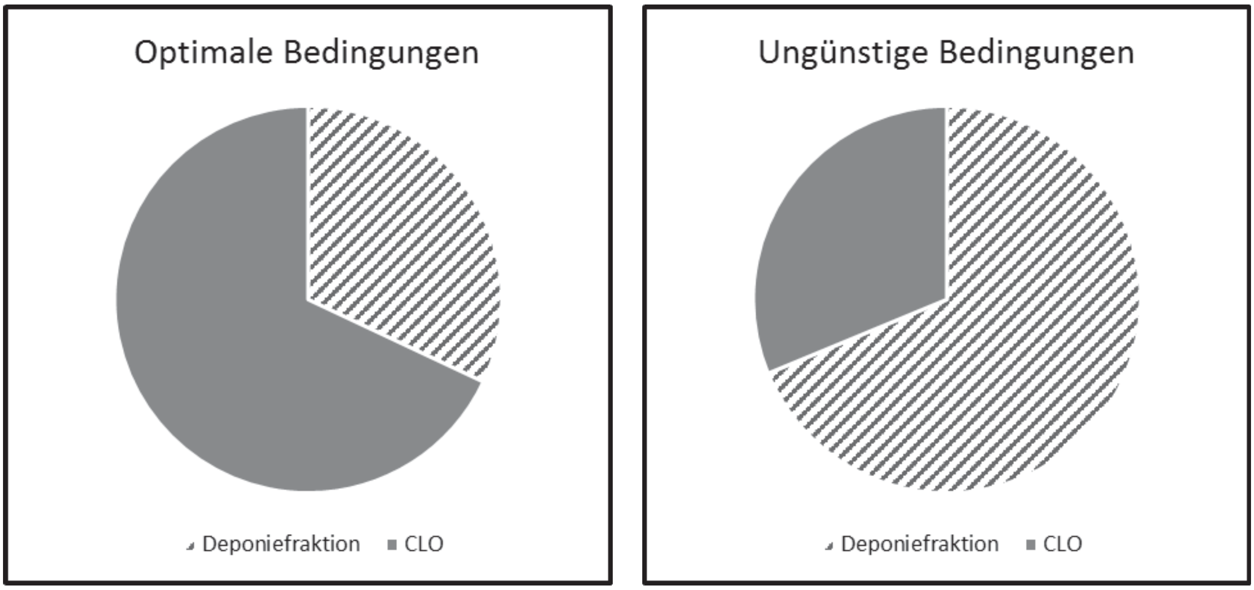

Abbildung 8: Exemplarische Massenbilanz mit Berücksichtigung des Anlagenbetriebes

In unseren Analysen konnte festgestellt werden, dass bei einem optimalen Anlagenbetrieb etwa 70 % der Outputmasse in der CLO-Feinfraktion (< 15 mm) lag. Nur 30 % der Abfallmenge musste als Deponiefraktion entsorgt werden.

Traten ungünstige Bedingungen auf, bildeten sich viele Abfallklumpen. In unseren Versuchen führten diese dazu, dass 70 % der Outputmasse in der Deponiefraktion zu finden war, während nur 30 % in der CLO-Fraktion vorhanden war.

Bei MBA’s mit CLO-Produktion können sich durch einen ungünstigen Anlagenbetrieb somit die Ablagerungskosten verdoppeln.

3 Fazit

Im Rahmen von Versuchen wurde festgestellt, dass der Betrieb einer MBA mit vorgeschalteter Vergärungsstufe deutlich komplexer ist als eine MBA ohne Vergärung. Voraussetzung für eine erfolgreiche aerobe Nachbehandlung ist die Herstellung optimaler Bedingungen. Vor der Realisierung einer MBA mit vorgeschalteter Vergärungsstufe ist anhand detaillierter Bilanzen (Massen-, Energie- und Wasserbilanzen) zu prüfen, ob eine Umsetzung sowohl technisch als auch wirtschaftlich sinnvoll ist.

Im dieser Studie wurden mehrere MBA's untersucht, jedoch wurden nur auf 2 Anlagen Versuche durchgeführt. Durch die Anzahl der Untersuchungen konnten aber Tendenzen ermittelt werden, die in weiteren Versuchen verifiziert werden. Durch Variation der Vergärungstechnologie müssen Parameter angeglichen werden und dürfen/können nicht direkt auf andere Anlagen übertragen werden.

4 Literatur

Europäischer Rat (Hrsg.) 1999 EU Deponierichtlinie 1999/31/EG

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Umstellung der MBA Gescher auf die kombinierte Restmüll- und Bioabfallbehandlung

Martin Idelmann

Entsorgungs-Gesellschaft Westmünsterland

Conversion of the MBT Gescher into a combined organic and residual waste treatment plant

Abstract

The Waste Management Company Westmünsterland "EGW" has a mechanical biological waste treatment plant (MBT-plant) for the pretreatment of residual waste in preparation to its disposal in landfills, which was put in operation in 2000. The MBT plant was converted in 2005 to meet new legal requirements. A regenerative thermal oxidizer (RTO) has been added to the biofilter for thermal exhaust air treatment and the tunnel composting was supplemented by an aerated windrow composting unit. Since 2012, the MBT plant was converted towards the biological treatment of separately collected organic waste. The prerequisites for this step were created by cooperative agreements between the districts of Borken and Recklinghausen and the city of Dortmund. The responsibility for the treatment of separately collected organic waste was transferred by the city of Dortmund and the district of Recklinghausen has been to the district of Borken, which delegated the task to its affiliated company, the EGW. By processing contingents from Dortmund, 50 per cent of the MBA plants were converted towards the treatment of organic waste in 2012. In 2014, a full conversion of the treatment of the organic waste was achieved, as additional organic waste was accrued from the district of Recklinghausen. Due to these changes, the RTO could be decommissioned. In future the exhaust air will be cleaned by the present biofilter. Since 2014, the residual waste from the district of Borken is only subjected to mechanical treatment and subdivided into high- and low-calorific fractions for thermal recovery in RDF (Refuse Derived Fuels) plants and incineration plants.

Inhaltsangabe

Die Entsorgungs-Gesellschaft Westmünsterland mbH (EGW) hat 2000 ihre Mechanisch Biologische Restmüllbehandlungsanlage (MBA) zur Konditionierung von Restmüll für die Ablagerung auf Deponien in Betrieb genommen. Die MBA wurde 2005 an die neuen gesetzlichen Anforderungen angepasst. Zur Abluftbehandlung wurde der Biofilter durch eine Regenerative Thermische Oxidationsanlage (RTO) ergänzt. Die Tunnelkompostierung wurde um eine belüftete Tafelmietenkompostierung ergänzt. Seit 2012 wurde die MBA auf die biologische Behandlung von Bioabfällen umgestellt. Die Basis für die Umstellung wurde durch die Kooperation zwischen dem Kreis Borken und der Stadt Dortmund sowie dem Kreis Recklinghausen geschaffen. Im Rahmen der Ko-operationen haben die Stadt Dortmund und der Kreis Recklinghausen ihre Aufgabe für die Behandlung von Bioabfällen an den Kreis Borken delegiert, der diese Aufgabe auf seine Tochter-Gesellschaft die EGW übertragen hat. Mit den Mengen aus der Stadt Dortmund wurde 2012 die Hälfte der MBA auf die Behandlung von Bioabfällen umgestellt. Mit den Mengen aus dem Kreis Recklinghausen wurde die MBA 2014 vollständig umgestellt. Durch die Umstellung konnte die RTO außer Betrieb genommen werden. Die Abluft wird zukünftig mit dem vorhandenen Biofilter gereinigt. Der Restmüll aus dem Kreis

Borken wird seit 2014 nur noch mechanisch in eine heizwertreiche und eine heizwertarme Fraktion getrennt, die einer thermischen Verwertung in Ersatzbrennstoffkraftwerken und Müllverbrennungsanlagen zugeführt werden.

Keywords

MBT, combined waste treatment, organic waste, residual waste, RTO, biofilter,

Anlagenumstellung, MBA, kombinierte Abfallbehandlung, Bioabfall, Restmüll, RTO, Biofilter

1 Aufgaben der Entsorgungs-Gesellschaft Westmünsterland

Die Entsorgungs-Gesellschaft Westmünsterland mbH (EGW) erledigt als 100-prozentige Tochter des Kreises Borken die im Verantwortungsbereich des Kreises liegenden Aufgaben der Abfallbehandlung und –verwertung:

- Restmüllbehandlung (MBA);
- Bioabfallkompostierung (BAK) und -vergärung (VGA);
- Grüngutkompostierung (GAK);
- Schadstoffsammlung.

Des Weiteren ist die EGW für die Nachsorge der zwei Hausmülldeponien des Kreises in Borken-Hoxfeld und Ahaus-Alstätte verantwortlich. In diesem Verantwortungsbereich kümmert sich die EGW um die:

- Sickerwasservorbehandlung;
- Deponiegasfassung;
- Errichtung der Oberflächenabdichtung in Ahaus-Alstätte bis 2015;
- Errichtung der Oberflächenabdichtung in Borken-Hoxfeld bis 2018.

Im Bereich der Abfallsammlung betreibt die EGW für 12 Städte und Gemeinden des Kreises Wertstoffhöfe, um den Bürgern hochwertige und haushaltsnahe Entsorgungsmöglichkeiten anzubieten. Der Kreis Borken hat frühzeitig damit begonnen, die Getrenntsammlung von Wertstoffen zu fördern. Pro Einwohner werden jährlich gut 210 kg Bio- und Grüngut erfasst und von der EGW verwertet. Im Landesdurchschnitt (NRW) werden in vergleichbaren Siedlungsgebietsstrukturen (< 500 Einwohner/km²) 135 kg erfasst.

Zur Deckung des Bedarfs an elektrischer Energie hat die EGW Anlagen zur Erzeugung von regenerativer Energie errichtet. Mit Hilfe von zwei Windkraftanlagen und einem

BHKW wird der Energiebedarf am Hauptstandort in Gescher zu mehr als 90 % gedeckt. In Schwachwindphasen erfolgt ein Bezug von elektrischer Energie. In Summe produziert die EGW deutlich mehr elektrische Energie als sie selbst konsumiert. Die Überschüsse werden auf Basis des EEG ins Netz eingespeist.

Abbildung 1: Kreis Borken - zentrale Lage des Hauptstandortes der EGW

2 Abfallbehandlungsanlagen am Standort Gescher

Am Verwaltungsstandort der EGW in Gescher wird der Großteil der Abfälle des Kreises Borken behandelt (Abbildung 2).

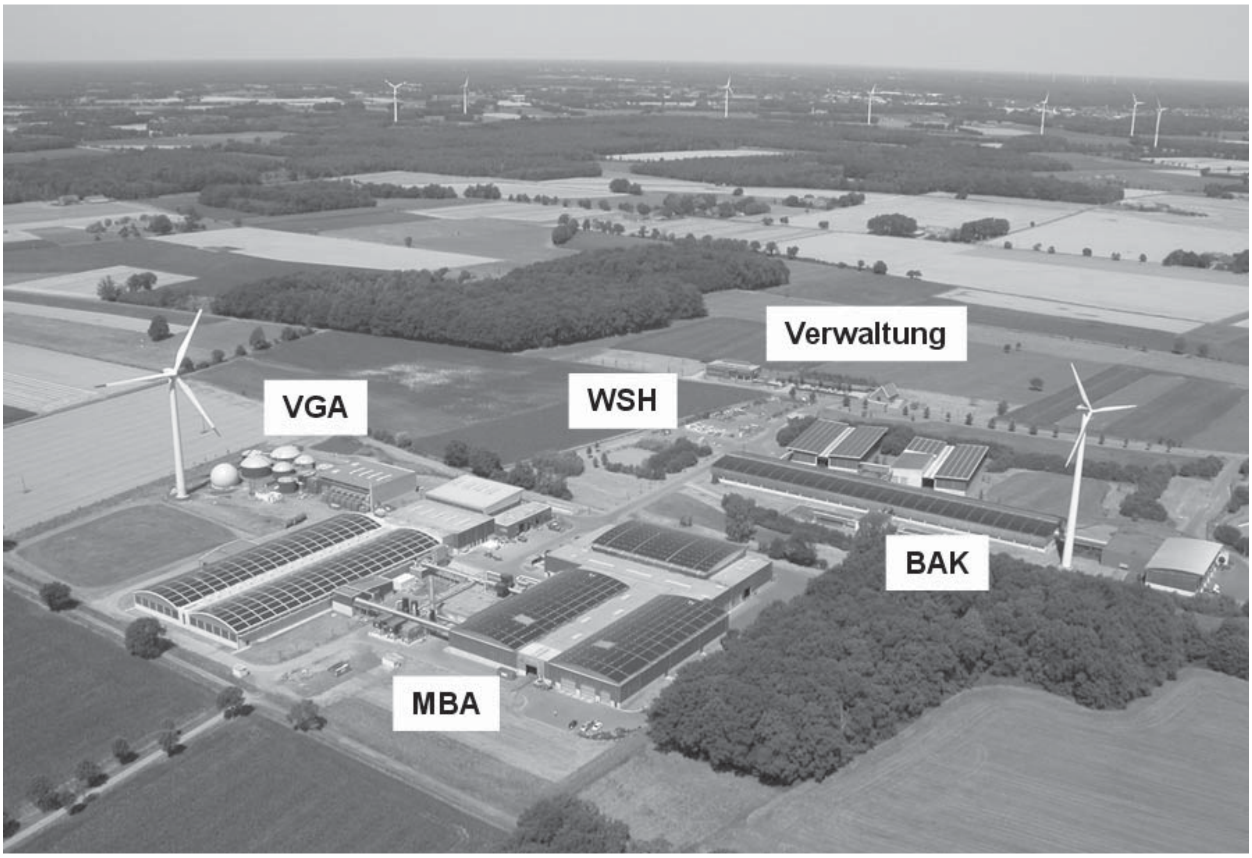

Abbildung 2: Abfallbehandlungsanlagen der EGW am Standort Gescher

Bereits 1986 wurde das Kompostwerk (Tafelmietenkompostierung) zur Verwertung der Bioabfälle des Kreises Borken in Betrieb genommen.

Ab 2000 wurde die Alt-MBA zur Vorbehandlung des Restmülls vor der Ablagerung auf der kreiseigenen Deponie in Borken-Hoxfeld betrieben. 2004 wurde die MBA im Hinblick auf die ab 2005 geltenden Ablagerungskriterien der DepV zur Ablagerung von mechanisch biologisch vorbehandelten Abfällen um eine geschlossene Nachrottehalle erweitert. 2005 wurde das Abluftbehandlungskonzept an die Anforderungen der 30. BImSchV angepasst. Hierzu wurden 3 RTO-Linien in Betrieb genommen, um die stark belastete Abluft aus der Intensiv- und Nachrotte zu reinigen. Die bis dahin zur Abluftbehandlung vorgesehenen geschlossenen Biofilteranlagen wurden vom stark belasteten Abluftstrom entkoppelt und dienten seither zur Behandlung von schwach belasteter Hallenabluft. Die in den RTO-Linien und im Biofilter gereinigte Abluft wurde über einen Abluftkamin emittiert und mittels Abluftmessstelle gemäß der 30. BImSchV überwacht.

Im Jahr 2004 wurde am Standort Gescher eine Vergärungsanlage zur Behandlung von Klärschlämmen in Betrieb genommen. Diese Anlage wurde später auf die Verarbeitung von Bioabfällen und organischen Reststoffen umgestellt.

3 Neuausrichtung der Bioabfallbehandlung am Standort Gescher im Anlagenverbund

Die Neuausrichtung der Abfallbehandlung am Standort Gescher zielt darauf ab, die drei Abfallbehandlungsanlagen stärker miteinander zu vernetzen und Synergieeffekte zu nutzen. Des Weiteren beabsichtigt die EGW ihre Kernkompetenz - die biologische Behandlung von Abfällen - mit der Intensivierung der Bioabfallverarbeitung zu stärken. Der angestrebte Anlagenverbund am Standort Gescher ist in Abbildung 3 dargestellt.

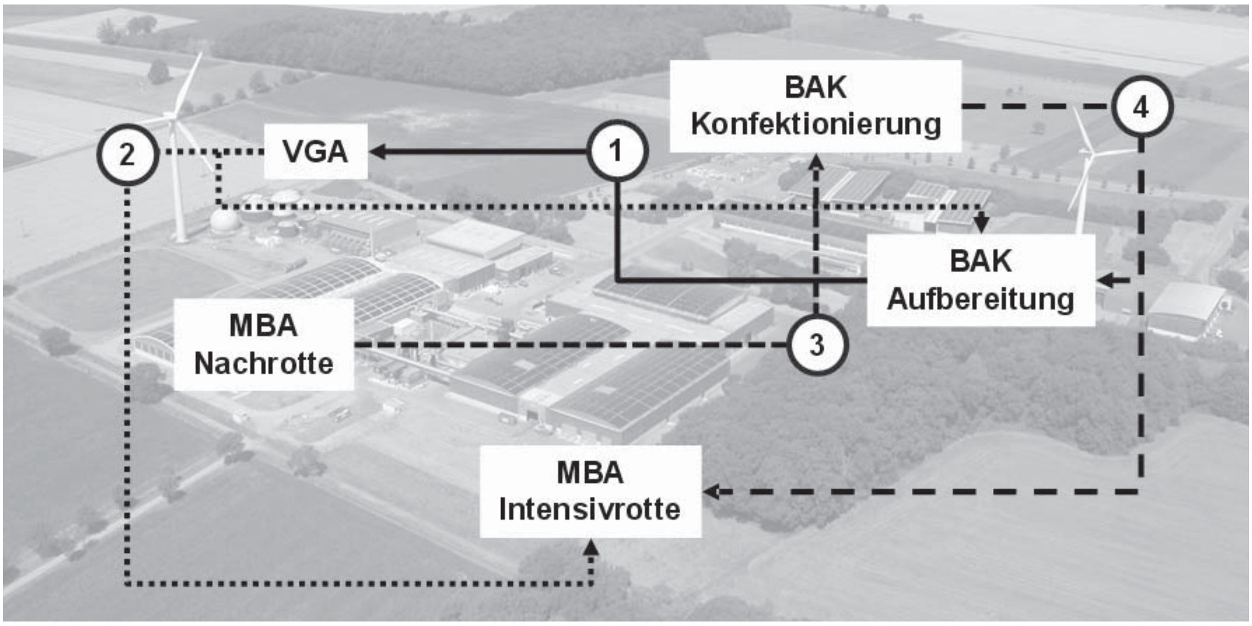

Abbildung 3: Anlagenverbund am Standort Gescher

1. Im Kompostwerk wird nach der Aufbereitung (Zerkleinern und Sieben) aus der Bioabfallfraktion < 80 mm mit Hilfe von Siebschneckenpressen eine Bioabfallsuspension hergestellt. Die Biosuspension wird in der Vergärungsanlage zur Biogasgewinnung eingesetzt.

2. Die flüssigen Gärreste der Vergärungsanlage werden zur Deckung des für die Bioabfallkompostierung erforderlichen Wasserbedarfs sowohl im Kompostwerk als auch in der Tunnelrotte der MBA eingesetzt. Bei der Rückführung kann auf eine Fest-Flüssig-Trennung verzichtet werden.

3. Die in der MBA hergestellten Fertigkomposte (Rottegrad 5) werden zur Konfektionierungsanlage des Kompostwerkes transportiert. Die abgesiebten Komposte (< 10 mm) werden im Kompostlager zwischengelagert und überwiegend in die Erdenindustrie vermarktet.

4. Die bei der Konfektionierung anfallenden Grobkomposte (10-40 mm und 40-80 mm) werden zur Deckung des für die Bioabfallkompostierung erforderlichen Struk-

turmaterials, das teilweise auch durch Grüngut gedeckt wird, ins Kompostwerk und in die MBA zurückgeführt.

5. Die bei der Verstromung von Biogas erzeugte elektrische Energie wird neben der in den beiden Windkraftanlagen erzeugten Energie zur Deckung des Eigenstrombedarfs am Standort Gescher genutzt.

4 Umstellung der MBA auf die Verarbeitung von Bioabfällen in zwei Schritten

4.1 Umstellung unter dem Regime der 30. BImSchV

Durch eine Interkommunale Kooperationsvereinbarung zwischen der Stadt Dortmund und dem Kreis Borken im Bereich der Bioabfall- und Restmüllentsorgung hat der Kreis Borken die Behandlung von jährlich ca. 20.000 Mg Bioabfall aus Dortmund übernommen. Im Gegenzug wurde die Stadt Dortmund mit der Behandlung von jährlich ca. 15.000 Mg Restmüll aus dem Kreis Borken beauftragt. Durch diese Kooperation werden dem Standort Gescher seit dem 01.01.2012 jährlich zusätzlich 20.000 Mg Bioabfall zugeführt und im Rahmen einer Logistikoptimierung mit dem Ziel der Vermeidung von Leerfrachten ca. 15.000 Mg Restmüll entzogen.

Die Intensivrotte und die Nachrotte der MBA Gescher sind zweischiffig konzipiert und ermöglichen die getrennte Behandlung von Restmüll und Bioabfällen. Da auch die Abluftführung und das Mietenbewässerungssystem in getrennten Abschnitten erfolgt, konnte die getrennte Behandlung von Restmüll und Bioabfällen unter einem Dach mit minimalen Umbaumaßnahmen erreicht werden.

Die Trennung von Prozesswasser konnte durch Umprogrammieren der Steuerungssoftware erreicht werden.

Zur getrennten Abluftführung musste die im Jahr 2005 getrennte Verbindung der Bioabfall-Tunnelreihe zum Biofilter wieder hergestellt werden und der bestehende Abluftpfad zur RTO getrennt werden. Die Abluft der Nachrottehalle wurde vollständig - auch die der Restmüllnachrotte - zum Biofilter geleitet. Hierzu musste die Voraussetzung gemäß § 16 der 30. BImSchV erfüllt werden, dass im Rahmen der Intensivrotte von Restmüll die Atmungsaktivität (AT4) auf weniger als 20 mg O_2/g reduziert wird, was durch monatliche Untersuchungen gegenüber der Genehmigungsbehörde nachzuweisen war. Diese Bedingung konnte bei einem durchschnittlichen AT4 von 10 mg O_2/g problemlos erfüllt werden.

Zur Ableitung der mittels Biofilter gereinigten Abluft musste ein neuer Kamin errichtet werden, um die Abluft aus der Restmüllbehandlung gemäß den Anforderungen der 30. BImSchV separat messen und überwachen zu können.

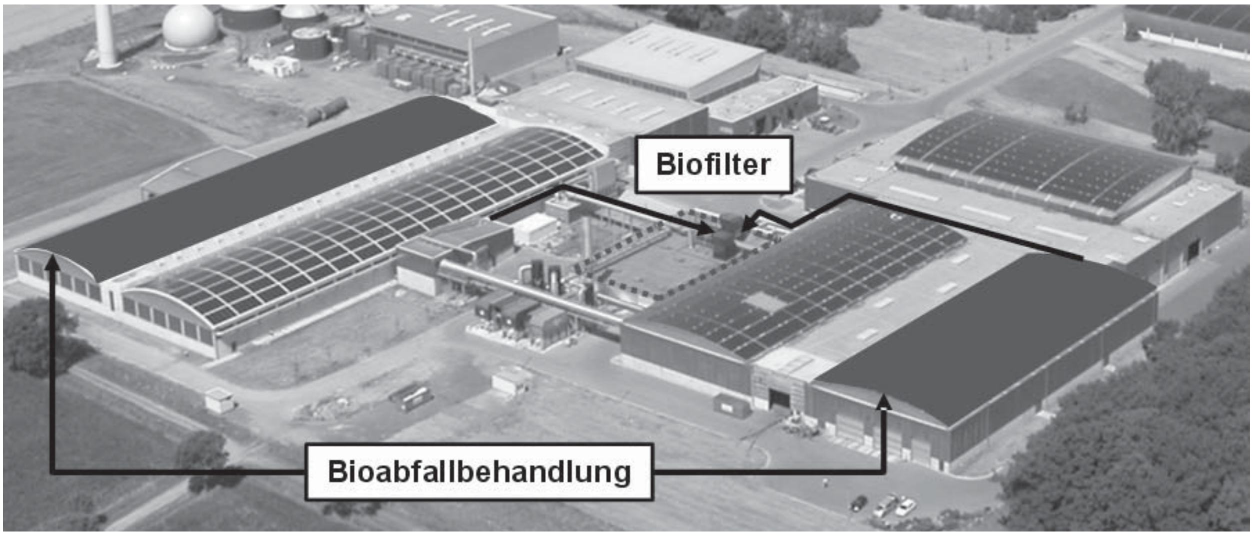

Abbildung 4: Getrennte Bioabfall- und Restmüllbehandlung unter gemeinsamen Dächern

4.2 Umstellung unter dem Regime der 4. BImSchV

Durch eine weitere interkommunale Kooperation zwischen dem Kreis Recklinghausen und dem Kreis Borken im Bereich der Bioabfallentsorgung hat der Kreis Borken die Behandlung von jährlich 40.000 Mg Bioabfall aus dem Kreis Recklinghausen übernommen. Durch diese Kooperation werden dem Standort Gescher für einen Zeitraum von 10 Jahren seit dem 01.01.2014 jährlich 40.000 Mg Bioabfall zugeführt. Dies stellt die Basis für eine vollständige Umstellung der biologischen Behandlungskapazitäten der MBA auf die Verarbeitung von Bioabfällen dar. Der Restmüll des Kreises Borken wird auch zukünftig in der MBA angenommen, allerdings nur noch mechanisch aufbereitet. Durch das Umnutzungskonzept wechselt die MBA aus dem Regime der 30. BImSchV in die 4. BImSchV. Im Wesentlichen ist hiervon die Abluftbehandlung betroffen. Zukünftig wird die gesamte Abluft kaskadenförmig genutzt und zum Schluss mittels saurer Wäsche und Biofilter gereinigt (Abbildung 5). Die RTO wird außer Betrieb genommen.

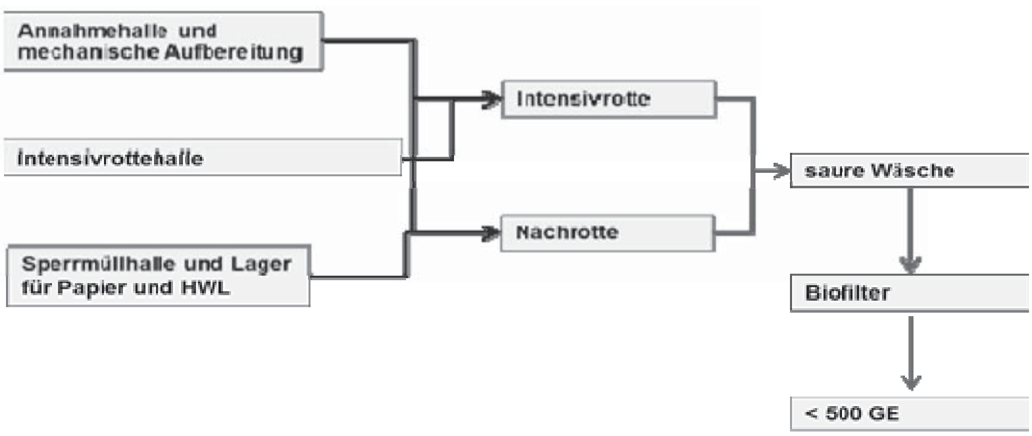

Abbildung 5: Abluftbehandlungskonzept nach Umstellung der MBA

4.2.1 Mechanische und biologische Bioabfallbehandlung

Zur Aufbereitung der Bioabfälle wird die in der MBA vorhandene Technik, bestehend aus Zerkleinerer, Trommelsieb und Windsichter eingesetzt werden. Durch die mechanische Aufbereitung erfolgt

- ein Materialaufschluss, der den Rotteprozess fördert;
- ein Abtrennen von Störstoffen, die durch Restmülleinträge (Fehlwürfe) bei der Sammlung nicht gänzlich unterbunden werden können.

Insbesondere durch den Windsichter werden die kunststoffhaltigen Störstoffanteile vor der biologischen Behandlung effektiv abgetrennt.

Die für die biologische Behandlung vorhandene Anlagenkapazität in der Intensivrottehalle (26 Tunnel mit je 300 m³ Kapazität) und Nachrottehalle (32 Rottefelder mit je 385 m³) beträgt 58.000 Mg/a an aufbereitetem Bioabfall plus 6.000 Mg/a Grüngut, wobei die Behandlung auf die Produktion von ausgereiften Fertigkomposten abzielt. Unter Berücksichtigung der Abtrennung von 3 % Störstoffen und 0,2 % Eisenschrott, entspricht die Verarbeitungskapazität der MBA 60.000 Mg/a Rohbioabfall.

Die in der MBA vorhandene Rottekapazität ist auf eine mittlere Rottezeit von knapp 13 Wochen abgestimmt. Zum Durchsatz von jahreszeitlich bedingten Abfallpeaks (125 %) reicht die Rottekapazität für eine Rottezeit von 10 Wochen. Selbst extreme Abfallpeaks von 140 % ermöglichen eine Mindestrottezeit von 9 Wochen. Die in der MBA gegebenen Rottekapazitäten stellen eine gesicherte Basis für die Erzeugung von hochwertigen und besonders ausgereiften Fertigkomposten dar, die primär zur Herstellung von Erden vorgesehen sind.

Zur Bewässerung des Rottegutes während der Intensivrotte wird neben anlagenbürgem Prozesswasser aus der Bioabfallkompostierung und Oberflächenwasser von den Dach- und Verkehrsflächen der MBA auch flüssiger Gärrest der Vergärungsanlage verwendet. Durch den Einsatz von flüssigen Gärresten sollen Nährstoffe in eine lager- und transportwürdige Form überführt werden.

Der in der MBA erzeugte Fertigkompost wird zum Kompostwerk transportiert und dort mit Hilfe der Feinaufbereitungstechnik in abgabefähigen Kompost (Siebdurch-gang) und Grobkompost (Siebüberlauf) fraktioniert.

4.2.2 Mechanische Aufbereitung von kommunalem Restmüll

Kommunaler Restmüll (46.500 Mg/a) aus dem Kreisgebiet wird zukünftig nur noch mechanisch aufbereitet. Im Zuge der mechanischen Aufbereitung wird der Restmüll durch Zerkleinern und Sieben in eine heizwertreiche und eine heizwertarme Fraktion getrennt. Die heizwertreiche Fraktion wird weiterhin zur Bedienung bestehender Lieferverpflichtungen in EBS-Anlagen verwendet. Die heizwertarme Fraktion wird primär in Müllverbrennungsanlagen zur Optimierung des Verbrennungsmenüs geliefert.

Anschrift der Verfasser(innen)

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Wiederherstellung der EG-Konformität von Anlagen nach Umbau und Erweiterung

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Re-establishment of EC-Conformity after conversion or enhancement of machinery

Abstract

Directive 2006/42/EC regulates the EC declaration of conformity of machinery with European regulations for safety and handling standards. The placing on the market of new machinery should be harmonized by this directive. In the case of conversion or enhancement of an existing machinery a re-establishment of the EC-Conformity should become necessary.

Inhaltsangabe

Die EG-Richtlinie 2006/42/EG regelt die EG-weite Konformität für das Inverkehrbringen von Anlagen und Maschinen in Bezug auf Handhabung und Sicherheit von Anlagen.
Im Falle einer Erweiterung oder eines Umbaus einer bestehenden Anlage kann eine neue Konformitätsbewertung notwendig werden.

Keywords

EG-Konformität, CE-Kennzeichnung, 2006/42/EG, Altmaschine; Konformitätserklärung, Inverkehrbringen, Sicherheit, Maschinenrichtlinie

EC declaration of conformity, CE marking, 2006/42/EC, Conformity; Safety, Handling

1 Die Europäische Richtlinie 2006/42/EG (Maschinenrichtlinie)

1.1 Grundlagen

Die Richtlinie 2006/42/EG des europäischen Parlaments und des Rates vom 17. Mai 2006 muss seit dem 29. Dezember 2009 angewendet werden.

Sie gilt für die folgenden Produktkategorien:

a. Maschinen;

b. auswechselbare Ausrüstungen;

c. Sicherheitsbauteile;

d. Lastaufnahmemittel;

e. Ketten, Seile und Gurte;

f. abnehmbare Gelenkwellen;

g. unvollständige Maschinen.

Im „Leitfaden für die Anwendung der Maschinenrichtlinie 2006/42/EG“ wird klargestellt, dass

- „Maschinen im weiteren Sinne“ die Produktkategorien a bis f umfassen,
- „Maschinen im engeren Sinne“ der Produktkategorie a entsprechen.

Daher wird die Richtlinie 2006/42/EG auch kurz als „**Maschinen**richtlinie“ bezeichnet.

Der Leitfaden vom Juni 2010 wird auf der EUROPA-Website der Kommission in zur Zeit 21 Sprachen veröffentlicht. Jedoch wird nur die englische Fassung von der Kommission überprüft. Daher sollte in Zweifelsfällen die englische Version als Grundlage herangezogen werden. Link:
http://ec.europa.eu/enterprise/sectors/mechanical/files/machinery/guide-appl-2006-42-ec-2nd-201006_en.pdf

1.2 Leitfaden für die Umsetzung der Richtlinie

Der deutsche Leitfaden liefert den folgenden Hinweis zum Thema des vorliegenden Beitrags:

> *Die Maschinenrichtlinie gilt auch für Maschinen, die auf gebrauchten Maschinen basieren, welche so wesentlich umgebaut oder wieder aufgebaut worden sind, dass sie als neue Maschinen angesehen werden können. Es stellt sich damit die Frage, ab wann ein Umbau einer Maschine als Bau einer neuen Maschine gilt, welche der Maschinenrichtlinie unterliegt. Es ist nicht möglich, präzise Kriterien zu formulieren, mit denen diese Frage in jedem Einzelfall beantwortet wird. Im Zweifel ist es für die Person, die eine derartige wieder aufgebaute Maschine in Verkehr bringt oder in Betrieb nimmt, ratsam, mit den zuständigen einzelstaatlichen Behörden Rücksprache zu halten.*

Der „Blue Guide“ vom April 2014 liefert als weiterer Leitfaden der Europäischen Kommission Konkreteres, wobei das „Produkt“ auch eine Maschinenanlage sein kann:

> *"Ergibt die Risikobewertung, dass die Art der Gefahr sich geändert und das Risiko zugenommen hat, so muss das modifizierte Produkt wie ein neues Produkt behandelt werden".*
>
> *… Außerdem gehen die Herstellerverpflichtungen auf denjenigen über, … der ein Produkt wesentlich verändert oder umbaut (wodurch ein neues Produkt entsteht), um es in Verkehr zu bringen.*

Die Erweiterung einer Anlage um einen neuen Anlagenteil, ist mit einer Zunahme des Risikos verbunden. Grund: Das Risiko des hinzugefügten Anlagenteils ist immer > 0.

Ausnahme: Das Risiko der alten Anlage wird soweit reduziert, dass das neu hinzukommende Risiko des hinzugefügten Anlagenteils gerade ausgeglichen wird. Weil dies schwer nachzuweisen ist, sollte sicherheitshalber immer von einer Risikozunahme ausgegangen werden.

1.3 Zweck der Maschinenrichtlinie

- Gewährleistung des freien Verkehrs von Maschinen im EU-Markt,
- hohes Niveau an Sicherheit und Gesundheitsschutz bei Maschinen,
- Harmonisierung (Angleichung) der Anforderungen an Sicherheit und Gesundheitsschutz.

Dazu müssen die Erzeugnisse grundlegende Sicherheits- und Gesundheitsschutzanforderungen erfüllen, die in den Anhängen der Maschinenrichtlinie aufgeführt sind.

Die Maschinenrichtlinie gilt für das Inverkehrbringen und die Inbetriebnahme innerhalb des europäischen Wirtschaftsraumes (EWR) sowie der Schweiz und der Türkei.

Es ist zu unterscheiden zwischen der Inbetriebnahme von Maschinen und der Benutzung von Maschinen, welche von den Mitgliedstaaten geregelt werden kann.

So liefert die deutsche Betriebssicherheitsverordnung (BetrSichV) in der ab dem 1.6.2015 gültigen Fassung folgenden Hinweis:

> *Das Vorhandensein einer „CE-Kennzeichnung“ am Arbeitsmittel entbindet nicht von der Pflicht zur Durchführung einer Gefährdungsbeurteilung.*

Von Bedeutung für das Verständnis dieses Beitrags sind folgende Begriffe aus der Maschinenrichtlinie. Der Begriff

a. "**Maschine**" bezeichnet

eine **mit** einem anderen **Antriebssystem** als der unmittelbar eingesetzten menschlichen oder tierischen Kraft **ausgestattete** oder dafür vorgesehene **Gesamtheit miteinander verbundener Teile** oder Vorrichtungen, von denen mindestens eines bzw. eine beweglich ist und die für eine bestimmte Anwendung zusammengefügt sind;

eine Gesamtheit von Maschinen …

g. "**unvollständige Maschine**" bezeichnet

eine Gesamtheit, **die** fast eine Maschine bildet, **für sich genommen aber keine bestimmte Funktion erfüllen kann**. Ein Antriebssystem stellt eine unvollständige Maschine dar. Eine unvollständige Maschine ist nur dazu bestimmt, in andere Maschinen oder in andere unvollständige Maschinen oder Ausrüstungen eingebaut oder mit ihnen zusammengefügt zu werden, um zusammen mit ihnen eine Maschine im Sinne dieser Richtlinie zu bilden;

h. "**Inverkehrbringen**" bezeichnet

die entgeltliche oder unentgeltliche erstmalige **Bereitstellung einer Maschine** oder einer unvollständigen Maschine in der Gemeinschaft **im Hinblick auf** ihren Vertrieb oder **ihre Benutzung**;

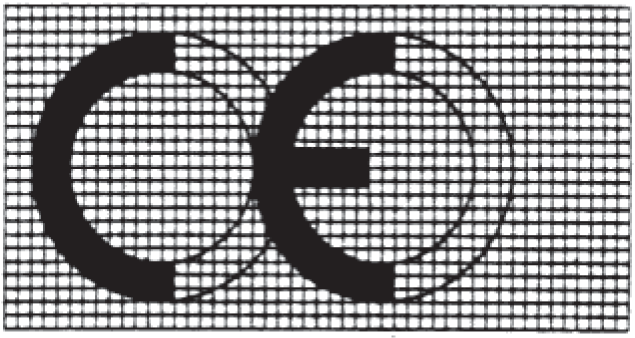
i. "**Hersteller**" jede natürliche oder juristische Person, die eine von dieser Richtlinie erfasste **Maschine oder eine unvollständige Maschine konstruiert und/oder baut** und für die Übereinstimmung der Maschine oder unvollständigen Maschine mit dieser Richtlinie im Hinblick auf ihr **Inverkehrbringen** unter ihrem eigenen Namen oder Warenzeichen **oder für den Eigengebrauch verantwortlich ist.** Wenn kein Hersteller im Sinne der vorstehenden Begriffsbestimmung existiert, wird jede natürliche oder juristische Person, die eine von dieser Richtlinie erfasste Maschine oder unvollständige Maschine in Verkehr bringt oder **in Betrieb nimmt, als Hersteller betrachtet**;

Nach Begriffsbestimmung a. kann eine komplexe Anlage (z.B. Abfallbehandlungsanlage) als Maschinen bezeichnet werden, wenn die Anlage eine gemeinsame Steuerung besitzt.

Ein Anlagenteil (z.B. eine in die Abfallbehandlungsanlage eingebundene Nachselektion) kann eine „unvollständige Maschine“ sein, wenn die Begriffsbestimmung g. zutreffend ist.

Von **„Konformitätsvermutung“** spricht man, wenn die Maschine mit der **CE-Kennzeichnung** versehen ist **und** die **EG-Konformitätserklärung** mit den in Anhang II Teil 1 Abschnitt A der Maschinenrichtlinie aufgeführten Angaben beigefügt ist.

1.4 Umsetzung der Maschinenrichtlinie



Die Abbildung oben zeigt die Gestaltung der CE-Kennzeichnung. Die Gitterhilfslinien dienen hier lediglich der Veranschaulichung der Gestaltungsmerkmale.

Die CE-Kennzeichnung ist in unmittelbarer Nähe der Angabe des Herstellers oder seines Bevollmächtigten anzubringen und in der gleichen Technik wie diese Angabe auszuführen.

Der **Hersteller muss vor** dem Inverkehrbringen und/oder der **Inbetriebnahme** einer Maschine

a. **sicherstellen, dass die Maschine** die in Anhang I aufgeführten, für sie geltenden **grundlegenden Sicherheits- und Gesundheitsschutzanforderungen erfüllt**;

b. sicherstellen, dass die in Anhang VII Teil A genannten **technischen Unterlagen** verfügbar sind;

c. insbesondere die erforderlichen Informationen, wie die **Betriebsanleitung**, zur Verfügung stellen;

d. die zutreffenden **Konformitätsbewertungsverfahren** gemäß Artikel 12 durchführen;

e. die **EG-Konformitätserklärung** gemäß Anhang II Teil 1 Abschnitt A ausstellen und sicherstellen, dass sie der Maschine beiliegt;

f. die **CE-Kennzeichnung** gemäß Artikel 16 anbringen.

Aufbewahrungsfrist nach Anhang II

Der Hersteller einer **Maschine** hat das Original der **EG-Konformitätserklärung** nach dem letzten Tag der Herstellung der Maschine **mindestens zehn Jahre lang aufzubewahren**.

Der Hersteller einer **unvollständigen Maschine** hat das Original der **Einbauerklärung** nach dem letzten Tag der Herstellung der unvollständigen Maschine **mindestens zehn Jahre lang aufzubewahren**.

Kategorien von Maschinen gemäß Anhang IV, für die ein Konformitätsbewertungsverfahren durch „**benannte Stellen**" durchzuführen ist. Kategorien, die in der Abfallwirtschaft relevant sein können:

13. Hausmüllsammelwagen für manuelle Beschickung mit Pressvorrichtung.

14. Abnehmbare Gelenkwellen einschließlich ihrer Schutzeinrichtungen.

15. Schutzeinrichtungen für abnehmbare Gelenkwellen.

21. Logikeinheiten für Sicherheitsfunktionen.

23. Schutzaufbau gegen herabfallende Gegenstände (FOPS).

Technische Dokumentation für Maschinen

- eine allgemeine Beschreibung der Maschine,
- eine **Übersichtszeichnung der Maschine** und die **Schaltpläne der Steuerkreise** sowie Beschreibungen und Erläuterungen, die zum Verständnis der Funktionsweise der Maschine erforderlich sind,
- **vollständige Detailzeichnungen**, eventuell mit Berechnungen, Versuchsergebnissen, Bescheinigungen usw., die für die Überprüfung der Übereinstimmung der Maschine mit den grundlegenden Sicherheits- und Gesundheitsschutzanforderungen erforderlich sind,
- die Unterlagen über die **Risikobeurteilung**, aus denen hervorgeht, welches Verfahren angewandt wurde; dies schließt ein:
    - eine Liste der grundlegenden Sicherheits- und Gesundheitsschutzanforderungen, die für die Maschine gelten,
    - eine Beschreibung der zur Abwendung ermittelter Gefährdungen oder zur Risikominderung ergriffenen Schutzmaßnahmen und gegebenenfalls eine Angabe der von der Maschine ausgehenden Restrisiken,

- die angewandten Normen und sonstigen technischen Spezifikationen unter Angabe der von diesen Normen erfassten grundlegenden Sicherheits- und Gesundheitsschutzanforderungen,
- alle technischen Berichte mit den Ergebnissen der Prüfungen, die vom Hersteller selbst oder von einer Stelle nach Wahl des Herstellers oder seines Bevollmächtigten durchgeführt wurden,
- ein Exemplar der Betriebsanleitung der Maschine,
- gegebenenfalls die Einbauerklärung für unvollständige Maschinen und die Montageanleitung für solche unvollständigen Maschinen,
- gegebenenfalls eine Kopie der EG-Konformitätserklärung für in die Maschine eingebaute andere Maschinen oder Produkte,
- eine Kopie der EG-Konformitätserklärung;

2 Umsetzung der Maschinenrichtlinie in nationales Recht

Richtlinien, die auf Grundlage des EG-Vertrags erlassen werden, entfalten keine unmittelbare Wirkung. Daher musste die Maschinenrichtlinie in nationales Recht umgesetzt werden.

Die Umsetzung in Deutschland erfolgte durch das Produktsicherheitsgesetz (ProdSG) und die darauf gestützte Maschinenverordnung (9. ProdSV).

Die Umsetzung In Österreich erfolgte durch die Maschinensicherheitsverordnung.

In der deutschen Maschinenverordnung wurde der Text der Maschinenrichtlinie weitestgehend unverändert übernommen oder es wurde auf die Anhänge der Maschinenrichtlinie verwiesen. Daher besteht in Deutschland quasi eine unmittelbare Wirkung der grundlegenden Sicherheits- und Gesundheitsanforderungen der europäischen Maschinenrichtlinie.

3 Beispiel aus der Abfallwirtschaft

Der nachfolgende Screenshot aus der Leitwarte einer Abfallbehandlungsanlage zeigt das R&I-Fließschema nach Erweiterung der Altanlage um den Anlagenteil „Nachselektion". Der neue Anlagenteil ist mit roten gestrichelten Linien eingegrenzt. Steuerungstechnisch hängen der neue und der alte Anlagenteil zusammen.

Die im blauen Bereich dargestellte erweiterte Abfallbehandlungsanlage ist daher als eine Maschine anzusehen.

Die Erweiterung der Anlage führt zu einer Zunahme des Risikos der erweiterten Anlage im Vergleich zur alten Anlage, weil das Risiko des hinzugefügten Anlagenteils immer > 0 ist. Wenn das Risiko des alten Anlagenteils unverändert bleibt, nimmt das Gesamtrisiko zu. Früher sprach man in Deutschland dann von „wesentlicher Änderung“.

Obwohl der alte Anlagenteil aus dem letzten Jahrtausend stammt, ist die erweiterte Anlage deshalb als neue Anlage (neue Maschine) zu betrachten.

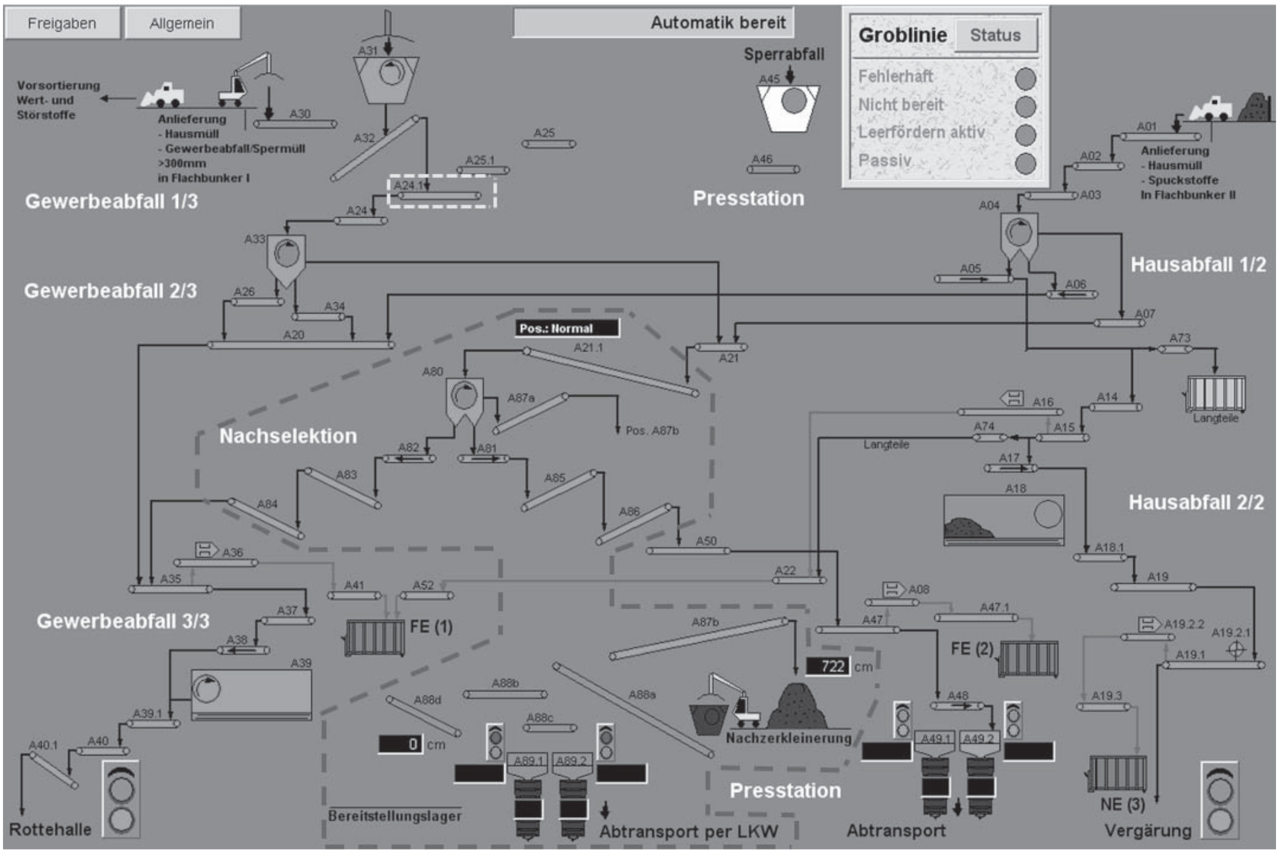
Die nachgerüstete „Nachselektion“ ist eine unvollständige Maschine. Für die unvollständige Maschine übergibt der Hersteller dem Käufer eine Einbauerklärung (frühere Bezeichnung: „Herstellererklärung“). Die Einbauerklärung muss sinngemäß folgenden Hinweis enthalten: Die Inbetriebnahme der Maschine oder Anlage, in die die unvollständige Maschine eingebaut ist, ist solange untersagt, bis die Konformität der Maschine mit der Maschinenrichtlinie festgestellt ist.

Danach ist für die erweiterte Anlage vor der erneuten Inbetriebnahme durch den Hersteller der erweiterten Anlage

- ein Konformitätsbewertungsverfahren durchzuführen,
- die technische Dokumentation zu erstellen,
- die EG-Konformitätserklärung zu erstellen,
- die CE-Kennzeichnung anzubringen,

Wenn vor der Erweiterung der Anlage nicht vereinbart worden ist, wer Hersteller der erweiterten Anlage ist, dann kann der Betreiber der Anlage als Hersteller fungieren. Siehe Begriffsbestimmung „Hersteller“.

Der Wirkbereich jedes einzelnen Not-Aus-Betätigungsschalters in der Abfallbehandlungsanlage und der Radlader / Bagger umfasst die gesamte dargestellte Abfallbehandlungsanlage.



4 Schlussfolgerung

Alle Veränderungen, Erweiterungen, Umbauten und Modifikationen von Anlagen und Maschinen verlangen nach einer Prüfung der Konformität.

Hierzu ist eine Risikoanalyse bzw. Gefährdungsbeurteilung der Änderungen als erster Schritt der Validierung vorzunehmen. Wenn das Gesamtrisiko der Anlage gestiegen ist, so ist in der Regel eine Erneuerung der EG-Konformitätserklärung notwendig.

Der Betreiber der Anlage ist verantwortlich für die Durchführung und die Konformitätserklärung einer Anlage nach deren Veränderung.

Die Einführung eines Change-Managements für alle technischen Tätigkeiten eines Unternehmens ist empfehlenswert und hilfreich für Betreiber und Geschäftsleitung.

Vor der Änderung einer Anlage sollte sichergestellt werden, das die notwendige Dokumentation. Die Gefährdungsbeurteilung und falls notwendig die EG-Konformitätserklärung vorliegen, bevor die Anlage wieder in Betrieb genommen wird.

5 Literatur

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EUROPEAN COMMISSION ENTERPRISE AND INDUSTRY	2014	The \`Blue Guide´ on the implementation of EU product rules DOI:10.2769/9091

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Hydrothermale Carbonisierung

– Einsatzmöglichkeiten und Potenziale

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Hydrothermal carbonization - capabilities and potentials

Abstract

Contrasting thermochemical technologies are used, leading to the production of different end products such as gas, oil and solids. Pyrolysis (pyrochar) and hydrothermal carbonization (hydrochar) are prominent technologies converting organic residues or waste into charcoal or charcoal like end products.

Due to the different production conditions of these technologies, end products have fundamentally different properties. Pyrochars are inert having a highly condensed aromatic ring system whereas hydrochars are still rich in carboxyl and hydroxyl groups leading to a high reactivity.

Despite or even because of the different material properties of hydrochars and pyrochars fields of application are highly diverse. Pyrochars can be used for soil amelioration and long-term C sequestration. In contrast, addition of hydrochars to fermentation process increases gas yield significantly. Furthermore, the hydrothermal carbonization process is able to produce furfurals like 5-HMF.

Hydrothermal carbonization as well as pyrolysis are both technologies with high potential using organic residues in a multiple sequential way, closing material cycles and refine biomass and waste.

Inhaltsangabe

Unterschiedliche thermochemische Technologien werden eingesetzt, um unterschiedliche Produkte wie Gas, Öl oder Feststoffe herzustellen. Die Pyrolyse (Pyrokohle) oder hydrothermale Carbonisierung (Hydrokohle) sind die bekanntesten Techniken zur Umwandlung von Biomasse oder organischen Abfällen in Kohle oder kohleähnliche Produkte.

Aufgrund der unterschiedlichen Prozessbedingungen dieser Technologien unterscheiden sich deren Erzeugnisse wesentlich voneinander. Pyrokohlen sind inert und weisen stark verdichtete aromatische Ringsysteme auf, während Hydrokohlen reich an sauerstoffhaltigen funktionellen Gruppen (z.B. Carboxyl-, Hydroxylgruppen) sind und somit wesentlich reaktiver.

Trotz oder gerade aufgrund der unterschiedlichen Eigenschaften von Hydro- und Pyrokohlen sind deren Anwendungsbereiche sehr mannigfaltig. Pyrokohlen können als Bodenzuschlagsstoff mit dem Ziel der langfristigen CO_2-Speicherung im Boden eingesetzt werden. Im Gegensatz dazu kann durch die Zugabe von Hydrokohle die Methanausbeute in Vergärungsprozessen signifikant gesteigert werden. Ferner kann mittels hydrothermale Carbonisierung die Plattformchemikalie 5-HMF hergestellt werden.

Sowohl die hydrothermale Carbonisierung wie auch die Pyrolyse sind Technologien, die ein hohes Potenzial besitzen, um organische Reststoffe vielfältig und hochwertig zu nutzen und um Stoffkreisläufe zu schließen.

Keywords

HTC, Hydrothermale Carbonisierung, thermische Konvertierung, Pyrolyse, Pyrokohle, Hydrokohle, Black Carbon, Terra Preta

HTC, hydrothermal carbonization, thermal conversion, pyrolysis, biochar, hydrochar, black Carbon, Terra Preta

1. Einleitung

Die thermochemische Konvertierung von organischen Reststoffen wurde in den vergangenen Jahren maßgeblich durch die Erforschung der im Amazonasgebiet (Brasilien) vorkommenden Indianerschwarzerden (Terra Preta) vorangetrieben. Der hohe Anteil an hocharomatischem Kohlenstoff (Black Carbon) in Kombination mit Einträgen aus Haushaltsabfällen, Biomasseresten und Exkrementen führte zu einem über Jahrtausende hinweg nachhaltig fruchtbaren Boden (Glaser und Birk, 2011). Eine aktuelle Studie von Wiedner et al. (2015) belegt das Vorkommen eines der Terra Preta vergleichbaren Bodens im norddeutschen Raum. Angeregt durch das entschlüsselte Geheimnis der anthropogen geschaffenen Böden entwickelten sich in den vergangenen Jahren verschiedenste Verfahren, die zur Herstellung von karbonisierter Biomasse dienen. Zwei Technologien, deren Endprodukte vermeintlich als Bodenzuschlagsstoff geeignet sein sollen, sind die Pyrolyse und die hydrothermale Carbonisierung (HTC). Die Eignung der Endprodukte als Bodenzuschlagsstoff, vor allem jene aus dem HTC Verfahren, werden aktuell kontrovers diskutiert. Abgesehen vom Einsatz als Bodenzuschlagsstoff haben einige Forschergruppen in jüngerer Vergangenheit gezeigt, dass die Einsatzmöglichkeiten der karbonisierten Biomassen weit über jenen als Bodenzuschlagsstoff hinaus reichen. Beide Verfahren können zukünftig als Schlüsseltechnologien agieren, um eine sinnvolle Kaskadennutzung von Biomasse zu gewährleisten. Um jedoch die Einsatzbereiche einschätzen zu können ist das Verständnis über die Eigenschaften der Endprodukte grundlegend. Daher wird im folgenden Beitrag zunächst auf die Materialeigenschaften der Produkte des HTC-Verfahrens eingegangen und mit denen der Pyrolyse verglichen. Die Einsatzmöglichkeiten sowie das Potential des HTC-Verfahrens werden im Anschluss anhand von wissenschaftlichen Studien und Praxisbeispielen aufgezeigt.

Aktuell gibt es noch keine Einheitlich definierten und verwendeten Begrifflichkeiten für die Endprodukte des Pyrolyse- bzw. HTC-Verfahrens. In diesem Beitrag werden die Begriffe Pyrokohle für Endprodukte aus dem Pyrolyseverfahren und Hydrokohle für die Endprodukte aus dem HTC-Verfahren verwendet.

2. Die Technik macht den Unterschied

Es gibt zahlreiche thermochemische Verfahren, die zur Herstellung von Gasen, Flüssigkeiten oder Feststoffen aus Biomasse dienen. Bei einigen Verfahren steht die Produktion von z.B. Gas oder Öl im Vordergrund und Feststoffe wie Holz- oder Aktivkohle entstehen lediglich als Nebenprodukt. Maßgebende Parameter für die Verteilung der Gas-, Flüssig- oder Feststoffausbeute sind die Zusammensetzung der Einsatzstoffe und die Betriebsbedingungen wie die Verweilzeit, Temperatur, Druck, etc. (Shafizadeh et al. 1982).

Die hydrothermale Carbonisierung ist ein thermochemisches Verfahren, welches Biomasse (z.B. Holz, Laub, Stroh, Lebensmittelreste, Biogasgülle etc.) zusammen mit Wasser und einem geeigneten Katalysator (z.B. Zitronensäure) unter Druck zu einem dunkelgefärbten, wässrigen Gemisch umwandelt. Je nach Reaktor kann dies bei Temperaturen zwischen 180 und 400 °C stattfinden, wodurch innerhalb weniger Stunden folgende exotherme Reaktion stattfindet:

$$C_6H_{12}O_6 \rightarrow C_6H_2O + 5\,H_2O + \sim 950\,\text{kJ/mol}$$

Kohlehydrat		Hydrokohle		Wasser		Wärme

Je nach Dauer, Temperatur und Zeit im HTC-Verfahren wird die Biomasse in mehr oder weniger große Kohlepartikel zersetzt, die sich im wässrigen Gemisch befindet. Die Eigenschaften der Hydrokohle ähneln stark der Braunkohle (Abb. 1) welche in starkem Kontrast zur Pyrokohle steht. Die Unterschiede entstehen verfahrensbedingt, da die Verkohlung der Rohstoffe durch die Pyrolyse in einem nahezu sauerstofffreien Milieu bei Temperaturen zw. 500 und 800 °C stattfindet. Durch den prozessbedingten höheren Grad der Decarboxylierung und Demethylierung der Biomasse ähnelt die Pyrokohle in ihren chemischen Eigenschaften der Steinkohle. Mit anderen Worten, durch die Pyrolyse erfährt die Biomasse einen hohen Verlust an CO_2 und CH_3-Gruppen, was zu einer hohen Aromatizität führt jedoch die Polarität verringert. Im Gegensatz dazu besitzen Hydrokohlen eine geringere Aromatizität dafür aber eine höhere Polarität was sie weniger stabil aber dafür reaktiver macht.

3. Kohle ist nicht gleich Kohle

Um die Einsatzmöglichkeiten der Hydrokohle besser einschätzen und verstehen zu können ist es von grundlegender Wichtigkeit, die Charaktereigenschaften des Materials zu kennen und zu verstehen. Hierzu gibt es bereits zahlreiche wissenschaftliche Veröffentlichungen, welche die Materialeigenschaften von Hydrokohlen z.B. aus unterschiedlichen Prozessbedingungen oder Biomassen charakterisieren und auch mit Pyrolysekohlen vergleichen.

Das Van-Krevelen-Diagramm (Abb. 1) stellt die atomaren Elementverhältnisse H/C (y-Achse) und O/C (x-Achse) dar, welches als Indikator für den Karbonisierungsprozess und somit auch der Stabilität der Kohle dient. Je niedriger das O/C und H/C Verhältnis ist, desto höher ist der Verlust von Sauerstoff und Wasserstoff während des Inkohlungsprozesses. Die Verluste von CH_3 (Demethylierung) ist ersichtlich durch ein kleiner werdendes H/C Verhältnis und der Verlust von CO_2 (Decarboxylierung) wird angezeigt durch ein geringer werdendes O/C Verhältnis und einer damit verbundenen Kohlenstoffanreicherung (Wiedner et al. 2013b). Das Van-Krevelen-Diagramm verdeutlicht, dass die Demethylierung und Decarboxylierung bei den Pyrokohlen deutlich weiter fortgeschritten ist als bei den Hydrokohlen. Außerdem ist zu sehen, dass die Elementverhältnisse der Hydrokohlen denen der Braunkohlen entsprechen. Eine Studie von Wiedner et al. (2013a) zeigte jedoch, dass die Erhöhung der Prozesstemperatur von 180 auf 210 und 230 °C die Elementarverhältnisse signifikant verringern lässt (Abb. 1) und die Hydrokohlen somit den rekalzitranten Eigenschaften der Pyrokohlen näher kommen.

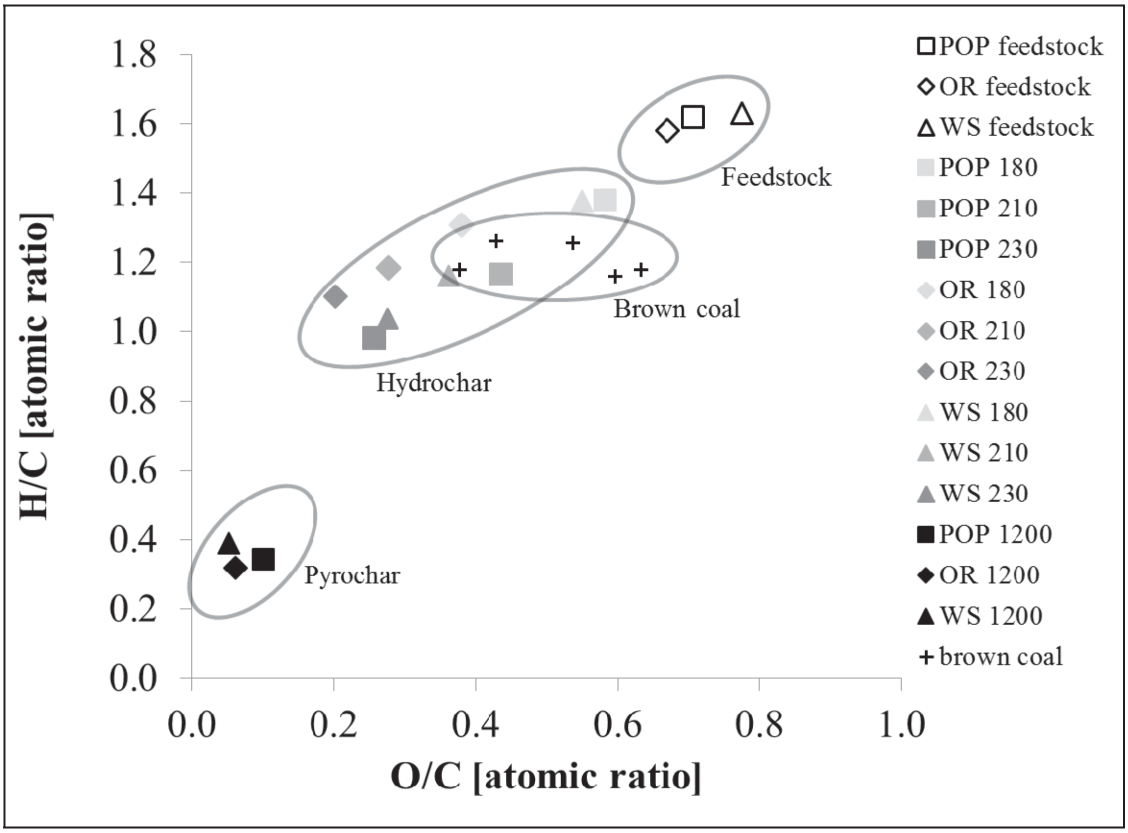

Abb. 1: O/C und H/C Verhältnisse von den unbehandelten Biomassen (feedstock) Pappel (POP), Oliventrester (OR) und Weizenstroh (WS), Braunkohle, Hydrokohlen produziert bei 180, 210 und 230 °C sowie Pyrokohle produziert bei 1200 °C (Abbildung modifiziert aus Wiedner et al. 2013).

Die Oberflächenchemie der Hydrokohlen (Abb. 2A), analysiert mittels Rasterelektronenmikroskopie (REM) und energiedispersiver Röntgenspektroskopie (EDX), zeigt (wie bereits durch das Van-Krevelen-Diagramm verdeutlicht) einen deutlich höheren Sauerstoffanteil in Vergleich zur Pyrolysekohle (Abb. 3B). Während der hydrothermalen Carbonisierung bleiben die in der Biomasse bereits vorhandenen sauerstoffhaltigen funktionellen Gruppen (z.B. Carboxyl-, Hydroxyl- oder Phenolgruppen) weitgehend vorhanden, während der Pyrolyseprozess zu einem Verlust von Sauerstoff führt. Dies bedeutet, dass Hydrokohlen im Vergleich zu Pyrokohlen, wesentlich reaktiver sind.

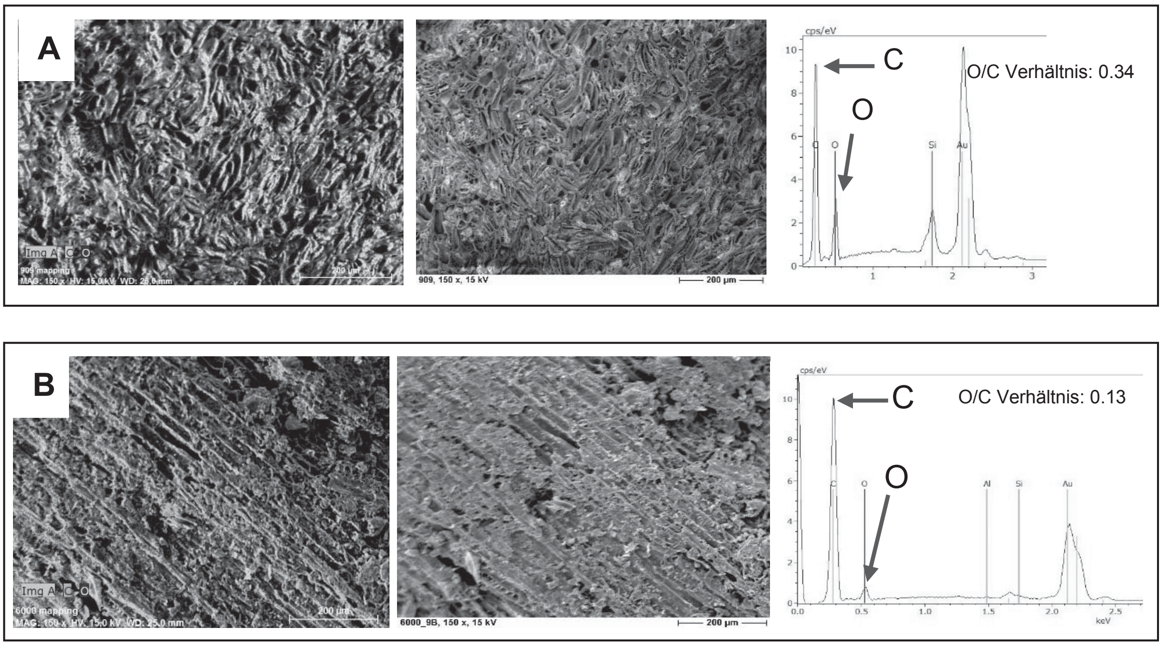

Abb. 2: Oberflächeneigenschaften einer Hydrokohle (A) und Pyrokohle (B) mittels REM-EDX: die Bilder zeigen ein Elementmapping (links) von Sauerstoff (O in blau) und Kohlenstoff (C in gelb), die Punkte der EDX Analyse (Mitte) und ein Spektrum (rechts) einer der EDX Messpunkte (Bilder: K. Wiedner).

Ein weiteres ganz entscheidendes Kriterium für die Charakterisierung von Hydrokohle ist der Anteil an sog. Black Carbon. Die Black Carbon Methode (Glaser et al. 1998 und Brodowski et al. 2005) nutzt Benzolpolycarbonsäuren (BPCAs), welche Auskunft über die Menge und die Zusammensetzung der kondensierten Aromaten in Kohlen geben. Die Quantität wie auch die Qualität des Black Carbons korreliert stark mit der Stabilität von Kohlen und ist eine wichtige Eigenschaft beispielsweise hinsichtlich des Einsatzes als Bodenzuschlagsstoff mit dem Ziel der langfristigen CO_2-Speicherung im Boden. Abbildung 3 zeigt, dass der Black Carbon Anteil von Pyrokohlen (A) durchschnittlich um das 10-fache größer ist als bei Hydrokohlen (B). Die beiden Kohlegruppen zeigen auch deutliche Unterschiede bezüglich der Carbonsäuren. Die Pyrokohlen (Abb. 3B) zeigen eine deutliche Dominanz von höhermolekularen Carbonsäuren (B6CA und B5CA), während die Hydrokohlen (Abb. 3B) eine nur recht geringen Anteil der stabilen Mellitsäure

(B6CA) haben und der größte Teil die niedermolekularen Säuren (B3CA und B4CA) ausmacht.

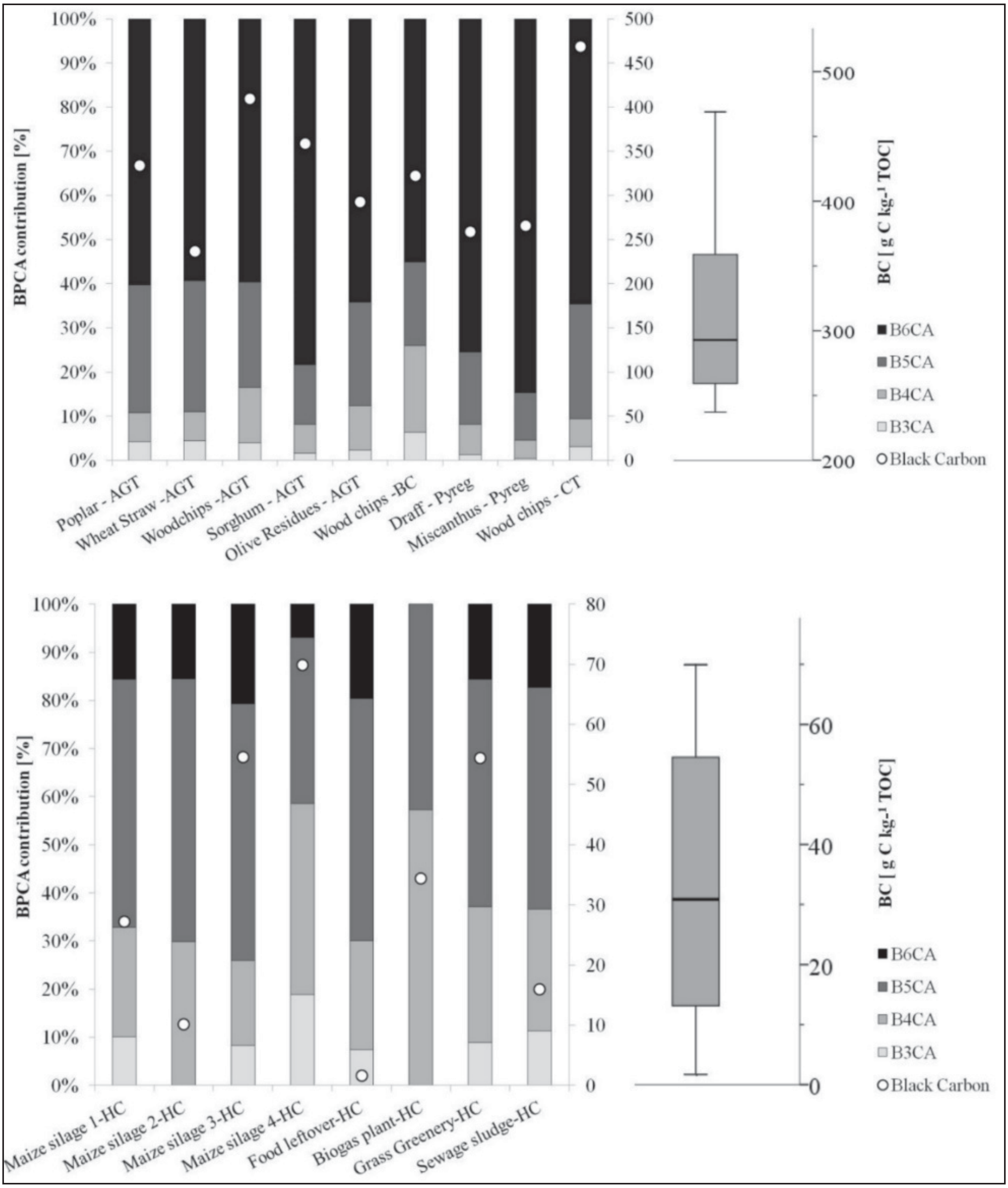

Abb. 3: Anteil und Qualität von Black Carbon in Pyrokohlen (A) und Hydrokohlen (B) (Wiedner et al. 2013 a).

4. Einsatzbereiche von Hydrokohlen – Praxisbeispiele und Zukunftsvisionen

Die oben dargestellten Eigenschaften der Hydrokohle entscheiden maßgeblich über deren Verwendung in der Praxis. Grundsätzlich ist aber auch bereits die Art der verwendeten Biomasse ein Kriterium für den Einsatz im HTC- oder Pyrolyseverfahren. An dieser Stelle soll klargestellt sein, dass beide Technologien derzeit noch mehr als Schlüsseltechnologien gesehen werden müssen, die einen Teil der vorhandenen Biomasse veredeln und somit die Effektivität für weitere Verfahrensschritte steigern. Abbildung 4 zeigt Beispiele für Einsatzbereiche, für die das HTC-Verfahren als Plattformtechnologie eingesetzt werden kann.

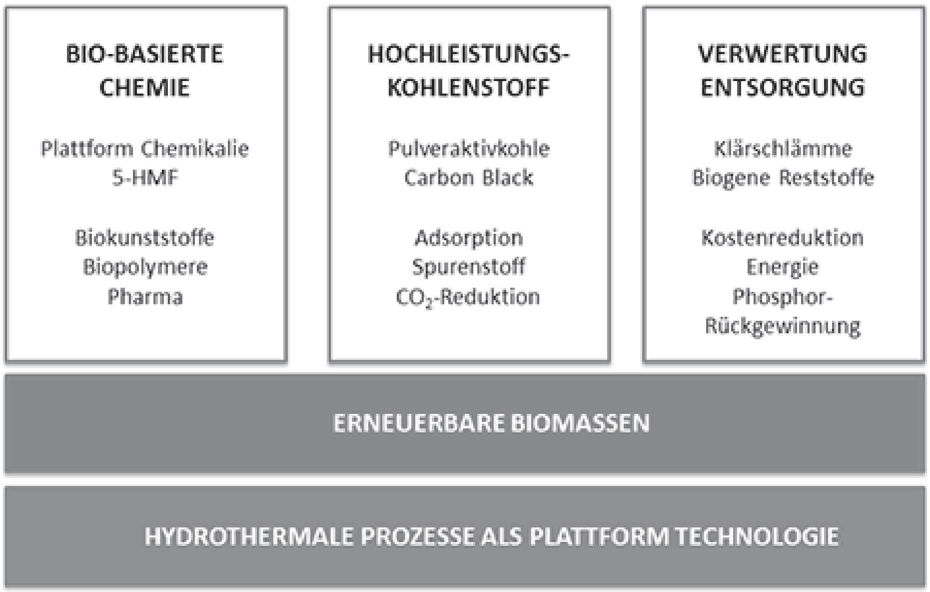

Abb. 4: Einsatzbereiche der HTC-Technologie (Bildquelle: www.ava-co2.com)

4.1 Optimierung der Gasausbeute

Eine Studie am Potsdamer Leibniz-Institut für Agrartechnik durchgeführt von Mumme et al. (2014) konnte zeigen, dass die Methanausbeute durch die Zugabe von Hydrokohle in der anaeroben Vergärung um bis zu 32% gesteigert und der Biogasprozess stabilisiert werden konnte. Die Ammoniumhemmung kann durch die Zugabe von Hydrokohle (und Pyrokohle) vermindert werden. Allerdings zeigte sich, dass mit steigender Ammoniumkonzentration die Hydrokohle ihre positive Wirkung verringert. Das in der Praxis eingesetzte Zeolith zeigte bei Ammoniumkonzentrationen von 6,6 g N kg^{-1} Reaktorinhalt noch deutliche Wirkung, während die Hydrokohle hier bereits die Grenzen erreicht hat. Grundsätzlich ist aber zu erwähnen, dass die in der Studie verwendete Hydrokohle (und Pyrokohle) nicht speziell für den Einsatz in Biogasreaktoren produziert wurde und durch weitere Studien die Hydrokohlen entsprechend optimiert werden müssen.

4.2 Bodenzuschlagstoff

Der Einsatz von Hydrokohle als Bodenzuschlagstoff wird derzeit noch kontrovers diskutiert. Die oben aufgezeigten Eigenschaften der Hydrokohle entsprechen nicht jenen Eigenschaften der in Terra Preta vorkommenden Kohle. Auch die Kohlepartikel anderer Anthrosole mit Terra Preta vergleichbaren Eigenschaften haben eher die chemischen Eigenschaften der Pyrolysekohle (Wiedner und Glaser, 2015). Für eine langfristige CO_2-Speicherung im Boden ist Hydrokohle aufgrund der geringen Aromatizität und damit geringen Stabilität nicht geeignet. Weitere Studien belegen, dass Hydrokohlen bereits nach mehreren Dekaden im Boden vollständig zersetzt werden (z.B. Steinbeiss et al. 2009; Naisse et al. 2013). Allerdings sind Hydrokohlen reich an funktionellen Gruppen, die sie befähigt, Nährstoffe im Boden pflanzenverfügbar zu speichern. Diese Eigenschaft muss bei den inerten Pyrokohlen zunächst durch Aktivierung wie z.B. Kompostierung erfolgen (Wiedner et al. 2012, Wiedner et al. submitted). Ein weitaus größeres Problem ist die mögliche toxische Wirkung einiger Hydrokohlen auf das Pflanzenwachstum (z.B. Busch et al. 2013, Reza et al. 2014). Eine Studie von Busch et al. (2012) deutet darauf hin, dass ein biologischer Abbau der toxisch wirkenden Substanzen während Kompostierung von Hydrokohlen möglich ist. Weitaus effektiver wäre es, das HTC-Verfahren dahingehend zu optimieren, dass toxische Substanzen erst gar nicht entstehen.

4.3 Plattformchemikalie 5-HMF

Das Karlsruher Institut für Technologie (KIT) entwickelte zusammen mit der AVA Biochem ein Verfahren zur industriellen Herstellung der Plattformchemikalie 5-Hydroxymethylfurfural (5-HMF). Diese ist Ausgangsstoff für zahlreiche Produkte in der Kunststoff- pharmazeutischen-, Lebensmittel- und chemischen Industrie. Das Verfahren basiert auf der hydrothermalen Carbonisierung mit dem Unterschied, dass die Bildung von Feststoffen während des HTC-Prozesses verhindert wird. Das Prinzip besteht darin, dass Cellulose aus der Biomasse gelöst wird, wodurch u.a. Glukose und Fruktose entsteht. Durch Wasserabspaltung aus der Fruktose kann die Plattformchemikalie 5-HMF gebildet werden. Ohne Unterbrechung des Prozesses an dieser Stelle entsteht durch Polymerisation von 5-HMF und weiteren Zwischenprodukten synthetische Kohle (weitere Informationen siehe www.innovation.kit.edu).

4.4 Klärschlammbehandlung und Phosphatrückgewinnung

Eine Studie der Züricher Hochschule für Angewandte Wissenschaften (ZHAW) und dem Industriepartner AVA-CO_2 zur Klärschlammbehandlung im Industriemaßstab ergab, dass das HTC-Verfahren deutliche Vorteile gegenüber gängigen industriellen Verfahren zur Klärschlammbehandlung hat. Es konnte gezeigt werden, dass im Vergleich zur thermischen Trocknung 62 % Wärmeenergie und 69 % Strom eingespart werden konnte. Anders als bei der Anwendung anderer Verfahren, konnten beim HTC-Prozesswasser keine refraktär gelösten organischen Kohlenstoffverbindungen (DOC) Verbindungen nachgewiesen werden. Die energetische Nutzung der entstandenen Hydrokohle durch Verbrennung ergab keine Überschreitung gesetzlich vorgegebener Emissionsgrenzwerte. Der Vergleich der Ökobilanz des HTC-Verfahrens mit gängigen thermischen Entsorgungsverfahren (v.a. Monoverbrennungsanlagen) führte zu deutlich besseren Ergebnissen. Die Phosphorrückgewinnung aus der Asche der Hydrokohle ist aufgrund der starken Alkalinität erheblich einfacher und umweltfreundlicher im Vergleich zur Phosphatrückgewinnung aus Asche aus anderen thermischen Entsorgungsverfahren, da der Säureeinsatz erheblich reduziert ist. Der ausführliche Schlussbericht der ZHAW Studie ist auf der Homepage der AVA CO_2 (www.ava-co2.com) erhältlich.

4.5 Energetische Verwertung

Die Möglichkeit, Hydrokohle als Energieträger zu nutzen, kann zu einer Substitution fossiler Primärenergieträger beitragen. Je nach Rohstoff, Dauer und Temperatur im HTC-Verfahren reduziert sich die initiale Biomasse um etwa 35 Masse-%. Durch die Kohlenstoffanreicherung hat aber die Hydrokohle einen wesentlich höheren Energiewert als das jeweilige Edukt. Der Brennwert der Hydrokohle steigt im Vergleich zum Edukt im Durchschnitt um ein Drittel an und ist vergleichbar mit dem der Braunkohle (~ 20 MJ/kg).

5. Fazit

Die im Beitrag dargestellten wissenschaftlichen Studien machen deutlich, dass sich Hydrokohlen maßgeblich hinsichtlich Ihrer chemischen Charaktereigenschaften (z.B. hohe Polarität und Aromatizität) von Pyrokohlen (geringe Polarität und hohe Aromatizität) unterscheiden. Diese Tatsache verdeutlicht, dass es für die Fachwelt von immenser Wichtigkeit ist, Begrifflichkeiten klar zu definieren und nicht ein und dieselbe Vokabel (z.B. Biokohle) für ein steinkohleähnliches (Pyrokohle) und braunkohleähnliches (Hydrokohle) Produkt zu verwenden. Zusätzlich müssen die Materialeigenschaften der Hydrokohle klar definiert werden um z.B. Qualitätsrichtlinien festlegen zu können. Dies erleichtert zum einen dem potentiellen Endabnehmer/Anwender die qualitative Einschätzung der Kohle und/oder für welche Anwendung diese geeignet ist. Viel wichtiger ist aber noch, dass der Weg zur legalen Anwendung der Hydrokohle z.B. in der Landwirtschaft nur durch die Einführung und Verwendung einer klar definierten Terminologie geebnet werden kann.

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HTC: Key technology in Biomass waste treatment

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Abstract

Hydrothermal carbonization is the physiochemical process by which organic waste material is converted into HTC biocoal and process water in a wet procedure at about 230 degrees temperature and 25 bar pressure within several hours. Hydrothermal carbonization is the industrial reproduction of the natural process by which biomass has been converted into fossil coal for millions of years. In this paper and in the presentation of Alfons Kuhles is the procedure of “Hydrothermal carbonization” explained, the GRENOL continuously operating HTC reactor, the mass energy balance of the GRENOL HTC procedure, usages and benefits of Hydrothermal carbonization as compared to the more established procedures of combustion, fermentation and anaerobe conversion (e.g. biogas production). In sum, HTC offers a new alternative procedure to process organic waste in an environmentally friendly manner, and to close the cycle of waste management.

Inhaltsangabe

Hydrothermale Karbonisierung ist der physio-chemische Prozess, mit welchem in einem nassen Verfahren bei ca. 230 Grad Temperatur und ca. 25 bar Druck innerhalb weniger Stunden organische Abfallstoffe in HTC Biokohle und Prozesswasser umgewandelt werden. Hydrothermale Karbonisierung ist die industrielle Reproduktion des natürlichen Prozesses der „Inkohlung“, mit welchem organische Reststoffe seit Jahrmillion zu fossiler Kohle umgewandelt worden sind. In diesem Aufsatz und dem dazugehörigen Vortrag erklärt Alfons Kuhles das Verfahren der Hydrothermalen Karbonisierung, den patentierten, kontinuierlich operierenden GRENOL HTC Reaktor, die Massen- und Energiebilanz des GRENOL HTC Reaktors, Nutzungsweisen und Vorteile der Hydrothermalen Karbonisierung im Vergleich zu den bekannteren Verfahren der Verbrennung, der Fermentation und der anaeroben Umwandlung (Beispiel herkömmliche Biogasproduktion).

Keywords

Hydrothermal Carbonization, waste management, CO_2-neutral, biomass processing, energy recovery, coal gasification, combined Heat and Power unit.

1 What is Hydrothermal Carbonization (HTC)?

Hydrothermal Carbonization is the procedure by which organic waste of all sort is converted into carbon and water at a temperature of about 230 degrees temperature and a pressure of about 25 bar in a wet procedure in a closed system. Contrary to other processes of converting biomass on the market, HTC is a physio-chemical, not a biological process of biomass processing in waste management. Under these conditions, an exotherm reaction takes place. Heat is produced during the splitting of carbohydrate chains from the original biomass. Hydrothermal carbonization is an industrial variation of the natural process of coalification by which organic residues have been converted to fossil brown and black coal as a result of heat and pressure for millions of years; the same process that we know from nature takes now place at much higher speed. Consequently, the original biomass is converted into biocoal and process water within 3 to 12 hours. Contrary to other procedures such as combustion, fermentation and anaerobe conversion (e.g. conventional biogas production), “Hydrothermal carbonization” has a carbon and energy energy balance that is far superior to other procedures of organic waste management, such as alcoholic fermentation, anaerobe conversion or combustion. In “Hydrothermal carbonization”, near to 100 per cent of the carbon and two thirds of the energy are conserved. One third of the energy contained in the original biomass is turned into exothermal energy and thus fed back into the system. Contrary to the other procedures, no carbon dioxide (CO_2) or methane (CH_4) is discharged into the atmosphere.

2 GRENOL Concept for closing the circle of waste management

GRENOL company consequently implements an integral concept of organic waste management and climate friendly, CO_2-neutral energy recovery. Rural, municipal and industrial waste materials are first separated into organic and inorganic waste materials. The inorganic materials, such as sand, concrete and stones are crushed to pieces, sorted and used for construction.

Metals are sorted and melted down for producing pure metals. Plastics are collected, sorted out and depolymerized to produce fuels like diesel and other oil derivatives.

The focus of GRENOL business activity in waste management is in organic waste management, for instance waste from food and beverage production, livestock manure waste, green waste, wood residues, sewage sludge, residues from biogas production. GRENOL uses the procedure of “Hydrothermal carbonization”, converts the original biomass into biocoal and process water. The biocoal can be pressed to briquettes, pellet or any other form. The water is used for producing fertilizer, or for producing additional biomass.

Going more into detail, the GRENOL process comprises all steps of environmentally friendly organic waste management and energy recovery. The first step is delivery of biomass waste. The second step is the preparation of biomass, e.g. crushing. The third step is “Hydrothermal Carbonization” of the biomass within 3 to 12 hours. The forth step is separation into coal and water. The fifth step is drying of biocoal, followed by briquetting the biocoal. The sixth step is energy recovery, using a coal gasifier and a combined heat and power unit (CHP). The seventh and last step is the treatment of process water. The GRENOL solution is a greenhouse, in which aquatic plants take the nutrients and “nearby” clean the process water. An alternative procedure for water treatment is vacuum destillation, in which the process water is concentrated in such a way that a N-fertilizer is produced.

3 Operation of the GRENOL HTC reactor

The GRENOL HTC reactor is a patented solution for the continuous HTC process in industrial scale, with a volume of 2,5 m^3 and a maximum capacity of 10 tons of biomass input material per day, with 20-30 per cent of dry matter. Continuous HTC process means that continuously, biomass is pumped into the reactor, and permanently as well, the mixture of HTC-biocoal and HTC process water is discharged from the reaction after about six hours length of stay in the reactor at about 230 degrees of temperature and about 25 bar pressure. The maximum pressure is 30 bar. Two electrical systems and one mechanical secure system guarantee the operational security. The SPS guarantees the intelligent control of the reactor. Moreover, the SPS automatically sends SMS or Mail to the operator/technical team in the case of problematic events. The maximum output is 1-2 tons of biocoal per day at full load (with increase potential as the HTC reactor is developed further). Simultaneously, 4-6 m^3 of HTC process water are produced.

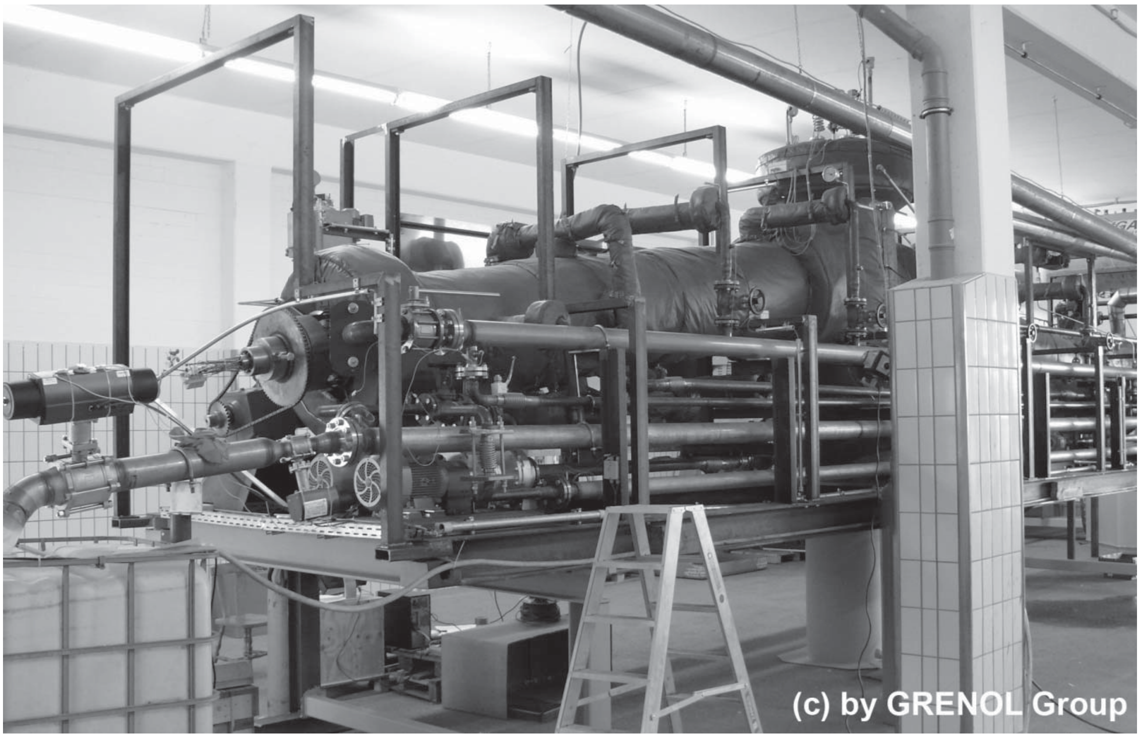

Figure 1: GRENOL HTC base module, capacity 10 tons biomass input per day

Once the original biomass has been pumped into the reactor, screw conveyors transport the biomass through the reactor. After about 6 hours, HTC coal and process water are discharged by the material outlet. The first great advantage of the continuously operating reactor is heat management system. It allows to use exothermal energy from “Hydrothermal carbonization”, discharged from the biomass during the process and to feed the heat back into the system using heat exchangers; thus, the biomass is heated up to about 230 degrees temperature in a short period of time, and the biomass at the exit is cooled down to about 40 degrees. The heat management is effective. Only heat losses in connection with isolation have to be compensated. No heat is misspent during the HTC process. Another great advantage is the modular construction of the HTC system.

The second advantage construction of the GRENOL HTC reactor means to implement a standardized construction of components and functional systems, in such a way that maintenance-intensive components can be exchanged easily. Ideally, a GRENOL HTC reactor is composed of three or more base modules of 10 tons of biomass each. This allows the operator to conduct a continuous operation 12 months a year, using three HTC modules for instance. Moreover, each HTC module is constructed on a 40 ft container, hence measures 12,1 m x 2,5 m x 2,8 m without periphery. The construction on a 40 ft container facilitates global transportation and sales since each base module can be transported by ship, truck or train. Moreover the GRENOL HTC plant can be adapted to the specific customer needs in waste management.

4 Mass- and energy balance of the GRENOL HTC reactor

The mass and energy balance is based on the HTC reactor with 10.000 tons of biomass per year with 30 percent dry substance, based on 3 GRENOL HTC base modules. Depending on the original biomass that is processed in the reactor, 225 MW electrical energy and 1,500 MW thermal energy must be added to convert the 10.000 tons of biomass each year into coal and water. However, in the HTC process 1,650 tons biocoal are produced. For the energy recovery of the HTC coal, the operator also needs a coal gasifier and a combined Heat and power unit (CHP). Thus, with the energy recovery from the HTC coal, the operator will obtain 2,700 MWh electrical energy and 5,400 MWh thermal energy from the HTC coal.

The resulting HTC biocoal is CO_2 neutral because it stems from fresh biomass that has not been converted into fossile brown coal or black coal in a natural process. Hence, the energy recovery from the HTC biocoal does not consume the natural fossile resources underground and the electrical and thermal energy from the energy recovery of HTC coal is climate neutral.

5 Common flowchart and required space

Following the common flowchart, the HTC process takes place with the following steps: First, biomass waste is delivered to the HTC plant. Second, the biomass is prepared for “Hydrothermal carbonization”, that is, mixing of biomass waste, crushing etc. The third step is “Hydrothermal Carbonization” of the original biomass within 3 to 12 hours. Step four is separation into coal and water. Step 5 is drying of biocoal, followed by briquetting the biocoal. Step six is energy recovery; this means to produce electric and thermal energy using a coal gasifier and a combined heat and power unit (CHP). Step 7 is HTC process water treatment, using a greenhouse, in which aquatic plants take the nutrients and "nearby" clean the HTC process water. An alternative procedure for water treatment is vacuum distillation for the production of an HTC fertilizer.

The space required for an HTC plant with three HTC base modules and periphery is about 1,500 m^2. Besides the three HTC base modules, biomass storage for seven days, a macerator (optional), coal water separation, a drying unit, storage for the HTC coal, a briquetting unit, a cogeneration unit and the greenhouse for the purification of the HTC process water.

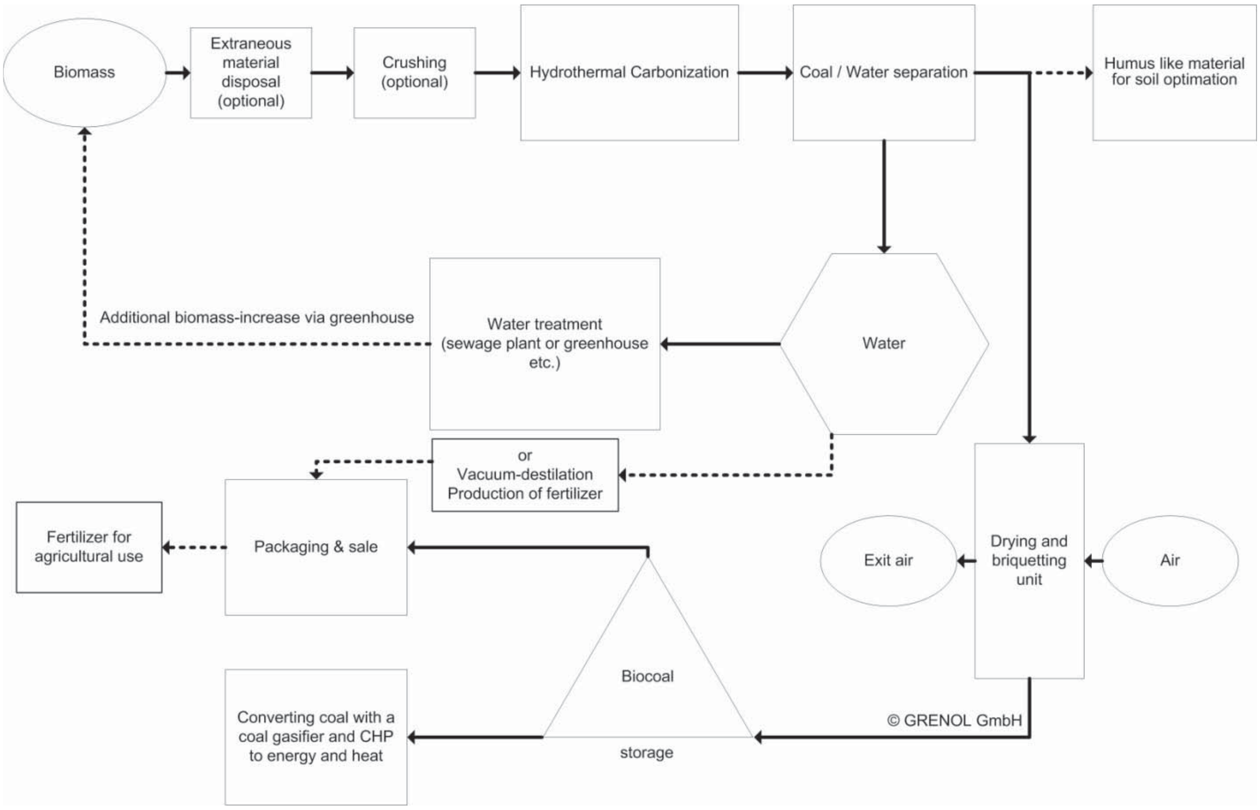

Figure 2: "Hydrothermal Carbonization" is usually conducted in these steps

6 Usages of HTC technology

The usage of the HTC technology that GRENOL GmbH recommends in particular is organic waste management with GRENOL HTC reactor, processing biomass for about six hours for receiving HTC coal, and subsequent energy recovery of the HTC coal with a coal gasifier and a combined heat and power unit (CHP) as described before, to obtain maximum electric and thermal energy from the original biomass. The coal is pressed to briquettes and used for energy recovery. Depending on national government funding, it is highly profitable to feed electric energy into the grid and to consume the thermal energy in a local heat net on a farm, in a village or neighborhood.

A second usage for HTC technology is to produce HTC humus like material which may serve to optimize agricultural soil. For producing the HTC humus like material, the procedure is the same but shorter. Biomass waste must be heated up to about 230 degrees temperature and 25 bar pressure and treated for about two to three hours in the HTC reactor. Using the soil optimizer is an important contribution against the fatigue of agricultural soil. Due to better nutrition, the process of photosynthesis in the plants is enhanced: The plants take solar energy plus water plus CO_2 from the atmosphere to produce additional biomass and oxygen. With better nutrition, using the HTC soil optimizer, plants have better conditions to draw more CO_2 from the atmosphere and grow faster, given all other conditions. Moreover, the HTC process water is used to produce fertilizer, using vacuum distillation.

Hence, GRENOL has conducted various experiments of soil auxiliary material with the products of “Hydrothermal carbonization”, to show, to what degree and in what forms plants tolerate HTC products. The experiments were conducted with lettuce plants. The experiments were done with great success: The lettuce plants did accept the humus-like HTC material and enhanced their growth significantly. Further development toward market level products continues and is conducted by GRENOL in cooperation with research institutions in the region.

A third usage for HTC technology is to convert sewage sludge is into HTC coal and water. In a contemporary sewage plant, after preliminary sedimentation the sewage sludge is put into a digestion tower, where fermentation takes place. Normally, the residues are burned or spread into the fields. With HTC technology, the digestion tower becomes obsolete. The sewage sludge is first treated by a centrifuge, and then processed by the HTC reactor for six hours to produce CO_2 neutral HTC coal and water, or for about three hours to produce a HTC humus like material. The great advantage of HTC as compared to the established procedure is that a physio-chemical process, not a biological process is conducted. Thus viruses, bacteria and fungi are destroyed, most antibiotics and hormones are cracked. Also it is easier to strip with less acid the containing phosphate from the coal, then of the ash from the burned sewage sludge.

Finally, the forth usage is specifically about the HTC process water which can also be used in an economic manner. The HTC process water is used for additional biomass production in a greenhouse, thus may serve as additional CO_2 sink. The additional biomass again is processed in the HTC reactor to serve for producing HTC coal and subsequently for energy recovery. The HTC process water which contains various nutrients, is cleaned by the aquatic plants in the greenhouse used for producing additional biomass, or for producing fertilizer for various agricultural uses using vacuum distillation.

7 Benefits of HTC technology

HTC technology for the management of biomass waste has manifold benefits as compared to other technologies of organic waste management, that is, as compared to combustion, fermentation and anaerobe conversion (e.g. conventional production of biomass).

First, HTC has various benefits with regard to the processing of biomass: With HTC technology, contrary to other procedures, any biomass, wet or dry, can be processed. With regard to the biomass, there is no necessity for varietal purity. Various sorts of biomass can be put together in the mixing tank before being pumped into the HTC reactor. However, it is important to take into account various features of the specific biomass wastes added: e.g. energy content, percentage of dry substance, and bulk density. Since only organic waste materials are processed, no production of energy crops takes place for "*Hydrothermal carbonization*", thus valuable farmland, needed for the production of nutrition, is preserved. Moreover, ecological resources are preserved: Woods, crude oil, gas, fossil brown coal, fossil black coal.

Second, HTC offers manifold benefits when it comes the management of organic waste in a closed cycle: HTC technology closes the waste management cycle and offers a climate-friendly, CO_2-neutral way to take away all organic waste materials from rural, municipal and industrial areas. HTC technology offers a way to a decentralize solution of the organic waste management and also to a decentralize energy recovery, particularly for rural areas and developing countries. Particularly for areas with high population density and resulting waste problems: HTC is a very space saving technology because large amounts of biomass waste can be densified to HTC biocoal and HTC water in a very short time.

Third, HTC offers various procedural benefits: Contrary to the other procedures of organic waste management as mentioned above, HTC is a physio-chemical, not a biological process. It is conducted at much higher temperature and pressure in very short time, that is, 6 hrs, depending on the features of the biomass. Moreover, HTC offers a huge hygienic advantage and makes an tremendous contribution to preventing the spread of disease as a result of the spread of bacteria, viruses, fungi contained in the organic waste in metropolitan areas or rural areas, e.g. due to human sanitation and to mass animal husbandry and widespread use of animal manure as organic fertilizer. In the HTC process, at 230 degrees temperature and 25 bar pressure, all bacteria, viruses, and fungi are destroyed; most hormones, residues from antibiotics and other harmful compounds are destroyed.

Forth, there are benefits related to the GRENOL HTC reactor: The HTC reactor is a closed system (machinery) which allows no discharge of climate damaging gases, such as CO_2 or CH_4. The continuously operating HTC reactor offers enormous advantages concerning the use of energy as compared to batch technology. In the more common batch or multibatch reactor, the biomass waste is once filled in, then the process of carbonization is conducted, and hereafter, the material is taken out and processed further in a different container; then a different container is filled with biomass waste and heated up; in any case, the material load, and the loss of time and energy is enormous. Due to the continuous operation in the HTC reactor, and because of the fact that continuously new wet biomass is pumped into the reactor and HTC coal and HTC water are released at the end, the full energy of the exothermal reaction can be fed back into the system, and heat exchangers guarantee a much more efficient energy management than can be achieved with batch or multibatch systems.

Finally, HTC also brings diverse advantages concerning the output material: HTC technology serves for the refining of organic waste materials and enables the production of a wide range of products that can be taken to a higher value, used for energy recovery given appropriate market conditions or developed further to be stand-alone products that can be marketed profitably. Examples are HTC coal briquettes (storable energy), energy wood (wood products containing HTC coal, usable for energy recovery), chemical base products, absorber coal, isolation material, auxiliary material, usable as soil optimizer, based on HTC humus like material, N-fertilizer based on HTC water. Specifically, the HTC water contains valuable components, e.g. minerals. However, the composition of ingredients contained in the HTC process water depends upon the original input biomass. Finally, HTC products can be especially useful for cultivating nutrient poor soils, thus growing crops and other foodstuffs where this was previously impossible.

8 Conclusion

Altogether, “Hydrothermal carbonization” offers a new alternative procedure to dispose organic waste in an environmentally and climate friendly manner, in an energy efficient way far superior to the procedures of combustion, fermentation and anaerobe conversion, without any discharge of carbon dioxide (CO_2) or Methane (CH_4). Thereby, “Hydrothermal carbonization” closes the cycle of waste management.

“Hydrothermal carbonization” with the GRENOL continuously operating HTC reactor with industrial capacity is a very fast, convenient and cost-efficient way to dispose large amounts of organic waste of various sort, from rural environments, metropolitan and industrial areas, to “densify” the large amounts of organic waste, and to carry the HTC biocoal and HTC process water to a higher value. Moreover, HTC enables the hygenization of the original biomass and thus makes a tremendous contribution to prevent the spread of diseases.

The GRENOL HTC reactor, in modular design with the periphery to process waste all the way from delivery of biomass to the energy recovery of HTC biocoal, is a practical and well proven device for the decentralized production of electrical and thermal energy, thus has enormous potential both for rural areas and for developing and emerging countries.

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The APECS-biomass model

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Abstract

Organic wastes in all their different shapes and compositions have gained significant commercial, political and academic interest during the last decade. The main driver for this development is the widely accepted consideration of organic wastes as valuable resources rather than problematic or worthless stuff. With the aim to turn the economy from its fossil basis into a bio-economy with presumably higher resource efficiency and less negative or even positive climate impact, governments in many countries have started to support the use of waste biomass in many ways including subsidies.

However, the increased use of organic wastes has also revealed various kinds of new problems including technical immaturity, long-term dependence on governmental support, changing regulations in terms of environmental requirements and end-of-waste criteria, and many more. Two major issues that surfaced in recent years are the formation of new and often problematic wastes (including GHG emissions) while upgrading the original waste and, because organic wastes have been used for ages in agriculture as organic fertilizer, the reduction of soil quality. The more organic matter is used energetically or for material purposes, the less is available to nourish our soils and crops with mineral nutrients (especially N and P) and with organic carbon.

In this light, the BMBF funded project APECS (Anaerobic pathways to renewable energies and carbon sinks) suggests a new approach to improve the resource efficiency of waste use and to address agricultural and environmental needs at the same time. The underlying concept of the APECS biomass model (Fig.1) is a strong integration of bio- and thermochemical conversion, soil amendment and carbon sequestration. In detail, a combined production of biomethane by anaerobic digestion and biochar by thermochemical treatment of digestate was investigated including the cross-use of internal waste streams.

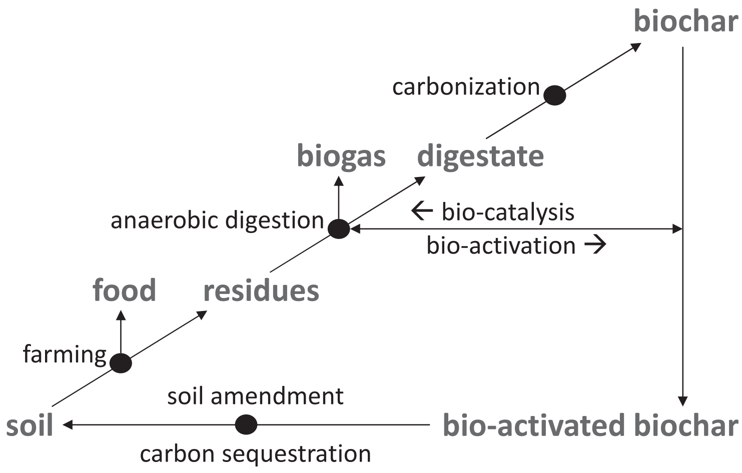

Fig.1 The APECS biomass model integrates biogas and biochar production and combines these with soil amendment and carbon sequestration

Major findings include: A new high-rate biogas reactor for solid materials (e.g. for straw and solid manure) was developed termed Upflow Anaerobic Solid-State (UASS) reactor sowing a 2-4 times higher conversion rate. Hydrothermal carbonization (HTC) can be used to turn digestate into biochar without prior drying. HTC can also be used to produce magnetic biochars for various environmental or biotechnological applications. Biochars from HTC (magnetic or non-magnetic) and from pyrolysis can be used as additive in biogas production for immobilization of microbial biomass and adsorption of chemical inhibitors.

The spent process liquor of HTC and the aqueous phase of pyrolysis oil are effective feedstocks for biogas production, which increases the overall energy efficiency of the system considerably. Biochars that have been added in a biogas reactor have high fertilizer values, which can improve plant growth. Use of hydrochar can improve the fertility of sandy-soils. Continuous carbonization and subsequent soil use of digestate can sequester carbon many times higher than without carbonization.

Biochar from HTC is less stable than from pyrolysis but can nourish functional soil microorganisms (e.g. MOs that bind atmospheric nitrogen). Biochars from HTC contain in raw state many volatile organic compounds (VOC), some of them inhibit plant growth. However, the VOCs degrade quickly in anaerobic digestion. Some VOCs forming in HTC (e.g. 5-HMF) have a high value as a basic chemical for industrial use. The HTC process can be designed and controlled (e.g. by NIR technique) to shift the reaction towards the desired range, quantity and quality of products.

Based on the results, we conclude that an integrated production of biomethane and biochar from organic waste streams (e.g. straw, manure, organic municipal wastes) can mark a considerable improvement in terms of resource efficiency, sustainable soil use, economic performance, and climate benefits.

The results of the APECS group haven be been published in over 30 peer reviewed journal articles. In addition, 5 patents were devolved during the project. For further information please visit www.atb-potsdam.de.

SolidWasteSim – Simulation of solid waste treatment

Development of a model and simulation system for complex mechanical processing in waste treatment plants

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Abstract

A critical analysis of mechanical processes in waste treatment plants hints at vulnerable spots in the interaction of plant units and deployed heterogeneous materials. The simulation of mechanical processes in waste treatment may depict the total material flow in a plant and as such, contribute to a better understanding of the behaviour in heterogeneous materials, to identify bottlenecks, to check plant modifications and hence, to support planning and reducing time for implementation period.

The project community has developed software for the dynamic simulation of user-specified plant configurations, based on a model library containing common plant components. The software is in test phase, and will be gradually developed and customized to real conditions. The simulation is based on a waste stream model, including the distribution of particle shape, size and material, water and total organic carbon content. The required waste stream data are obtained by specific waste sampling and a data regression method to estimate the waste compositions of fine fractions. Intervals of confidence are calculated from sorting results to describe the data quality and to define the valid ranges for the results of plant component simulations. Results from the simulation of a lightweight granulator and a drum screen are validated by comparison with the respective valid ranges. The need for improvement of these process models is identified.

Keywords

Mechanical waste treatment simulation, plant design optimization, analytical and empirical waste stream characterization, composition data estimation by statistical regression, statistical evaluation of waste stream compositions, validation of simulation results

1 Introduction

SolidWasteSim stands for a research and development project started in March 2012 with duration of two and a half years. It is partially funded by the Federal Ministry of Education and Research (BMBF). The project community consists of ARGUS GmbH, the Department of Process Engineering and Solids Processing of the Berlin Technical University and GreenDelta GmbH.

The main project targets (and the corresponding responsible partners) are 1) characterization of solid waste streams (ARGUS GmbH, project coordination), 2) modelling of mechanical processes (TU Berlin) and 3) implementation as simulation software (GreenDelta GmbH).

The project is aiming at the development of a simulation tool for planning and design of mechanical treatment processes for solid waste. Most existing process models are derived from mineral processing and offer only limited service in solid waste treatment. Their implementation in waste treatment plants usually requires a long trial and modification period until the desired functionality can be achieved.

The software tool will feature a user-friendly graphical interface for the simple definition and selection of the plant design, combination and configuration of aggregates, access to waste analysis datasets, waste composition and properties for all existing waste streams and presentation of results.

Fundamental for the simulation is the knowledge of technologically relevant characteristics of the expected waste streams in adequate detail and sufficient statistical certainty. This paper is addressing the waste stream characterization model that is employed for simulation, especially of the lightweight granulator, and it focuses at the validation of simulation results by the data obtained from sorting analyses and regression models.

2 Waste stream characterization

2.1 Waste stream sampling and modelling

With the detailed waste characterization the process models can be supplied with the required data for advanced waste treatment simulations. Non-distributed material properties are obtained from analyses or literature (e.g. heating values, electrical conductivity). Distributed input data are generated from complex sorting analyses of waste streams of aggregates of an operating material recovery facility. The total plant input (behind shredder), the in- and outputs of a lightweight fraction granulator, a drum screen and an optical sorter were analysed with respect to fifteen material groups, eight particle size intervals and four shape types. Thus, for each waste stream there are used two three-dimensional matrices, one for the distribution of the dry matter mass, and one for the distribution of the water mass. For the process simulation fully populated matrices have to be produced, starting from analyses of the original substance, i.e. from the wet waste.

Due to the higher difficulty of sorting fine fractions in the original substance in the before mentioned detail, the sorting method for fine fractions is facilitated. Due to the high effort for drying and total organic carbon measurements, sorted and classified waste samples were aggregated to material groups. These adaptions produce data gaps in the matrices that are employed to characterize the waste streams (see Table 1). The population of the data gaps is described in part 2.2.

The lightweight granulator has two input streams, one input contains coarse material, and the other input contains fine material. There is one granulator output which is the refuse derived fuel produced by the facility. From each input stream were taken eighteen waste samples of approximately equal volume. From the output stream thirty samples of equal volume were taken. Sampling was carried out during plant operation, covering approximately two weeks.

The input waste has been classified according to eight particle size intervals, i.e.]0;10],]10;16],]16;25],]25;40],]40;60],]60;100],]100;160] and]160;300] mm. The three latter fractions were analysed in full detail (materials and shape). For the fractions]25;40],]40;60] the particle shape was not a parameter, only the material. For sorting the fractions]10;16],]16;25], only mixed material groups (burnable, inert) were considered. The fine fraction]0;10] stands for the sieving residue that was not sorted further. The Table 1 shows the population of the mass distribution matrix that is obtained from sampling and sorting of the fine granulator input (example for paper/cardboard and aluminium).

Table 1 Distribution matrix of the mean mass of the original substance [kg] (abbreviated)

<table>
<tr><th>group</th><th>material</th><th>shape</th><th>300</th><th>160</th><th>100</th><th>60</th><th>40</th><th>25</th><th>16</th><th>10</th></tr>
<tr><td rowspan="5">burnable materials</td><td rowspan="4">paper, cardboard</td><td>flat</td><td>0.009</td><td>0.091</td><td>0.144</td><td rowspan="4">0.066</td><td rowspan="4">0.051</td><td rowspan="5">0.036</td><td rowspan="5">0.021</td><td rowspan="10">0.067</td></tr>
<tr><td>hollow</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>compact</td><td>0.007</td><td>0.038</td><td>0.022</td></tr>
<tr><td>elongated</td><td>0.002</td><td>0.017</td><td>0.018</td></tr>
<tr><td>…</td><td>…</td><td>…</td><td>…</td><td>…</td><td>…</td><td>…</td></tr>
<tr><td rowspan="5">inert materials</td><td rowspan="4">non-ferrous metals: aluminium</td><td>flat</td><td>0</td><td>0</td><td>0</td><td rowspan="4">0.001</td><td rowspan="4"><0.001</td><td rowspan="5">0.001</td><td rowspan="5"><0.001</td></tr>
<tr><td>hollow</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>compact</td><td>0</td><td>0.002</td><td>0.002</td></tr>
<tr><td>elongated</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>…</td><td>…</td><td>…</td><td>…</td><td>…</td><td>…</td><td>…</td></tr>
</table>

As can be seen in the Table 1, the analyses of the 60 and 40 mm fractions do not contain information about the shape distribution. The 25 and 16 mm fractions are divided into burnable and inert materials, and thus do not offer information about the mass of the single materials nor the shape distribution.

In order to produce a fully populated matrix, the measured mass of 60 and 40 mm paper, cardboard, e.g., has to be split up over the shape types. As a first approach, the distribution of the mass fractions over the shape types is estimated by linear interpolation between the 100 and <10 mm fraction for each material. In the 100 mm fraction the mass distribution over shape is known for each material. It is assumed that the materials in the fine fraction <10 mm contain 100 % compact particles, or 0 % flat, hollow and elongated particles, respectively. This approximation for the shape distribution is also applied for the 25, 16 and 10 mm fractions. It has to be taken into account that the mass of the single materials (e.g. paper) in the mixed material groups (burnable) has to be estimated, before the shape distribution percentages can be applied. The estimation is explained in the following chapter.

2.2 Data generation from regression

Data gaps in the original substance mass matrix are populated with the help of a statistical regression model. The model calculates RRSB-distribution-parameters with a linear fit of the data obtained from the waste analyses. With these parameters the mass fractions of a cumulative distribution can be estimated for each material in the 25, 16 and 10 mm fractions. The measured masses of the mixed material groups (burnable, inert, <10 mm) are split up over the single materials, so that the masses are conserved.

In detail, the measured data in the 300, 160 and 100 mm fraction are aggregated by materials. From the five upper fractions (300 to 40 mm), five data points result for each material. In the first step, the lower fractions (25 to 10 mm) are neglected. The absolute material masses are transformed into cumulative mass fractions. These fractions are prepared and transformed for plotting in a RRSB-distribution grid. Plotting into a log-normal-grid led to worse correlations. The here used exponential distribution was introduced by Rosin, Rammler, Sperling and Bennett (RRSB). It is defined by the equation 1.

$$Q_r(x) = 1 - \exp\left[-\left(\frac{x}{x'}\right)^n\right] \qquad (1)$$

The distribution sum Q_r is a function of the particle size x. By linear regression, the RRSB-distribution parameters n (uniformity) and x’ (fineness) are estimated. These parameters are used for calculating the corresponding cumulative mass fractions and absolute material masses in the 25, 16 and 10 mm fractions. These extrapolated material masses correspond to a certain mass distribution. It is assumed that the measured masses of the mixed material groups can be distributed proportionally among the single materials. This procedure is repeated for each waste sample. The arithmetic means of the single material masses are determined. This results for example in the fully populated matrix of the fine fraction granulator input, as shown in the Table 2.

Table 2 Fully populated distribution matrix of the mean mass of the original substance, granulator input, fine fraction [kg] (abbreviated)

material	shape	300	160	100	60	40	25	16	10
paper, cardboard	**flat**	0.009	0.091	0.144	0.030	0.015	0.004	0.001	0.001
	hollow	0	0	0	0	0	0	0	0
	compact	0.007	0.038	0.022	0.032	0.033	0.016	0.010	0.035
	elongated	0.002	0.017	0.018	0.004	0.002	<0.001	<0.001	<0.001
thermoplastic	**flat**	0.036	0.109	0.069	0.007	0.001	<0.001	<0.001	<0.001
	hollow	<0.001	0.002	0.008	0.001	<0.001	<0.001	<0.001	<0.001
	compact	0.004	0.055	0.054	0.015	0.005	0.002	0.001	0.002
	elongated	0.018	0.023	0.007	0.001	<0.001	<0.001	<0.001	<0.001
…	**…**	…	…	…	…	…	…	…	…
non-ferrous metals: aluminium	**flat**	0	0	0	0	0	0	0	0
	hollow	0	0	0	0	0	0	0	0
	compact	0	0.002	0.002	0.001	<0.001	<0.001	<0.001	<0.001
	elongated	0	0	0	0	0	0	0	0
…	**…**	…	…	…	…	…	…	…	…

All generated data were aggregated by materials and plotted again into the RRSB-grid to determine the distribution parameters n and x' for both input streams (see Table 3). The coefficient of determination r^2 reaches high values for nearly all materials, expect for PVC, thermoset and copper, or glass and minerals, respectively. The latter materials were very rare to find in the input waste flows that are characterized as lightweight materials.

Table 3 RRSB-distribution parameters and coefficients of determination, granulator inputs

material	fine input stream			coarse input stream		
	n [-]	x' [mm]	r^2 [-]	n [-]	x' [mm]	r^2 [-]
paper, cardboard	1.7	71.5	0.93	1.6	110.1	0.81
thermoplastic	2.5	119.8	0.95	2.6	202.7	0.82
PVC	10.0	259.7	0.55	7.7	116.9	0.80
thermoset	0.0	-/-	0.00	3.8	35589.4	0.14
organic	1.6	64.6	0.94	0.9	30.2	0.76
wood	1.7	55.3	0.84	8.3	124.0	0.85
textiles	2.9	143.1	0.93	11.2	182.0	0.94
others	2.7	91.2	0.92	1.6	140.1	0.74
glass	8.4	98.8	0.69	0.0	-/-	0.00
ferrous metal	9.7	138.0	0.84	5.4	132.9	0.61
copper	0.0	-/-	0.00	4.1	860.2	0.58
aluminium	8.0	116.2	0.88	8.4	98.8	0.69
minerals	9.1	100.6	0.69	0.0	-/-	0.00
compounds	2.1	104.0	0.92	6.7	129.6	0.60

From the original substance mass matrix the dry matter and water mass distribution matrices are created. The water mass matrix results from multiplication of the fully populated original substance matrix with the corresponding water contents. In spite of extensive drying activities, the measured water contents do not result in a fully populated matrix. Data gaps are closed by assuming equal water contents for similar materials or neighbouring fractions. The water contents are arithmetic means of the analysed sample water contents. The mean dry matter mass matrix is obtained by subtraction of the mean water mass from the mean original substance mass. Both mass distribution matrices, dry matter and water mass, are required for the waste stream characterization in the simulation software.

3 Validation of simulation results

3.1 Valid ranges

In this paper, the simulation results for the output stream of the lightweight granulator and for the output streams of a drum screen are validated. Simulations are based on feeding the process models with the analysed waste stream data in order to generate results. In general, the simulation results are compared to the calculated intervals of confidence obtained from waste analyses. Regarding the fine fractions 25, 16 and 10 mm, the data generated from regression are used for the definition of confidence intervals (see part 2.2). It should be emphasized that the confidence intervals obtained from regression results do not have the same quality as those from waste analyses. For the purpose of validating the simulation results of the fine fractions they are used, nevertheless.

In case of the granulator, the confidence intervals are built for the normalized masses of the dry matter and the water mass matrices characterizing the granulator output stream. The intervals are interpreted as upper and lower limits for the simulation results, i.e. for the calculated dry matter and water masses. The mass distribution among materials and particle sizes is considered. A validation of the distribution over shape is only considered for the upper fractions (300 to 100 mm) at this state of the project.

The limit values are obtained from calculating confidence intervals and relative errors assuming a confidence level of 95 % and t-distribution. Relative errors are defined for the original substance mass and the water contents. The Table 4 shows the relative errors of the material mass in the original substance of the granulator output. By definition, the granulator does only produce particles <60 mm.

Table 4 Relative error of the mass of original substance, granulator output [%] (abbreviated)

material	300 - 100	60	40	25	16	10
paper, cardboard	-	± 31	± 20	± 29	± 39	± 43
thermoplastic	-	± 29	± 17	± 35	± 39	± 62
ferrous metals	-	± 110	± 76	± 205	± 175	± 160
organic	-	± 44	± 34	± 61	± 65	± 63
textiles	-	± 69	± 31	± 44	± 61	± 68
…	-	…	…	…	…	…

Applying the law of error propagation leads to error margins for the water and the dry matter masses in the output stream. The resulting error margins are transformed into lower and upper limits that define the range of valid simulation results. These ranges are presented in the Table 5 for the dry matter mass matrix of the output stream. It has to be taken into account that the values have been normalized with the sum of the dry matter mass means for reasons of comparison with the simulation results.

Table 5 Valid ranges (normalized) for the dry matter mass simulation results [-] (abbreviated)

material	300 - 100	60	40	25	16	10
paper, cardboard	-	0.021 - 0.055	0.042 - 0.078	0.034 - 0.089	0.015 - 0.065	0.014 - 0.121
thermoplastic	-	0.060 - 0.111	0.082 - 0.119	0.029 - 0.097	0.012 - 0.053	0 - 0.120
ferrous metals	-	0 - 0.004	0 - 0.005	0 - 0.001	0 - <0.001	0 - 0.001
organic	-	0.002 - 0.006	0.007 - 0.020	0.001 - 0.045	0 - 0.051	0 - 0.118
textiles	-	0.002 - 0.030	0.012 - 0.029	0.008 - 0.041	0.001 - 0.046	0 - 0.116
…	-	…	…	…	…	…

The Table 6 gives the ranges for valid simulation results for the water masses of the output stream. The values have been normalized with the sum of the water mass means.

Table 6 Valid ranges (normalized) for the water mass simulation results [-] (abbreviated)

material	300 - 100	60	40	25	16	10
paper, cardboard	-	0.022 - 0.043	0.045 - 0.070	0.043 - 0.084	0.027 - 0.065	0.061 - 0.155
thermoplastic	-	0.004 - 0.014	0.007 - 0.020	0.041 - 0.089	0.022 - 0.054	0.034 - 0.145
ferrous metals	-	0 - 0.003	0 - 0.008	0 - 0.001	0 - <0.001	0 - 0.001
organic	-	<0.001 - 0.004	0.007 - 0.014	0.009 - 0.039	0.009 - 0.048	0.032 - 0.142
textiles	-	<0.001 - 0.016	0.010 - 0.021	0.014 - 0.037	0.010 - 0.044	0.026 - 0.138
…	-	…	…	…	…	…

With these data the simulation results of the output stream can be validated.

3.2 Simulation results *vs.* limit values

The development of the process models of the simulation's aggregate library is carried out on a phenomenological basis (PLATZK, ABEL & KUYUMCU 2013). Occurring physical phenomena are modelled in a way that reflects the physical realities inherent in the process. The interconnection of basic operations depends on the internal structure of the modelled aggregate. The phenomenological modelling approach allows visualizing the impact of any process parameter on the plant or aggregate operation and on the material stream composition and its properties.

3.2.1 Lightweight granulator

The comparison of the dry matter simulation results with the upper and lower limits measured empirically (and where necessary completed by RRSB-regression) is visualized in Figure 1 for paper/cardboard and thermoplastic.

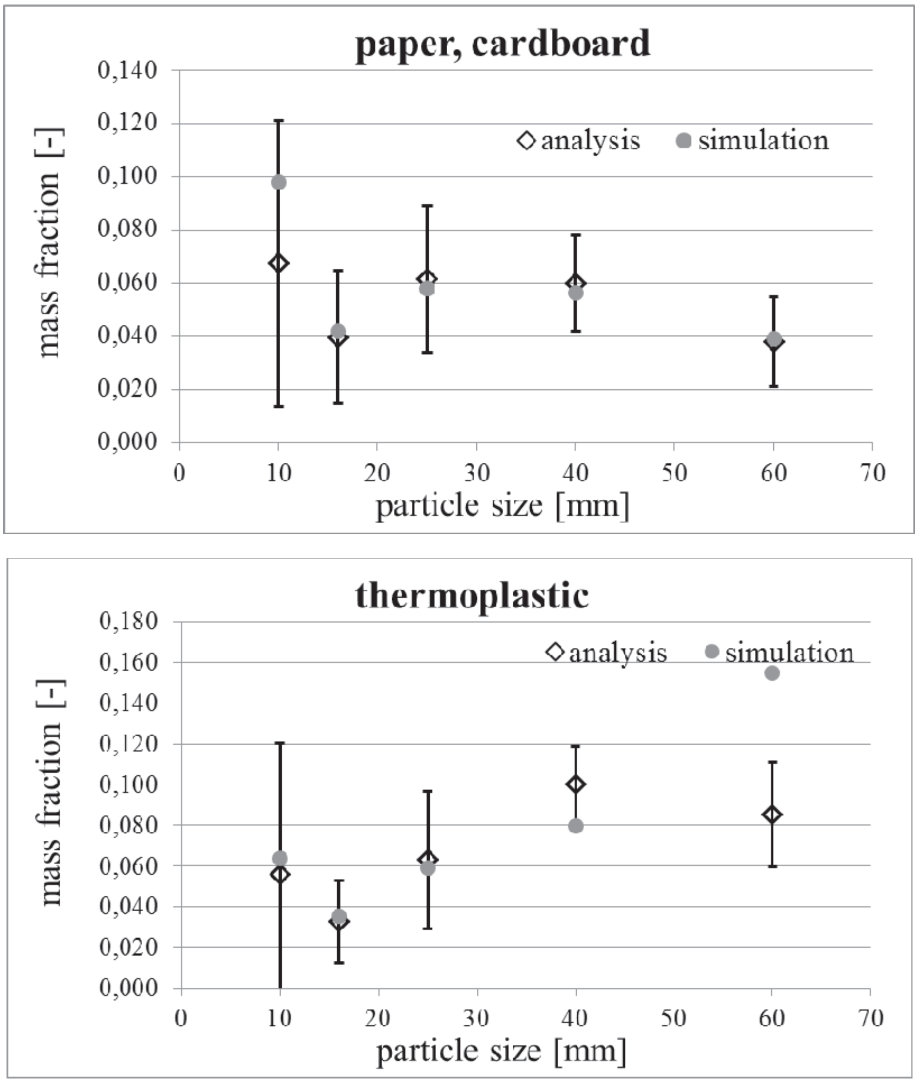

Figure 1 Comparison of the simulation results and limit values for the dry matter mass, granulator output stream (selected materials)

In this example the figures show that there is a good estimation for the mass fractions of paper and thermoplastic in the granulator output stream. For thermoplastic, the estimation is unsatisfactory in the 40 and 60 mm fractions. Relevant outliers can also be found for the material groups textiles, compounds and others.

3.2.2 Drum screen

A similar procedure is applied to validate the simulated output streams of a drum screen with a different dataset. The Figure 2 shows this comparison for the dry matter of the coarse output stream.

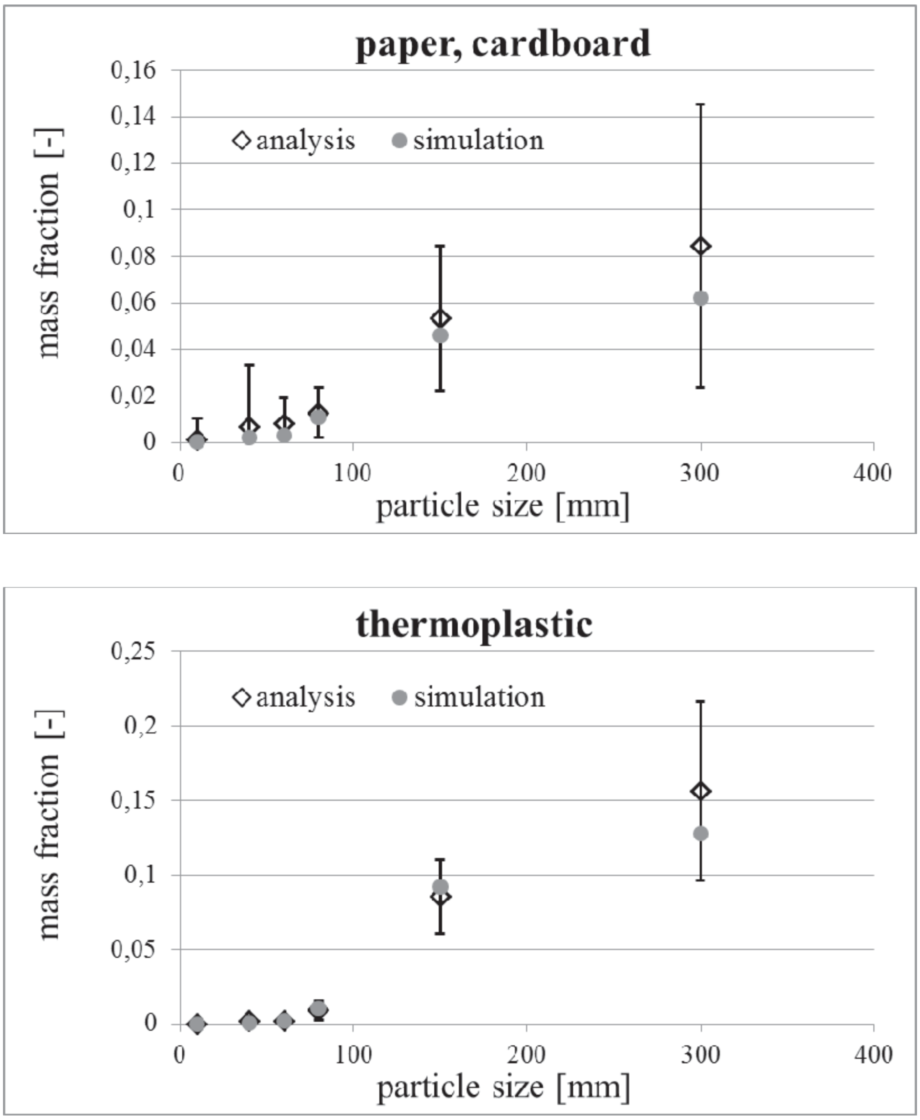

Figure 2 Comparison of the simulation results and limit values for the dry matter mass, drum screen, coarse fraction output (selected materials)

For the most important material groups there is generally a good approximation by the simulation to the mass fractions resulting from waste analysis. Organic material however is overestimated in the 300 and 80 mm fractions.

The comparison for the fine output stream also indicates a good approximation by simulation (see Figure 3).

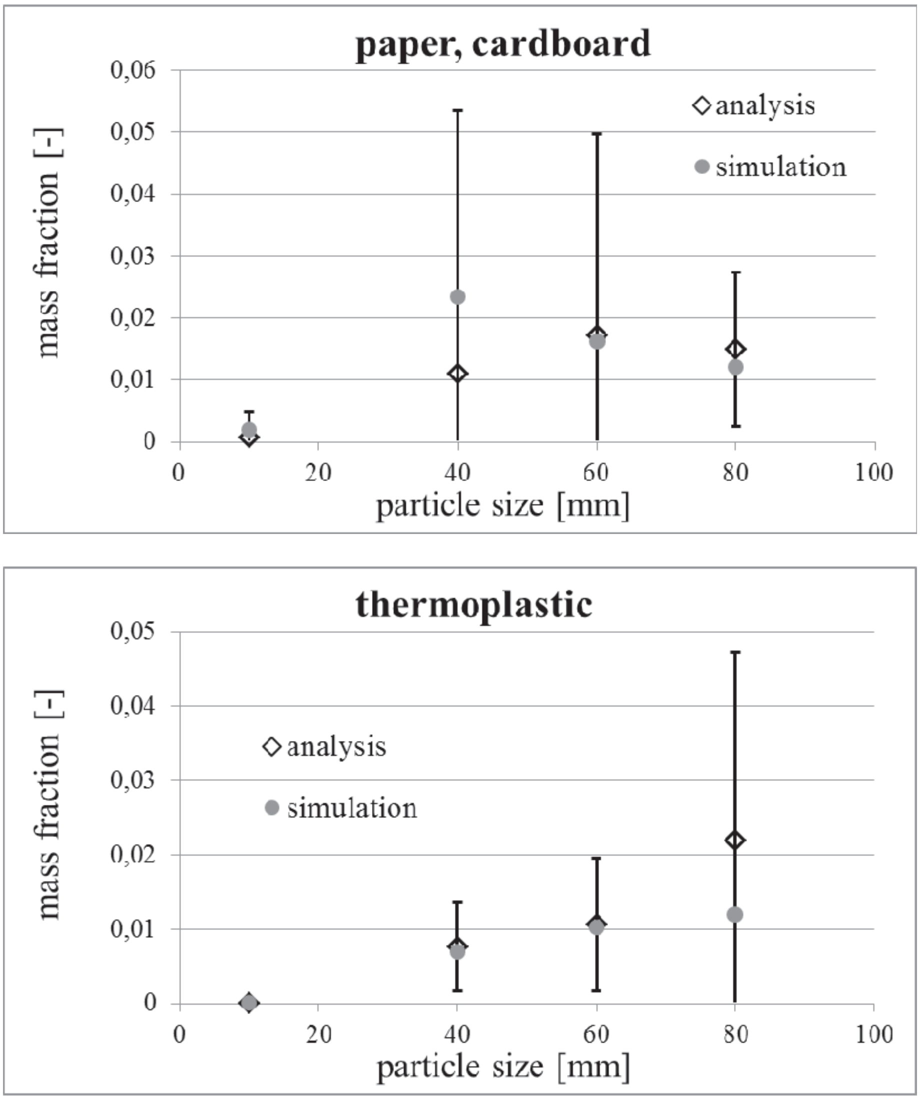

Figure 3 Comparison of the simulation results and limit values for the dry matter mass, drum screen, fine fraction output (selected materials)

In this case, the simulated organic mass fractions are in the valid range. However, glass as major fraction is outside the valid range, indicating need for improvement of this process model detail.

4 Discussion and outlook

A waste stream characterization model has been defined to be used in the simulation software. Composition data of the waste streams are obtained from waste analyses of an operating plant and from a regression model. The regression results, i.e. high correlation coefficients, lead to the conclusion that it is possible to distribute the measured mass of mixed material groups among the single materials in such a way that RRSB-distribution can be assumed for most components. Small correlation coefficients for PVC, thermoset and copper, or glass and minerals, respectively, could be explained by the very scarce presence of these materials in the waste streams.

Valid ranges for the simulated masses of the waste stream components can be defined on the basis of confidence intervals and error propagation. It must be stressed that the waste stream model works with high uncertainties that cannot be excluded (e.g. mass flow fluctuations in an operating recycling plant). This is also the case for the water contents and rare materials. The data base can be extended by already existing data from other waste analyses.

In conclusion, useful results could be produced under difficult sampling conditions. The first step of a validation process for the implemented process models has been shown here in a promising approach for a granulator and a drum screen. The presented validation method identifies improvement requirements of the implemented process models. This method can be applied for the validation of other plant aggregates. It is intended to adapt future waste analyses to make them a data source for the validation and continuous improvement of the employed process models.

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Application of paper sludge for co-fermentation in MBT

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Einsatz von Papierschlämmen zur Co- Vergärung in MBAs

Abstract

During the production of paper and packaging materials, various paper sludges are produced as waste material. This research project, funded by the DBU, investigates co-fermentation in the digesters of mechanical biological treatment plants (MBT) as an ecological and economical solution for the use of these residuals. Three types of paper sludge from different ways of paper production were analyzed. The slurries were checked for possible inhibition effects upon the biogas process in MBT and their biogas yield. First results have shown that the co-fermentation of paper sludges in digesters of MBT plants could be useful. The results found so far do not show definite inhibition effects.

Keywords

Paper sludge, deinking sludge, biogas, residues, paper factory, MBT, digestion

Papierschlamm, Reststoffe, MBA, Papierfabrik, Biogas, Deinkingschlamm

1 State of the art

Over the past years biological ways of utilization of paper mill sludges became more and more restricted. Spreading on fields with or without previous composting or digestion is now prohibited for many industrial sludges in Germany. Thus, digestion in MBT plants was found to be an energetically reasonable alternative for paper mill sludges. In 2013 4.8 million tons of residues were produced in pulp and paper mills (JUNG, 2014). Approximately 70 % of these are suitable for digestion. According to JUNG, 2014 this corresponds to one million tons of sludges from deinking process, 0.1 million tons of biological sludges from waste water treatment (WWT) and 2.3 million tons of primary sludges containing waste fibres and fillers. Small paper particles are always part of the fine fraction of residual waste as used in the digestion stage of MBT plants. Municipal solid waste, source separated organics and biological sludge of municipal WWT also contain paper in different portions. So far no problems in digestion caused by paper were reported. On the contrary, in some cases paper fraction is welcome, known to stabilize the digestion process and to improve dewatering of digested slurries.

Co-digestion of not specified paper mill sludges was already realized in 1987 in the biogas plant Zobes, Plauen (TWISTL, 2000). Biological sludges from paper mills are currently co-digested in the biogas plant of Infraserv GmbH & Co. Höchst (MUNDHENKE, 2012) and after pre-treatment in a demonstration project in Crofton, BC (SKENE, 2011). Nevertheless MBT plant operators are skeptical of co-digestion of paper mill sludges as these may contain chemicals from paper production in higher concentrations than paper.

Recently some researchers published their results regarding digestion and co-digestion of paper mill sludges. All studies refer to primary or biological sludges, none of them to deinking sludge. Most of the research focuses on biogas yield and its optimization by pretreatment techniques and optimum mixture of substrates. None was investigating possible inhibition effects so far.

In our present work we investigate not only the potential biogas yields of different sludge qualities including de-inking, biological and primary sludges of various paper productions, but also potential inhibition effects on anaerobic digestion and concentrations of potentially inhibiting substances.

2 Materials and methods

2.1 Paper sludge

During the first period of this research project, twenty different paper sludges of four different paper production types were determined. The chosen production types were categorized as woodfree paper (WF), woodcontaining paper (WC), packaging paper made of RCF (recycling fibres) without de-inking (PP) and grafic paper made of RCF with de-inking (GP). Furthermore, the following three types of sludge were selected: Deinking sludge (D) as residual from the deinking process of waste-paper, biological sludge (B) of wastewater treatment and primary sludge (P). In order to increase the dewatering of biological sludge of waste water treatment, some paper mills mix their slurries. For this reason seven samples are mixtures of biological and primary sludge and one sample is a mixture of biological, primary and deinking sludge. Corresponding to the proportions of respective slurries a category is selected. Moreover, four different samples from digesters of MBT plants and one composting plant were analyzed and compared. Two of them were based on dry fermentation and two of them on wet fermentation. All paper slurries were characterized by means of various analyses and batch-tests to determine the biogas yield and possible inhibiting effects.

Dry matter and organic dry matter are important parameters to evaluate the water content, the proportion of inorganic substance, and the digestible part of the substrate used. The dry matter content (DM) was determined according to DIN EN 12880. The weight of the dry matter within the sample was determined on a tray by drying it at a temperature of 105°C to constant weight (DIN-EN ISO 12880, 2001).

To determine organic dry matter (oDM), a dried and ground sample was weighed out in a crucible. The sample was incinerated in a muffle furnace at 550°C. The analysis was conducted according to DIN EN 12879. The ash residue of the burnt sample was weighed out to determine the inorganic dry matter. To calculate oDM, inorganic dry matter was subtracted from the dry matter (DIN EN 12879, 2001).

During biogas formation, organic carbon is converted into methane and carbon dioxide by microorganisms. Among others, the nutrient supply and the C/N ratio are important factors.The amount of Carbon (C), nitrogen (N), and hydrogen (H) was analyzed with the elemental analyzer Vario EL (Fa. Elemental). For this purpose, 10 mg of the dried and ground sample were weighed into a tin boat. The analysis was performed in duplicate. The samples in the tin boats were burned at 950 °C. Downstream, the resulting nitrogen oxides were reduced to nitrogen. The resulting gas mixture was fed into a separating and measuring system. A software program calculated the contents of C, H and N. From this, the C/N ratio was calculated.

Ammonium-nitrogen was determined according to DIN 38406 part 5 using photometric analysis. Therefore the sample was centrifuged for 10 minutes at 5000 rpm and the supernatant was centrifuged for further 10 minutes. Then the supernatant was filtered with a membrane, mixed with reagent solutions and filled up with distilled water to a volume of 10 ml. Then the samples, reference standards, and control samples were able to be measured with a photometer (DIN 38406-5, 1983).

2.2 Biogas yield

The biogas and methane yields of the examined samples were determined by means of batch-tests in 30 l barrels. Gas bags were connected to the barrels to capture the volume of gas produced. The barrels were filled with seed sludge and paper sludge and placed in a climatic chamber at 38° C (Figure 1). The batch experiments were carried out in accordance with VDI guideline 4630. Each sample was determined in triple repetition. Sewage sludge was used as seed sludge and cellulose as the control sample.

Figure 1 climatic chamber with barrels and gas bags during a biogas yield batch-test

Detecting the quality and quantity of the biogas produced provided information on the progress of the fermentation of the paper sludge. Therefore, the composition and quantity of the biogas were analyzed every working day. The composition of the biogas was measured by using an infrared meter (visit 03, Messtechnik EHEIM GmbH), which analyzed the parameters methane, carbon dioxide, hydrogen, hydrogen sulfide, and oxygen. The volume of gas formed was determined by a drum-type gas meter (Ritter Apparatebau GmbH & Co.KG). Gas temperature and air pressure were detected for each measurement. The measured data were transferred to an Excel data sheet and converted to biogas yields in liter under standard conditions (l_n) related to the amount of organic dry mass (kg oDM) or related to fresh mass (kg FM).

2.3 Inhibition test

Possible inhibiting effects on the biogas process were tested by batch-tests with high resolution recording of the produced volumes of biogas. The kinetics of biogas formation were assessed by using the ANKOM® Gas Production System. The pressure increase in the headspace of 500 ml glass bottles was measured at a temporal resolution of 30 minutes and the biogas volume was calculated by applying the ideal gas law. The inhibition test was implemented in triple repetition in a climatic chamber at 38° C. Pellet sludge of wastewater treatment from a paper mill was used as seed material. The experimental setup is shown in figure 2.

In variation 1 the kinetics of biogas formation of seed sludge were recorded. In variation 2 the kinetics of biogas formation of seed sludge and a defined amount of paper sludge (potential inhibitor) were recorded in order to observe potential inhibition effects on the seed sludge.

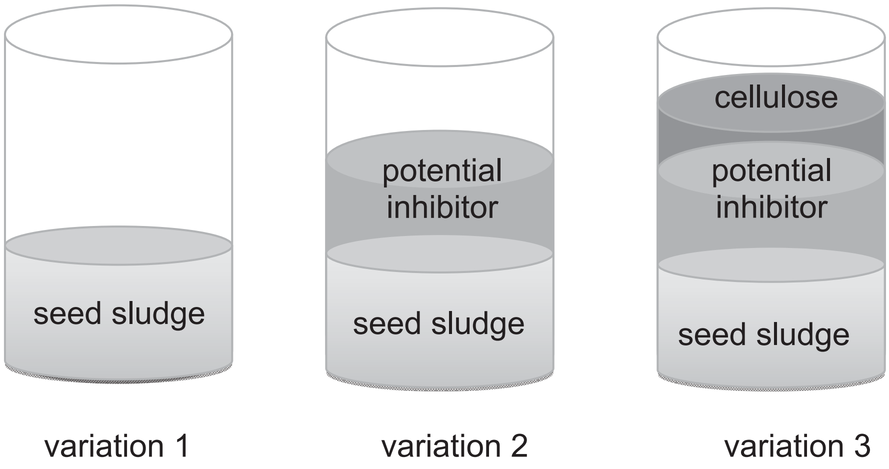

Figure 2 experimental setup of the inhibition test

This was calculated by subtracting the mean value of biogas formed of seed sludge from the mean value of total biogas formed. Paper sludges were added in four different doses (100%, 75%, 50% and 25% of the maximum dose) in variation 2. The dose of paper sludge depends on the organic matter content of used seed sludge. The maximum dose of paper sludge corresponded to a ratio between organic matter of seed sludge and organic matter of paper sludge of 0.25. In variation 3 cellulose was added additionally in order to observe potential inhibition effects on the kinetics of biogas formation from cellulose. Therefore the biogas formed in variation 2 was subtracted from the total biogas yield of variation 3. In variation 3 three different doses of paper sludge and cellulose as well as 100% cellulose were tested. The layout of the inhibition test is shown in table 1.

Table 1 Inhibition test approach with the ANKOM Gas production system

Inhibition test	Seed sludge	Paper sludge	Cellulose	Repetition
variation 1	x			3
variation 2	x	25%		3
variation 2	x	50%		3
variation 2	x	75%		3
variation 2	x	100%		3
variation 3	x	25 %	75%	3
variation 3	x	50%	50%	3
variation 3	x	75%	25%	3
variation 3	x	0%	100%	3

3 Results and discussion

3.1 Characterization of paper sludge

Biogas is the product of anaerobic digestion of organic substance. The energy content of the paper sludge samples corresponds with the dry matter and organic dry matter contents. These parameters are also important for transportability, storage capability and the technology for feeding the fermenter. In figure 3 median, minimum and maximum values of dry matter content in percentages of fresh mass of 17 slurries are shown. The dry matter content of de-inking slurries is the highest with 62% to 68%. Biological slurries and mixed slurries show lower DM contents between 12% and 39%. The DM of primary sludge ranges between 20% and 60%. De-inking sludges contain high concentration of minerals, mainly calcium carbonate, generating high DM after dewatering. Primary sludges mainly consist of fibres generating good dewaterability compared to biological sludges of WWT consisting of bacteria that are known to be hard to dewater.

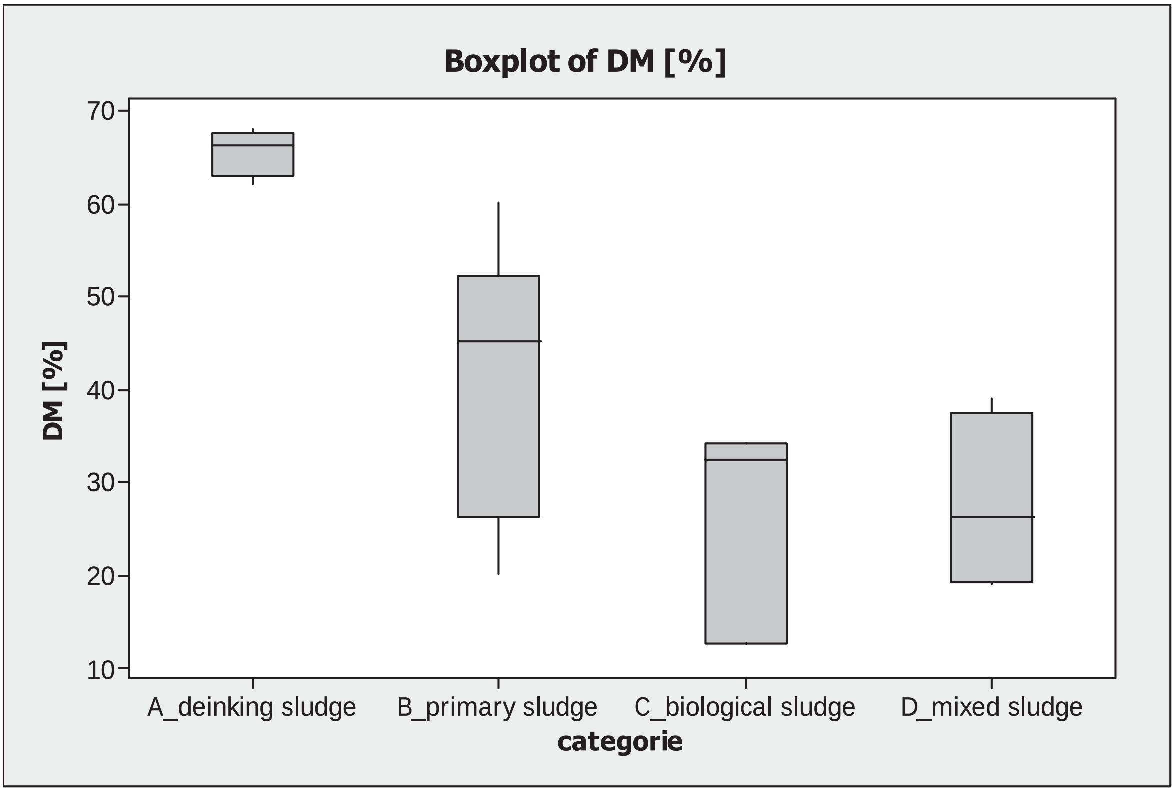

Figure 3 dry matter content of deinking, primary, biological and mixed sludge

Contrary to the DM of de-inking sludge the oDM in percentage of dry mass is the lowest with a median of 30% due to the high mineral content. Primary, biological and mixed sludge show higher oDM values in a range of 38% to 85% (figure 4) as they contain fibres and bacteria increasing the organic matter.

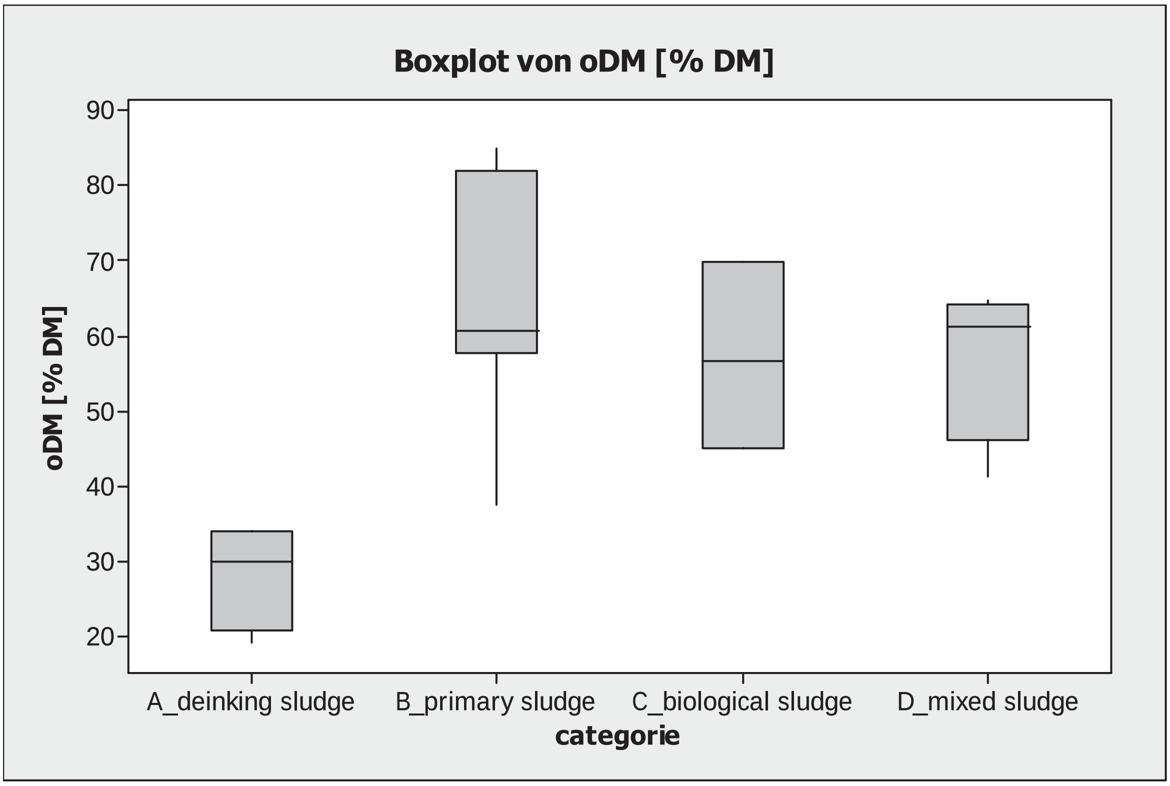

Figure 4 organic dry matter of deinking, primary, biological and mixed sludge

To determine the proportion of organic matter in paper sludge the oDM related to fresh mass was calculated. The median of the organic dry matter content of de-inking sludge is 19 % of fresh matter (FM) and the median of primary sludge is 23 % of fresh matter. The lowest results for the organic dry matter content were determined for the categories biological and mixed sludge with 15 % and 14 % of fresh matter.

In figure 5 the C/N ratio is shown. While the carbon content in primary, biological and mixed sludge ranges between 24 % and 41 %, the carbon content of de-inking sludge is lower with values between 19 % and 23 %.The content of nitrogen in de-inking and primary sludges is very low with a mean value of 0.2 %, whereby a mean value of 4 % was measured in biological and mixed sludges. Out of this a C/N ratio between 5 and 36 resulted for biological and mixed sludge and a high C/N ratio of 64 to 266 for de-inking and primary sludge. According to Eder (EDER, 2012) a C/N ratio of 10 to 40 is best for microorganisms in digesters.

Paper mill sludges generally are quite poor in nitrogen. Only biological sludges contain significant quantities as N is dosed for growth of the bacteria in the waste water treatment plants.

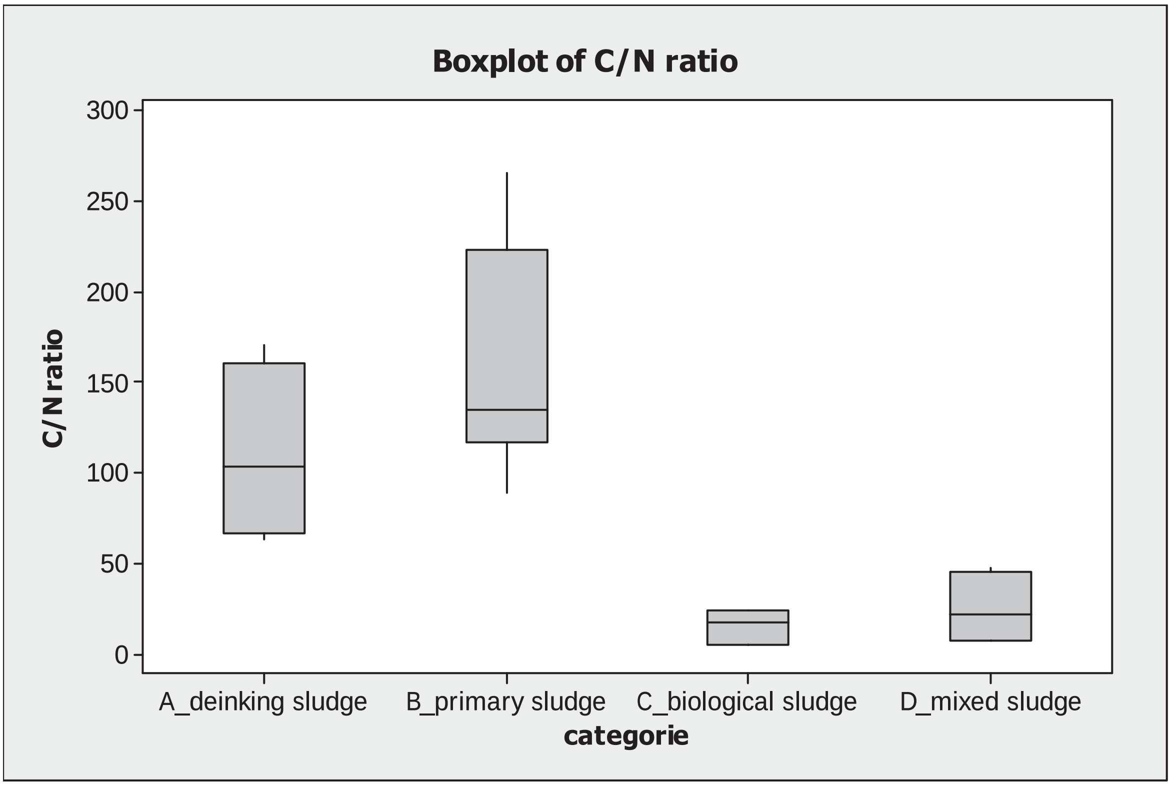

Figure 5 C/N ratio of deinking, primary, biological and mixed sludge samples

3.2 Quantity and quality of biogas from paper sludge

The biogas yields of the different paper sludges depend, among other things on the water content and the organic fraction. In figure 7 the biogas yield related to organic dry matter (oDM) content and to fresh matter (FM) of eight paper sludges is shown. According to KTBL (KTBL, 2007) the biogas yield of maize silage is 600 l_n/kg oDM and the yield of organic waste is 615 l_n/kg oDM.

The biogas yields of de-inking slurries analyzed so far vary from 256 to 406 l_n/kg oDM and from 52 to 64 l_n/kg FM. Highest biogas yields were achieved from primary sludges with values between 309 and 547 l_n/kg oDM or 85 and 164 l_n/kg FM. Lowest biogas yields related to fresh mass were recorded for biological sludges with 23 and 44 l_n/kg FM. This is associated with low dry matter content of biological sludges as described in chapter 3.1.

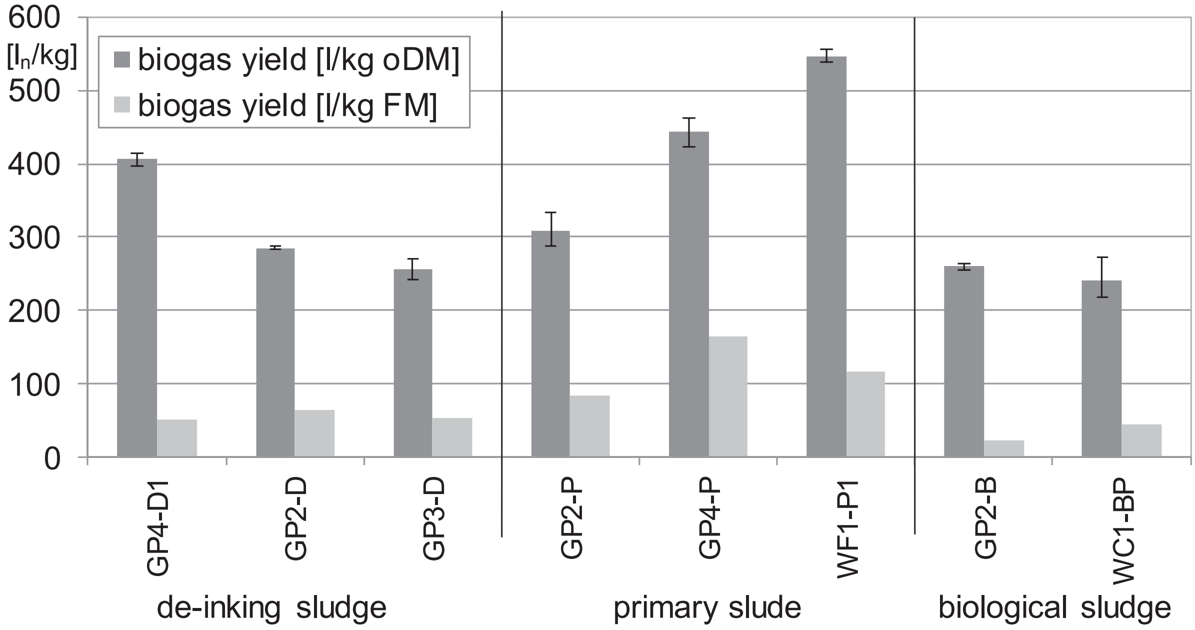

Figure 7 biogas yields of several de-inking, primary and biological slurries related to organic dry matter (oDM) and fresh mass (FM)

Additionally the methane content of biogas is an important figure for the energetic use of the gas. The mean concentration of methane in gases derived from de-inking sludges was measured to be 56 %. The highest concentration of methane was measured for biological sludges with 65 % and the lowest concentration was measured for primary sludges with 53 % of methane. Thus, the primary sludge with the highest biogas yields related to fresh mass produces the lowest methane concentration. Nevertheless the methane yield of primary sludge related to FM is highest and the methane yield of biological sludge is lowest. However, further research on pretreatment of biological sludges for codigestion is needed. The methane yields related to oDM and FM and the methane concentrations are shown in table 2.

Table 2 methane yield and concentration of de-inking, primary and biological sludge

category	**methane yield [l_n/kg oDM]**	**methane yield [l_n/kg FM]**	**methane [Vol %]**
de–inking sludge	238	31	59%
	158	36	56%
	160	33	63%
primary sludge	160	44	52%
	247	92	54%
	293	63	54%
biological sludge	185	16	70%
	140	26	59%

In figure 8 biogas yield curves of three different primary sludges are shown. The primary sludge WF1-P1 from a paper plant with woodfree paper production formed most of its biogas in the first 20 days. With respect to a mean retention time of MBT digesters of 20 days, the velocity of biogas formation is crucial for a codigestion in digesters of MBT plants. Compared to the biogas yield curve of primary sludge GP2-P, after 20 days the biogas yield of primary sludge GP4-P shows only a small difference. However, at this time the GP4-P primary sludge was still relatively active and continued to produce gas over the following 20 day. Thus, only 68 % of the biogas from GP4-P formed in this biogas yield test could be used if it was fermented in a MBT digester with a retention time of 20 days.

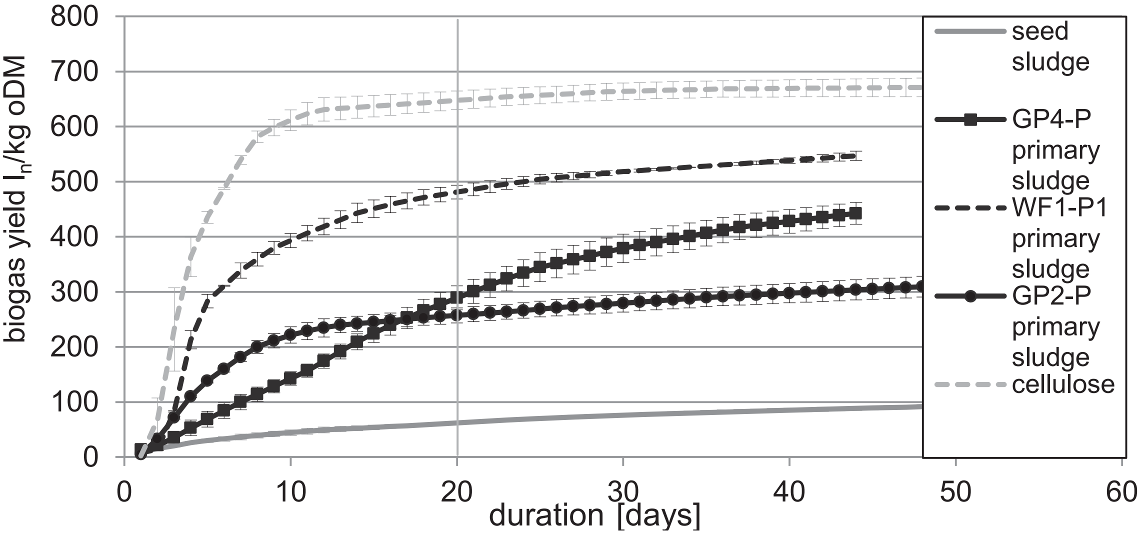

Figure 8 biogas yield curves of primary sludge, cellulose and seed sludge related to organic dry matter (oDM)

Consequently measuring gas yield as well as kinetics of methane and biogas formation are relevant to assess the suitabilty of paper sludge for co-digestion. As shown in figure 8, the biogas formation and the biogas yield differ very much within the category primary sludge. Further gas yield tests are needed to evaluate correlations between sludge categories and possible influences of the production type.

These first results have shown that biogas yields depend on DM and oDM of the respective paper sludge. Especially the biogas yields of primary sludges indicate that co-fermentation in MBT plants could produce additional gas and, thus, be a good way to utilize these residues. However, further results of biogas yields from paper sludges are needed and more data needs to be collected, which is currently happening within the project.

3.3 Inhibition test

In addition to the biogas yields of different types of paper sludges, the potential of inhibition by substances used for paper production has been analyzed. De-inking sludge may contain high amounts of mineral oil based printing inks and some components of special papers. Especially the mineral oil components were suspected to be able to inhibit the anaerobic digestion process. De-inking flotation accumulates 70-90% of mineral oil saturated hydrocarbons (MOSH), mineral oil aromatic hydrocarbons (MOAH) and polycyclic aromatic hydrocarbons (PAH) in de-inking sludge (BMEL, 2012). Because of this, mainly de-inking slurries were examined in the inhibition test system up to now.

To ensure comparability of results, the inhibition test has been implemented with pellet sludge and with fermenter content of MBT plants as seed sludges. The biogas formation started slower in samples with pellet sludge than in those with fermenter content. Nevertheless results have shown comparable kinetics for both seed sludges.

In figure 9 kinetics of biogas formation of a biological sludges of wood containing paper production in different concentrations are shown. All concentrations showed similar kinetics of biogas formation, starting with an increase from day one to day four. Based on these results, it seems to have no inhibiting effect due to the seed sludge.

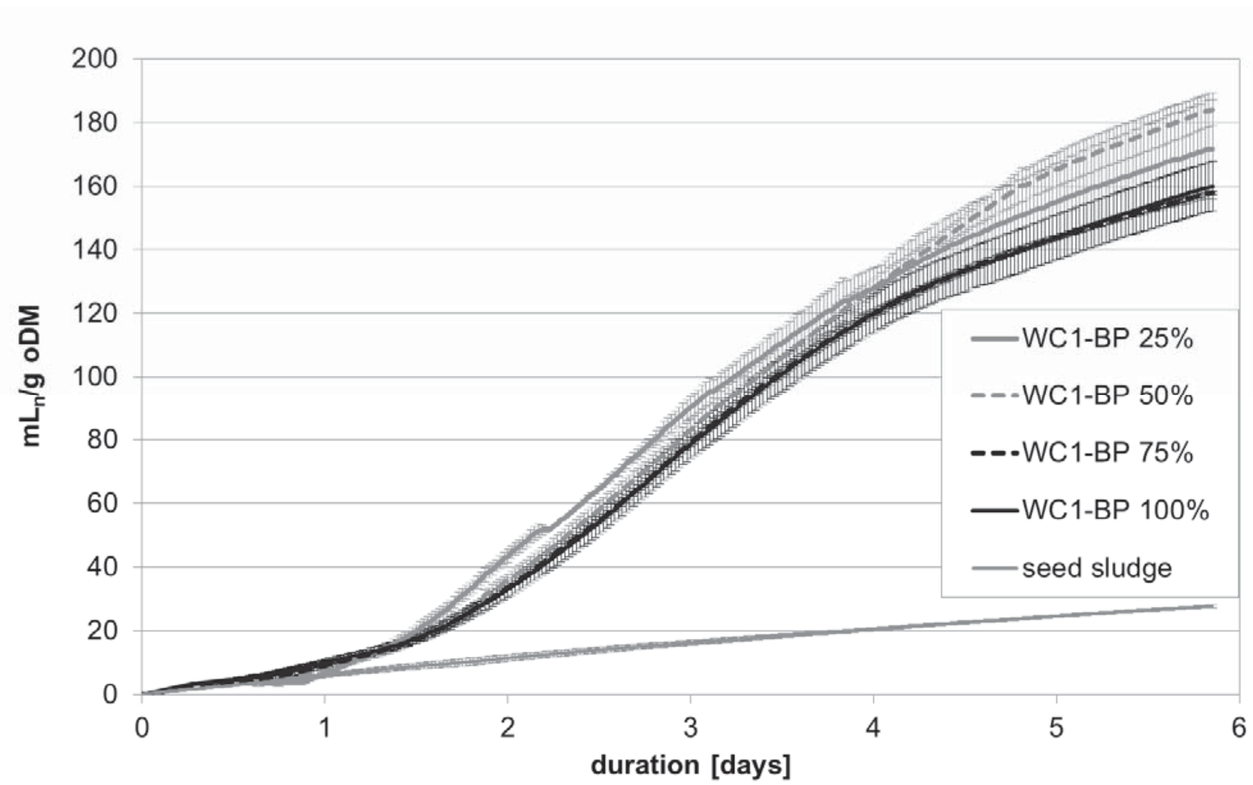

Figure 9 kinetics of biogas formation of a biological sludge in different concentrations

In variation 3 of the inhibition test (Chap. 2.3) the biological sludge WC1-BP was mixed with 25 %, 50% and 75 % cellulose. The kinetics of biogas formation of 25% and 75%

cellulose are shown in figure 9. Potential inhibition effects of the biological sludge WC1-BP on the fermentation of the standard substrate cellulose were analyzed. Kinetics of biogas formation of all three variants are very similar. The curve of biogas formed from cellulose mixed with 25 % biological sludge shows a slightly slower increase than the other biogas formation curves. Nevertheless, an inhibition of the biogas formation out of cellulose cannot be assumed.

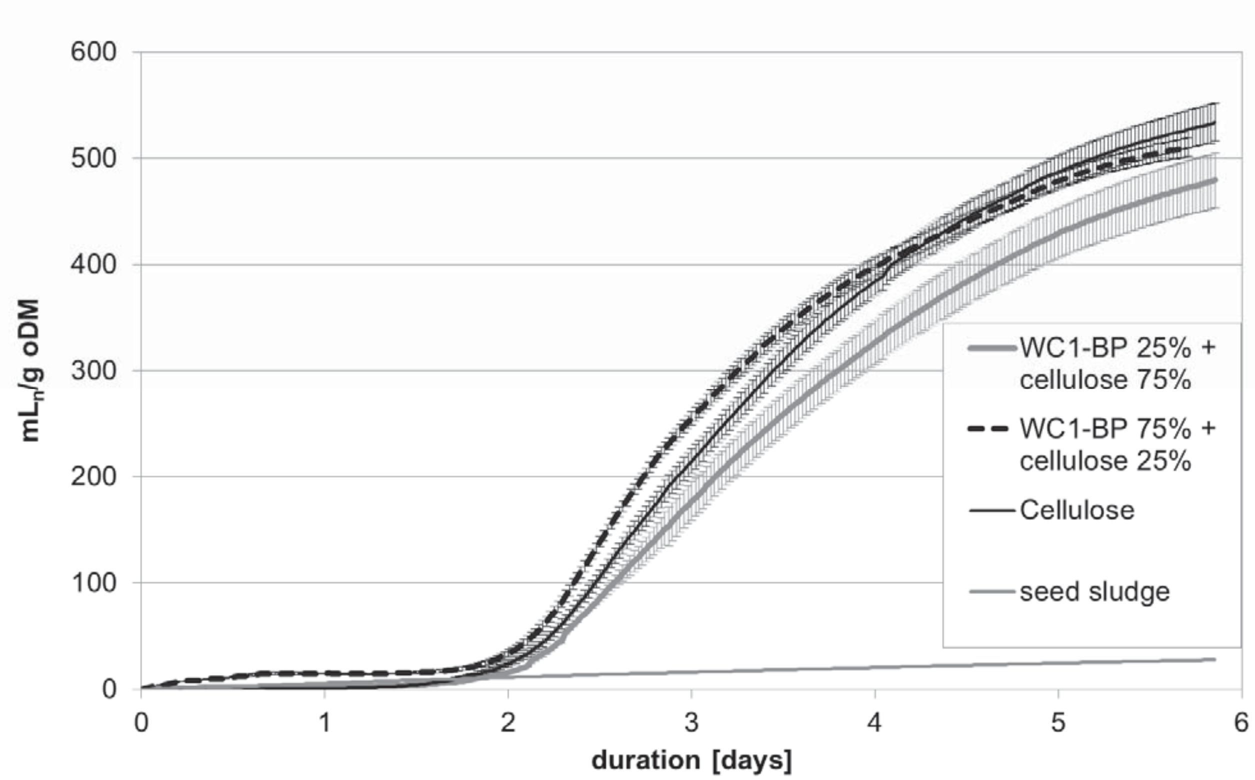

Figure 10 kinetics of biogas formation of cellulose mixed in different concentrations with a biological sludge

Results have not shown definite inhibition effects so far. For more detailed statements on inhibition effects of paper sludge further research is needed. More analyses on the influence of mineral oil content, chlorocarbons and heavy metals are currently being performed.

Altogether it can be summarized that all investigations carried out so far show significant potentials to use paper sludges as additional substrate in MBT plants in order to produce additional gas for sustainable energy generation.

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Waste management centre in Gipuzkoa

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Abstract

In Gipuzkoa, a major debate has started up regarding the management of waste, caused by the project to construct an incineration plant. Their defenders maintain that it is a technology on the rise in Europe and that it is compatible with recycling, while its critics reject this premise and hold that incineration, as well as being harmful to health and the environment, goes against recycling, insofar as it destroys raw materials that could be recovered.

Since they accessed public office in 2011, the current managers of GHK, the public waste management company in the province of Gipuzkoa, have dedicated their efforts to devising a new alternative project related to the recycling objectives set by the European Environment Commission, such as the mechanical biological treatment (MBT) plant presented at this conference.

The latest rejected product from this MBT would meet the inertisation criteria necessary and would go to the recovery of degraded areas, such as the recovery proposal for the Osinbeltz abandoned quarry.

Keywords

Sustainable treatment of waste. Matter made inert. Recovery of degraded areas. Land Art.

1 Introduction

1.1 Waste Management Centre in Gipuzkoa – Zubieta's MBT project

1.2 Location of Gipuzkoa

Gipuzkoa is one of the seven provinces in the Basque Country. It is located in north-east Spain, close to the border with France. It has a surface area of 1,909 km2 and a population census of 708,631 inhabitants.

GHK is a public company responsible for the management of waste and construction of the infrastructures necessary to treat it for the entire region of Gipuzkoa

1.3 Planning waste management in Gipuzkoa

In the previous political legislature (2008-2011), a waste management model based on incineration was planned, which provoked extensive public debate on the suitability of the proposed technology. This debate, nevertheless, transcended the boundaries of the technical environment and became a topic of political confrontation, leading to unprecedented media coverage and a radicalisation of positions.

The planning which considered the need for an incinerator plant was supported by correct programmatic bases, in that it was inspired by the waste management hierarchy of the European Union, which are, in the following order, prevention, reuse, recycling, other recovery and elimination. However, the prognosis carried out was wrong, as it described a waste generation scenario on the rise, when reality has shown the opposite; i.e., the effects of the economic crisis together with active pro-recycling policies have shown that every day we are generating less waste, which calls into question the need for an incineration plant.

From the data that was in the possession of the planners when designing the incineration plant, we know that they were aware of this reality but, nevertheless, they decided to go ahead with a project that was, by any reckoning, oversized, as all of the political representatives now admit.

Specifically, the complex in its entirety was dimensioned to treat a quantity of 320,000 t/year of waste, which once treated in an MBT bio-drying plant, would be reduced to 260,000 t/year. This was the nominal capacity for which the incineration plant was designed.

However, in 2014, the year in which the plant should have entered operation if its construction had not been halted, in Gipuzkoa 302,000 t of waste was generated, of which 130,000 t was separated at source (43% of the total), continuing the material recovery channel through recycling. Therefore, only 170,000 tons of waste not separated at source was left for treatment. If the complex had been constructed [MBT bio-drying + incinerator], once the waste had been dried in the MBT, we would have had 120,000 t left to be burned, in a plant designed to burn 260,000 t! The over-sizing of the plant was evident.

	prognosis	v	real data	
Capacity of the WMCG complex	320,000 t/year		170,000 t/year	MSW - Collection without separating in 2014
Nominal incineration capacity	260,000 t/year		120,000 t/year	Once dried

1.4 Real evolution of waste in Gipuzkoa:

Clearly there has been a change in mentality among the residents of Gipuzkoa, if we consider the evolution of the region in terms of recovery through the selective collection of waste.

In recent years there has been an exponential increase in the percentage of selective collection. If before 2011 the average annual increase was 1 percentage point, from that year to the present the annual increase has been as follows:

From 2011	To 2012: + 2.5%
From 2012	To 2013: + 3.3%
From 2013	To 2014: + 5.5%

Selective Waste Collection:

2014: 130,000 t (prognosis)

2013: 119,500 t

Increase 8%

Rate: 43%

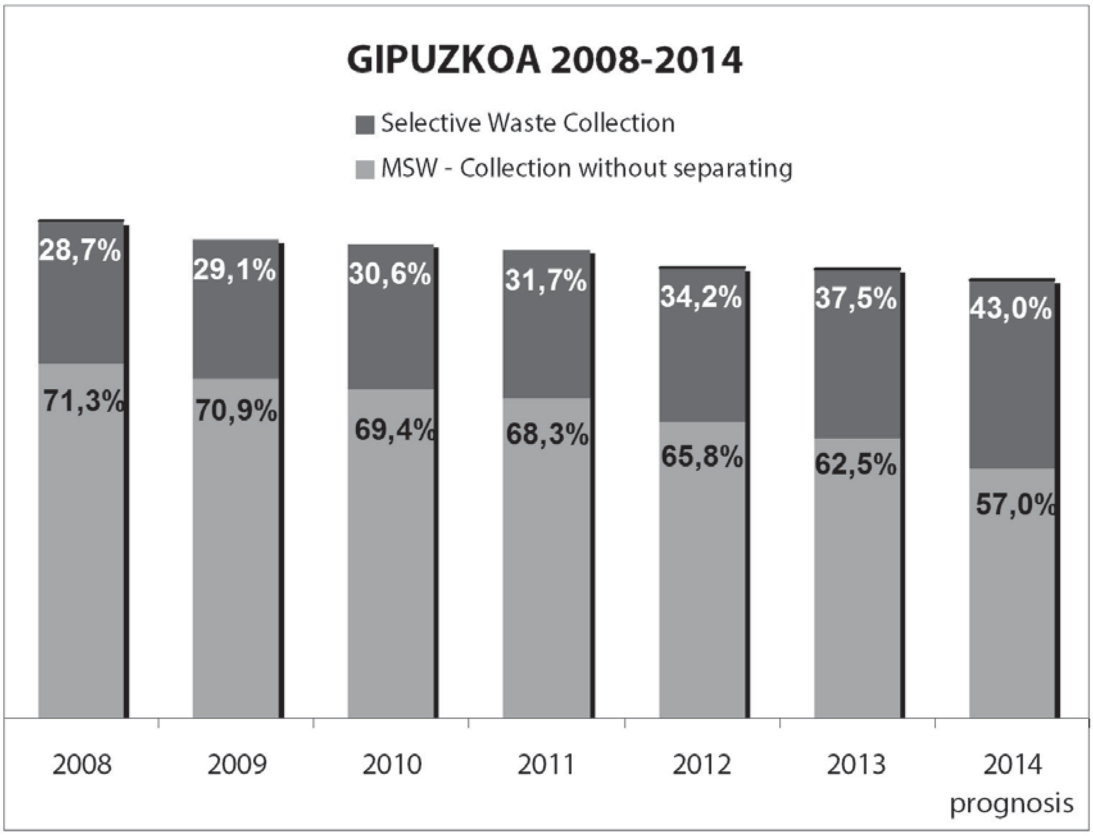
MSW - Collection without separating:

2014: 172,000 t (real data)

2013: 199,168 t

Decrease: 16%

Rate: 57%



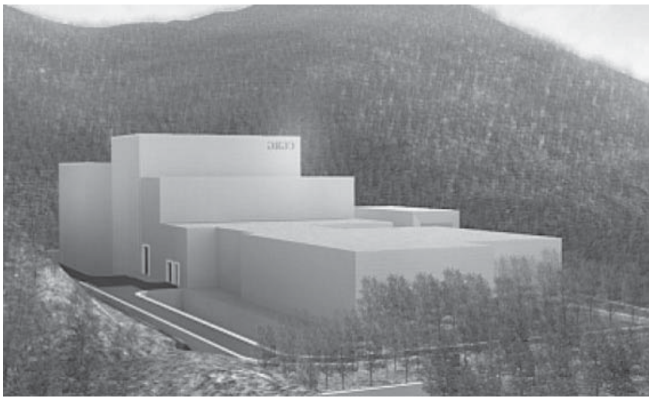
This change in mentality, which has occurred naturally, albeit slowly, has accelerated as a result of the active willingness of a large part of the population to show that another type of waste management is possible, where the concept of sustainability may be accommodated.

2 Incineration Plant Project, preceded by MBT plant

This new scenario of progress in selective collection has made the construction of a complex for treating waste focused on drying it in an MBT plant in order to then burn it unfeasible.

The cost of the complex amounted to 223 million euros, which, including financial expenses, interest, land purchase, etc. meant an outlay of 500 million euros, a figure that would require an increase in the rate per ton treated, unaffordable for most municipalities in the region.

As for possible income from burning waste, the incinerator plant project envisaged electricity production of 190,000 MWh/year. However, this same power calculation, already subject to a quantity of waste that is not generated, was based on a calorific value of waste (LCV) of 2,960 Kcal/t (12,400 KJ/t), a figure which is difficult to reach in the event of avoiding burning recyclable raw materials such as light packaging, paper and cardboard, as ordered by the European environmental guidelines.



Cost of constructing the complex:
€ 223 million
Total expenses:
€ 500 million
Nominal capacity of the plant:
320,000 t/year
PCI basis for calculation:
2,960 Kcal/t (12,400 KJ/t)

Moreover, the environmental impact that such an infrastructure would produce should be taken into account, such as the slag produced from thermal combustion (65,000 t/year), the toxic ash considered to be hazardous waste (13,000 t/year) or greenhouse emissions in the form of gases emitted into the atmosphere (90,000 t/year).

3 Zubieta's MBT plant project

3.1 Regulatory framework:

The MBT plant in Zubieta (Gipuzkoa) was designed in accordance with Directive 2008/98/EC (Waste Framework Directive) of the European Union, rigidly respecting the European hierarchy of waste treatment:

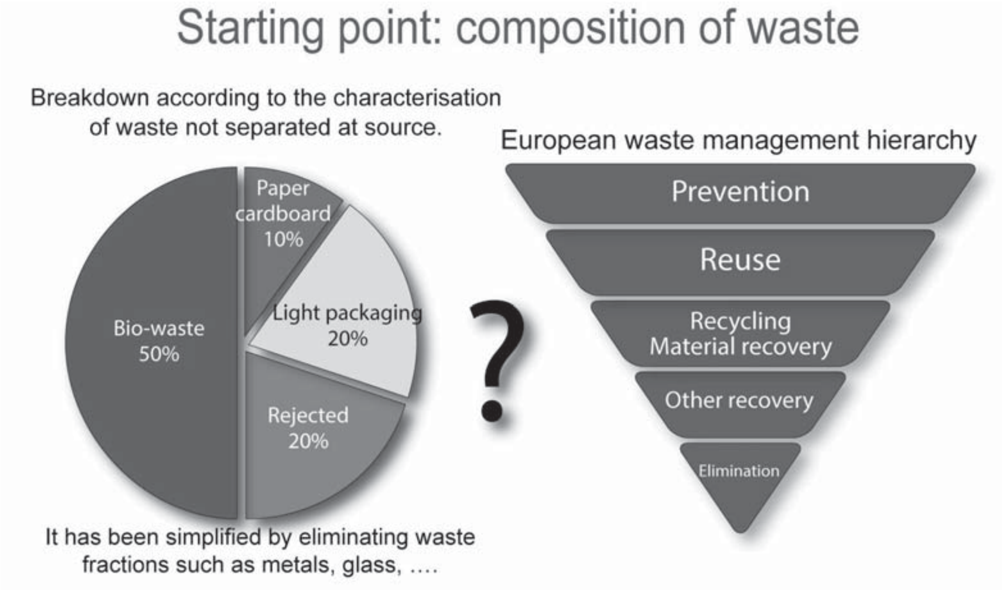
This hierarchy requires waste managers to give priority to the level immediately above, before dealing with the level immediately below. In this sense, the proposed incineration plant breached the hierarchy, since it prioritised "energy recovery" on level 4 ("Other recovery") before "material recovery" on the level above.

The Zubieta MBT plant presented at this conference will correct this situation, since it focuses basically on "material recovery" or the recycling of waste, and only allocates the rejected fraction that it was not possible to recover to the lower level "other recovery", as will be explained below.

3.2 Starting Point: Composition of Waste

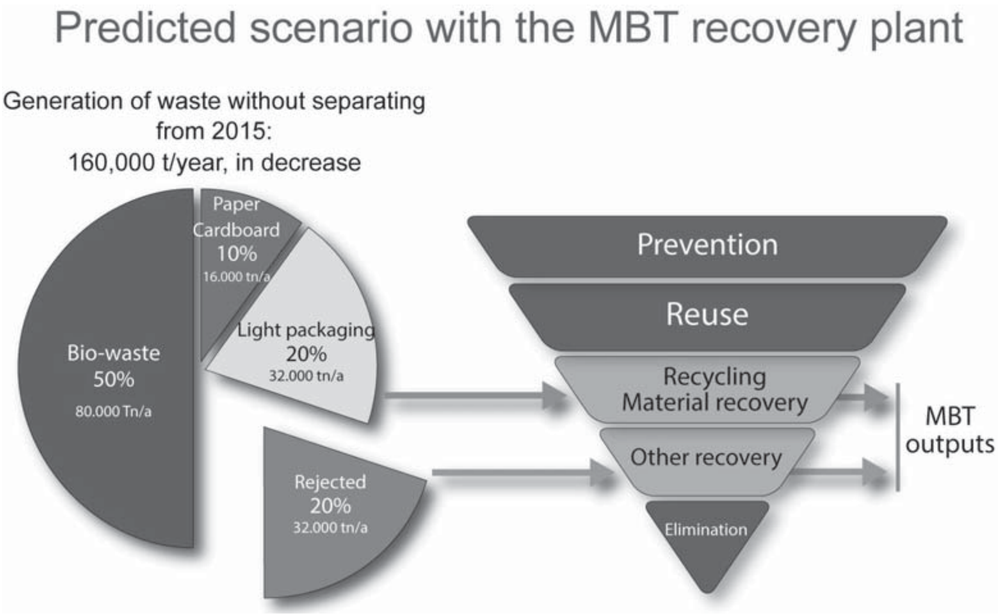
The starting point is in characterising waste that has not been separated at source (MSW). The last study carried out in Gipuzkoa revealed that 80% of the waste collected without being separated is recyclable, with the following breakdown: 50% Organic Matter, 20% Light Packaging and 10% Paper and Cardboard (simplified proportions ignoring small fractions such as glass, metals, etc.)

Finally, 20% of the waste collected without being separated is rejected material which cannot be recycled or recovered, which raises the question of what to do with it. It seems obvious that there is not a sufficient amount to justify an incineration plant.



3.3 Predicted scenario with the MBT recovery plant

The solution that the Zubieta MBT provides is the maximum "material recovery" of recyclable raw materials coming from the flow of waste that has not been separated at source and treatment of rejected material as "other recovery".



When we analyse output from the MBT, we will clearly see the resulting material recovery percentages, as well as the characterisation of the rejected material and treatment that it is given. But before that, we will look at the criteria that have guided us when designing the MBT plant.

3.4 Zubieta's MBT construction criteria.

The MBT plant in Zubieta (Gipuzkoa) has been designed in accordance with the following criteria:

1. **Maximum material recovery**. Main objective: increase the rate of recycling. 60% in 2016.
2. **Versatility** Flexibility to adapt to new waste flows, depending on the progress of selective collection.
3. **German regulation**s for regulating pretreated waste. Objective: Maximum inertisation of residual matter.
4. **Maximum return on investment**: Recovery of 85% of the investment made.

Preparation of the project:

- HAASE Environmental Consulting (HEC). Neumuenster, Germany.
- Project completed, pending environmental authorisation by the Basque Government.
- Budget: € 60 million

3.5 Zubieta's MBT plant project. Inputs:

The Zubieta MBT plant has been designed to treat three different types of waste flows: A main flow of waste collected without being separated of approximately 160,000 t/year; a second flow of light packaging separated at source of approximately 13,000 t/year; and a third flow of organic matter separated at source of 20,000 t/year.

1) **MSW or waste collected without separating: 160.000 t/year**

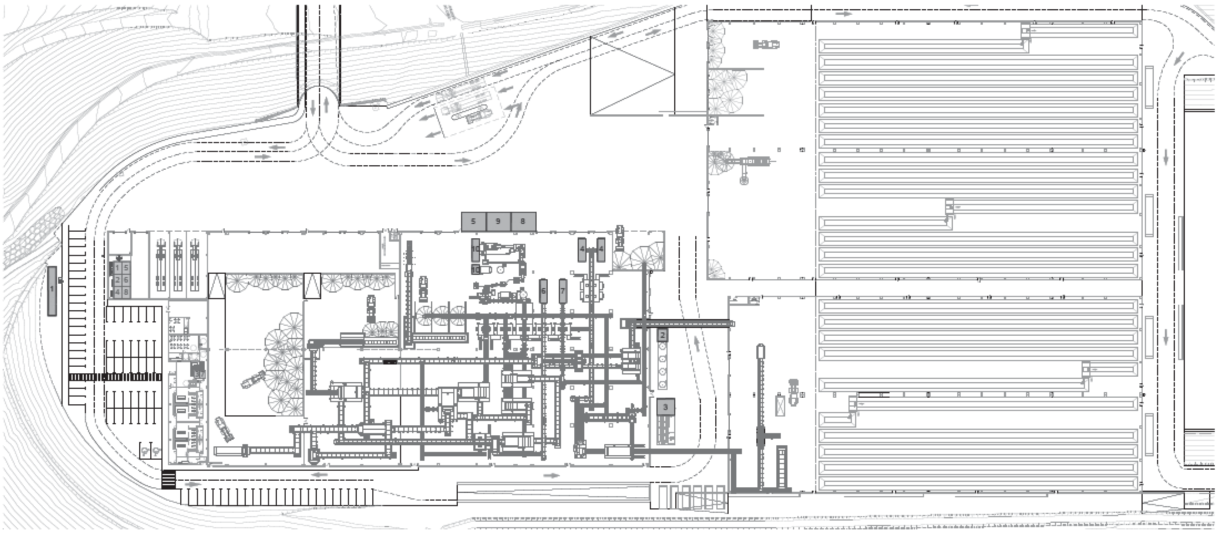
   Objective: Recycle everything possible and make the latest rejected inert.

2) **Light packaging: 13.000 t/year**

   Objective: classify to optimise their recycling.

3) **Bio-waste from selective collection: 20.000 t/year**

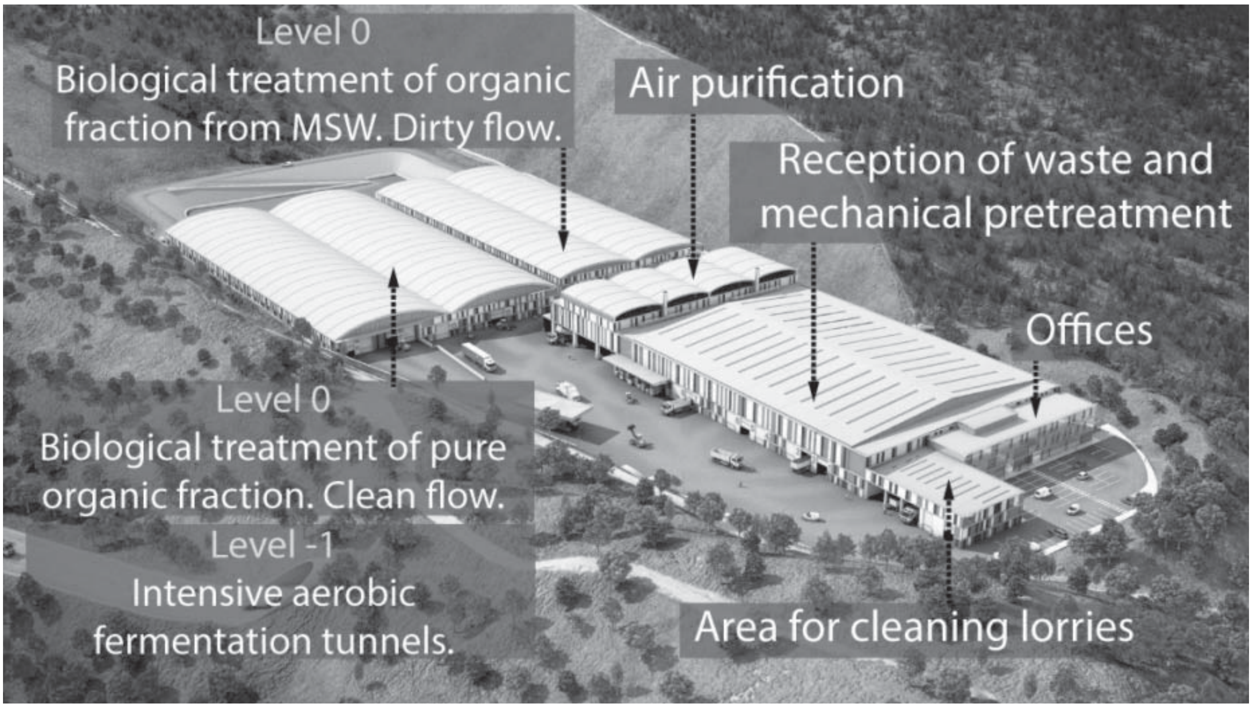
   Objective: to make top quality compost for agricultural use.



The design of the plant will allow it to be adapted to different waste flows, to the extent that it advances selective collection, as a result of which in future it is expected that the plant will be dedicated less to treating mixed waste and more to classifying waste separated at source, to send it on to the appropriate authorised managers.

3.6 Description of Zubieta's MBT processes

The Zubieta MBT plant will include the following spaces:



3.7 Water management

Special care was taken in the design of the Zubieta MBT plant for the managing water, providing it with the instruments necessary to make use of rainwater and thus have less reliance on the public supply network.

To summarise, the following criteria for the sustainable use of water have been taken into account:

Criteria:

- Use of rain water to minimise network use.
- Use of the leachates in the composting process.
- Minimise the discharge of water to the drainage system and run-off.
- Ensure the quality of water discharged, respecting the quality criteria.

3.8 Management of air and smells

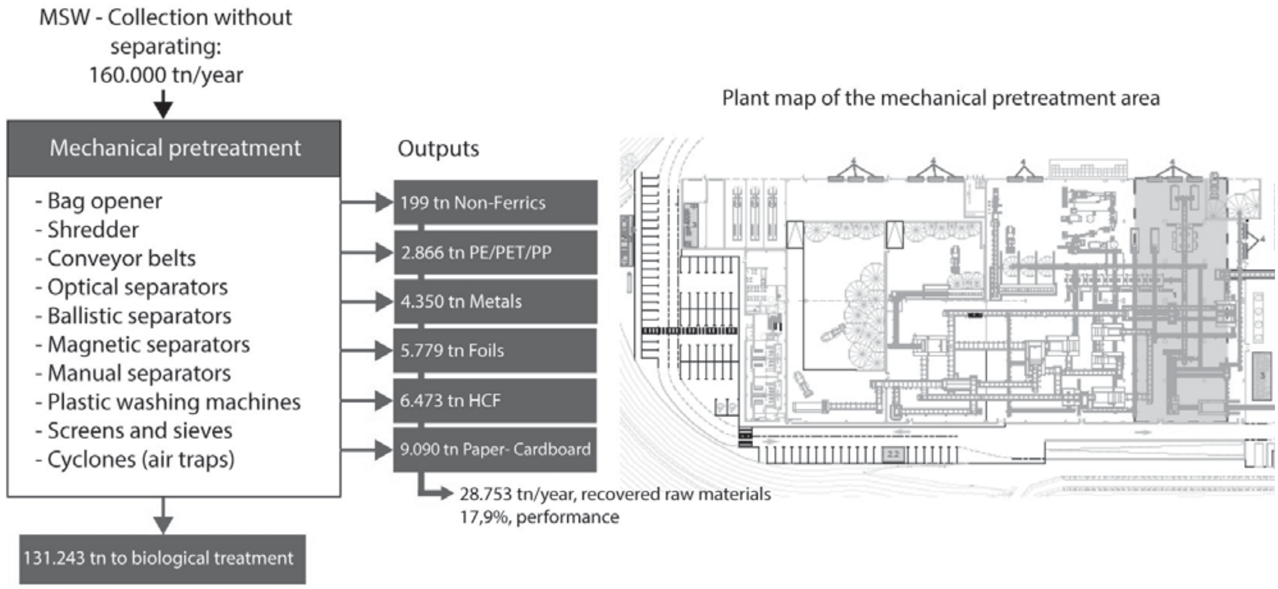
Another aspect in which special care has been taken is the correct treatment of air and smells. For this purpose, the plant has been provided with dust filters, scrubbers and bio-filters to prevent solid particles in suspension and the spread of bad smells, according to the following criteria:

Criteria:

- Avoid solid particles in suspension.
- Recirculating all of the air flows to minimise their treatment.
- Prevent the production of odours by means of bio-filters.
- Design of mass-produced bio-filter with scrubber, to capture odorous particles.

3.9 Mechanical pretreatment

Mechanical treatment applies to the main flow of waste that has not been separated, estimated at 160,000 tons per year, which is expected to decrease as efficient selective collection systems increase.



It is expected to recover 28,753 tons of raw materials which are mixed with biological waste by means of optic, magnetic, and ballistic systems. This is an initial recovery of 17.9% of waste, in the form of non-ferrous metals, plastics PE, PET and PP, metals, foil, paper and cardboard.

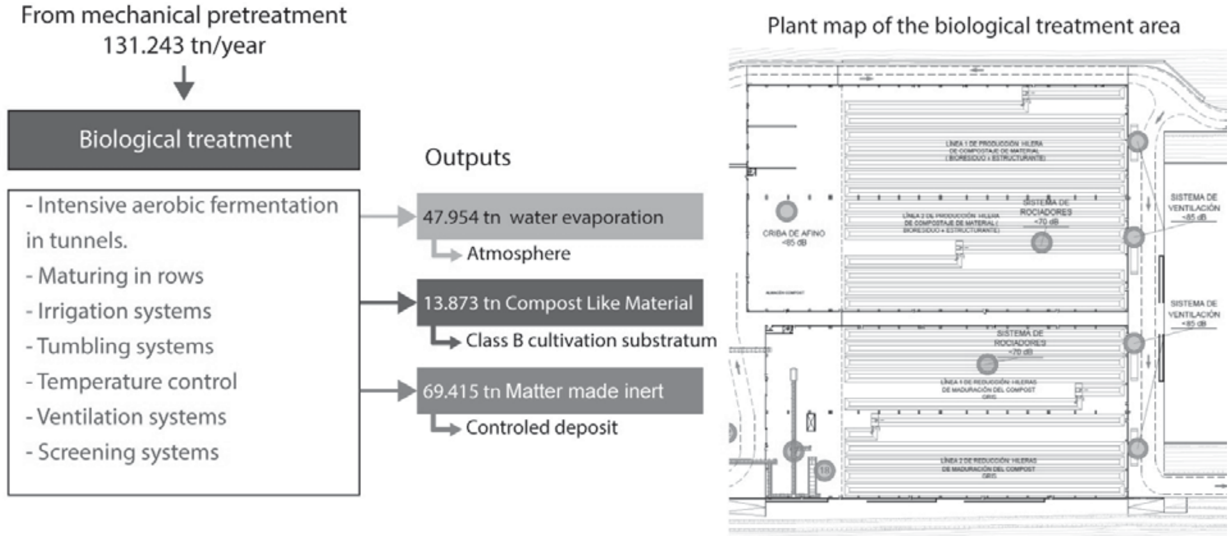
The remaining waste, made up mainly of organic matter and non-recoverable waste, passes directly to the biological treatment facilities, at a rate of 131,243 tons per year.

3.10 Biological treatment

A) Treatment of the organic fraction contained in the MSW and separated by means of mechanical procedures at the plant. This treatment consists of 2 phases:

1) Intensive aerobic fermentation in tunnels, located on the ground floor of the biological treatment area, in which waste of an organic nature carries out the natural process of bio-oxidation for 6 weeks, under strict controls of temperature and humidity.

2) Maturing in rows for another 6 weeks, on the upper floor of the biological treatment area, with turning and forced aeration systems At the end of this process 13,873 tons per year of compost-like material will be obtained, suitable as a class B substrate, and 69,415 tons per year of inert matter, which will be dedicated to the recovery of degraded areas.



B) Treatment of bio-waste with a high purity obtained at source by means of selective collection

One of the buildings located on the upper floor will be dedicated to the flow of organic waste separated at source. Fermentation and ripening systems will be applied by means of forced aeration, humidity control (moisture - water content) and temperature control, as well as turning/tumbling systems. The result will be that, for an input flow of 20,000 tons per year of organic matter, to which it will be necessary to add the appropriate structuring material, 5,000 tons per year of top-grade compost will be obtained for use in agriculture and gardening.

3.11 Dep V-2009 regulations

For the design of the Zubieta MBT plant, the German waste pre-treatment regulations (Deponieverordnung, Dep-V, 2009) have been taken into account, being the strictest at a European level in terms of minimising negative effects on the environment.

This standard sets the maximum values that mechanically and biologically pretreated material should have to be considered inert and be deposited in a controlled area.

- German regulations that mechanically and biologically regulate pretreated waste.
- It establishes the maximum values that inert matter should have before being taken to a controlled landfill.

Three core values:

Of a set of parameters that matter should meet to be considered suitable for being deposited in a place prepared for this end, the following three are the most important:

1) **Biological Activity (Breathing Activity, AT4) 5 mg/g**

   Maximum biological degradation that the matter should have to be considered inert.

2) **Degradation of Carbon (Degradable Organic Carbon, DOC) ≤ 300 mg/l**

   Proportion of degradable organic carbon present in solid waste.

3) **Low Calorific Value (Low Calorific Value, LCV) ≤ 6000 kJ/kg**

   The amount of heat produced in the combustion of a unit of measurement.

3.12 Matter made inert as an opportunity to recover degraded areas

The treatment due for the last fraction of waste conveniently allows a new focus for the use of the aforementioned inert matter in the fermentation and maturing tunnels, as matter for sanitary landfill in places that require a recovery operation. In other words, we can consider that we are making use of the last fraction of the waste as "other recovery", from the moment when we use this matter for the recovery of degraded areas.

Inert matter is matter which, due to its conditions of process or storage, does not suffer physical, chemical or biological transformation. It does not dissolve in contact with

water, is not biodegradable and does not react in contact with chemical or physical substances. In addition, when it comes into contact with other particles, it does not generate adverse reactions in them. Therefore, it cannot contaminate the environment, or cause negative effects on the health of people or animals.

Use of waste as "**Other recovery**"

The legislation that supports this use of inert matter can be found in Directive 2008/08/EC, of November 19, from the Parliament and Council of Europe, Annex II, R10.

Regulations:

– Directive 2008/98/EC of the European Parliament and Council of November 19, 2008, Annex II, R10

3.13 Osinbeltz quarry (Zestoa, Gipuzkoa)

For the purposes of a possible recovery operation, the Osinbeltz quarry in Zestoa is the largest one in the province of Gipuzkoa and the one which has the greatest need of recovery. At present, it is in a state of semi-abandonment and does not contribute anything to the community, in the sense that the population is prohibited to access it due to the deplorable conditions in which it is found. As a result of this, it has a suitable profile for a recovery project, by means of sanitary landfill using the inert matter coming from the Zubieta MBT plant.

1. It is the largest quarry without activity in Gipuzkoa.
2. Lacks usefulness in its current state.
3. It has a profile suitable for recovery.

Osinbeltz Quarry. Zestoa. Gipuzkoa

The action lines proposed revolve around the following themes:

Action lines:

1. Promote environmental balance
2. Strengthen proximity networks.
3. Promote individual and social welfare

Having reached this point, waste managers should reach the unavoidable commitment to ensure that, during the life of the dump, the effective inertisation of the matter resulting from the MBT plant can be guaranteed, in order to be able to assure residents in the adjacent localities that no bad smells will come out of this place clouding the air, or leachates contaminating the water.

In this sense, the correct preliminary preparation and waterproofing of the dump is fundamental and should be carried out in accordance with the most demanding regulations.

3.14 Land Art

Land Art is a stream of contemporary art that uses the framework of and materials from nature as artistic expression. Also called "landscape construction art" or "land art", is art generated from a place, which usually mixes disciplines such as sculpture and landscape architecture, where the concept of "public space" plays a decisive role.

The concept that underlies Land Art can be summarised in the following definitions:

- Make the landscape a work of art.
- Artistic experience that establishes a dialogue with nature
- Recover space for the public

A proposal of what Osinbeltz quarry could become in the future

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From Selective Collection to Solid Recovery Fuel and 50% recovery achievement: two Italian case studies

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Abstract

Developments in the management of Municipal Solid Waste (MSW) has followed a very complex evolution in Europe, where, gradually, the principle that, in addition to minimizing the production of waste, the necessity to maximize its recovery has been established. This leads to consider the waste as a potential resource, with both environmental and economic benefits. However, considering the different waste management systems in EU, the results obtained are very different because they are affected by different aspects (socio-economic structure, traditions, conformation of the territory, critical environmental issues, etc). The present study took into account the situation in two developed and rich areas located in the Northern Italy, comparing the different approaches with the aim at improving the waste management by optimizing the recovery of waste, especially from an energy point of view, and in particular, realizing solid recovery fuel (SRF) starting from the residual municipal solid waste (RMSW).

Keywords *Municipal Solid Waste (MSW), Residual Municipal Solid Waste (RMSW), Recovery, Solid Recovery Fuel (SRF), Selective Collection (SC), Take Back Programs (TBP), Combustible Solid Recovery Fuel (SRF_{comb}), Calorific Value.*

1 Introduction

The new challenge in the European Union (EU) countries is the achievement of recovery through different strategies/treatments of 50% of the produced municipal solid waste (MSW). In this context the selective collection (SC) seems to be a sustainable solution but also needs to be integrated with other processes. In the last decade, the conventional and innovative thermal treatments were the most used ones for the management of the residual waste (RMSW) in order to exploit it, from the energetic point of view (Ryu et al., 2007; Consonni and Vigano, 2011; Ionescu et al., 2013; Torretta et al., 2014; Rada and Ragazzi 2014).

In Europe the situation began to change with the introduction of the UNI CEN/TS 15357 – 15747 norms since 2006. In Italy, instead, the situation began to change with the introduction of the Decree 205/2010 regarding the fuels that can be obtained from MSW taking into account the indications from the European norms (Rada and Andreottola, 2012; Lorber et al., 2012; Trulli et al., 2013). This legislation was updated through the Decree no. 22/2013, introducing the term of “combustible solid recovery fuel (SRF)”, and requiring to be only in the first 3 characterization classes (LHV ≥15-25 MJ/kg, Cl ≤ 0.2 -1%, Hg ≤ 0.02-0.03 Mg/MJ), in order to be classified as “End of Waste”.

On July 2, 2014, the European Commission adopted some proposals aimed at developing a more circular economy in Europe and at promoting recycling in the Member States. The achievement of the new targets for waste recovery will make Europe more competitive, using materials that would not be wasted but recovered from products at the end of life. The new targets regard the achievement of 70% MSW recycling and of 80% waste packaging by 2030 and since 2025, the prohibition of landfilled recyclable waste. Another objective is the reduction of marine and food waste.

The present paper analyses the possibility to produce SRF and combustible SRF through the implementation of a good selective collection in two areas from the North part of Italy. Also the target of 50% recovery is discussed.

2 Material and methods

The two chosen case studies regard areas near Austria and Switzerland, where the interaction with the neighbours affects the organization of the society.

In the *first case study* (near the German speaking territory) the MSW management was and is a priority of the Region. Four regional Waste Management Plans (WMP) were issued in the last 17 years. Anyway, the province together with the environmental agency included in the last Waste Management Plan the possibility to construct a MBT plant for SRF production, and its utilization in cement factories. The SC was performed since the 90s with three main streams: recyclable materials, food waste and residual materials through street containers and eco-centers. In the first 10 years, the SC efficiency increased from near zero to about 16%, arriving today to overcome 75%, thanks also to the introduction of kerbside SC, coupled with eco-centers. In 2012 the residual waste production of an inhabitant was about 121 kg inh^{-1} y^{-1}. This region is in the first places together with the Veneto region in the list of the Italian regions with a very good implementation and efficiency of SC. At the moment there are 148 working eco-centers, 6 in construction and 1 planned.

The first case study today has 16 valley communities, from which 6 are very tourist (the average inhabitants increase in 2012 varied from 65% to 113% in the two most tourist ones), from 22% to 40% in other four, from 9.5% to 13% in other five and from 1.2% to 4% in the last ones. Even if they are tourist, the efficiency of SC has not been influenced, also because many campaigns with materials in more languages (Italian, German, English, Russian, etc.) were and are made every year, in order to explain with words and pictures how the SC must be made (Rada et al., 2013).

The waste collected through selective collection (75%) is treated in few plants placed in the region: 1 composting and 2 anaerobic digestion plants for food waste and green waste. The other fractions are recovered outside the province. The RMSW is sent in 8 landfills and a plant for SRF production is planned near one of these landfills.

In the *second case study* (near the Swiss territory) the MSW management at regional level was taken into consideration since 1994 when the first WMP was issued, even if the first legislation about SC, waste transport and disposal was issued in 1941/366. The first requested targets by the WMP regarded the achieving of a 40% SC efficiency until 2003, and the prohibition to be landfilled waste that has a lower heating value (LHV) higher than 13 MJ/kg, and/or waste that can be recovered as materials or as energy. The SC efficiency today is adequate being about 65%. The SC is made through kerb-side for paper and packaging, glass and food waste in about 95% of the 141 municipalities. Only a part of the 141 communities is tourist.

This second case study, in 2012 had a MSW production of about 450 kg inh^{-1} y^{-1}, and a SC of about 63%. Taking into account this data, the province was 18th in the list of the Italian provinces. From the total produced MSW, 63% was collected through selective collection and the rest 37% (28% RMSW, 6% bulky waste, 3% sweeping waste) was sent to final treatment (13% incinerated in three different plants, 9,4% landfilled and 9.2% sent to different selection plants).

The waste collected through selective collection (63%) is treated in different plants that are placed in region: 15 composting / anaerobic digestion for food waste and green waste, 11 for paper recovery, 15 for plastic recovery and 12 for wood recovery.

In both the case studies the selective collection has a standard program (2 withdraws by week for food waste and only 1 withdraw by week for the other fractions); only minor differences in the collection of some fractions are implemented in the selected case studies. For example in the first case the collection is for glass and packaging waste alone, instead in the second case the glass is collected together with the cans.

In Figure 1 the dynamics of the SC in both considered cases is reported. Regarding the first case study the increase reported since 2002 can be explained as follows:

- in this year the province proposed an incineration plant; but the capital cost of the proposed incineration plant resulted very high because of the limited source separation of MSW;
- a very intensive and complete campaign of communication regarding the SC was implemented in order to decrease the quantity of RMSW that could be incinerated in the proposed plant.

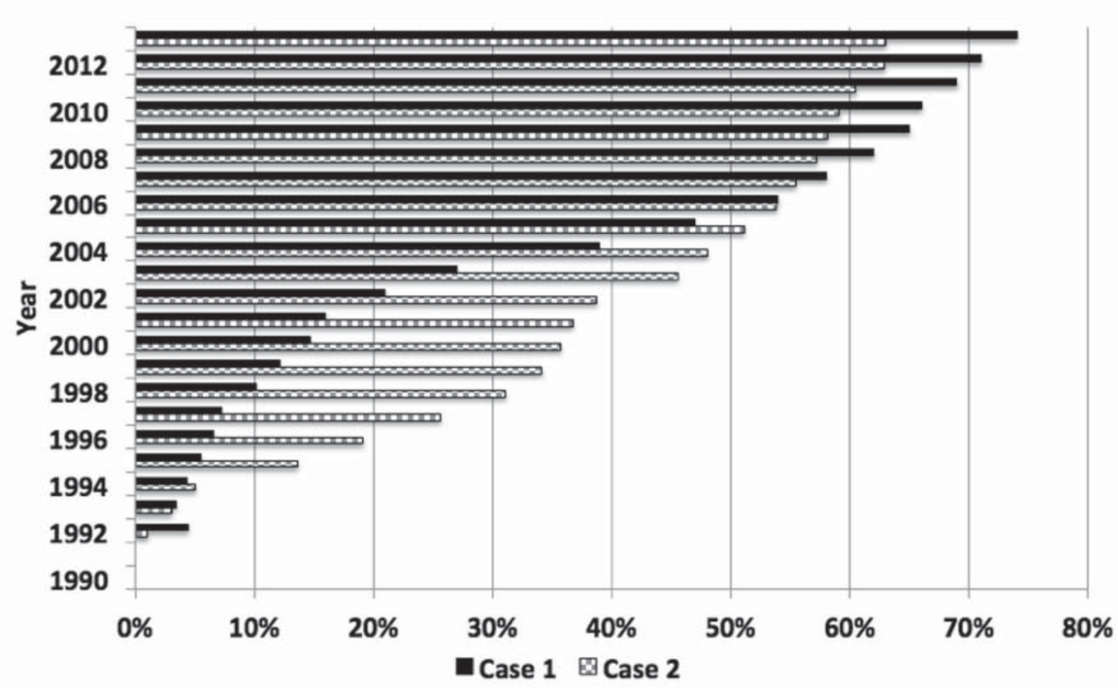

Figure 1 Selective collection dynamics

The differences in the composition of MSW and RMSW in the two case studies are not very high, as it can be seen from Figure 2 and 3. The influence of SC efficiency is visible mainly for the recyclable fractions: food and green waste (FW, GW), and papers and diapers. The implementation of the SC in all the communities gives these differences.

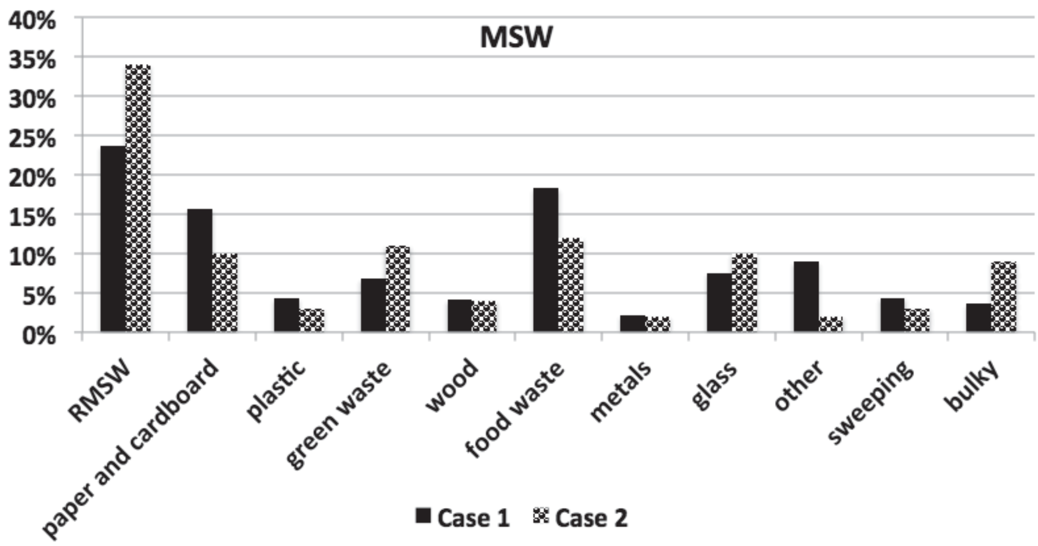

Figure 2 MSW composition

For the development of the research, the lower heating value (LHV) of each fraction was used in order to determine the LHV, Chlorine and Mercury content of the RMSW. The used data are collected form the scientific literature (Ciuta et al., 2015; Rada and Ragazzi 2014; Lombardi et al., 2013; Horttanainen et al, 2013; Komilis et al., 2012; Rotter et al., 2007 and 2011).

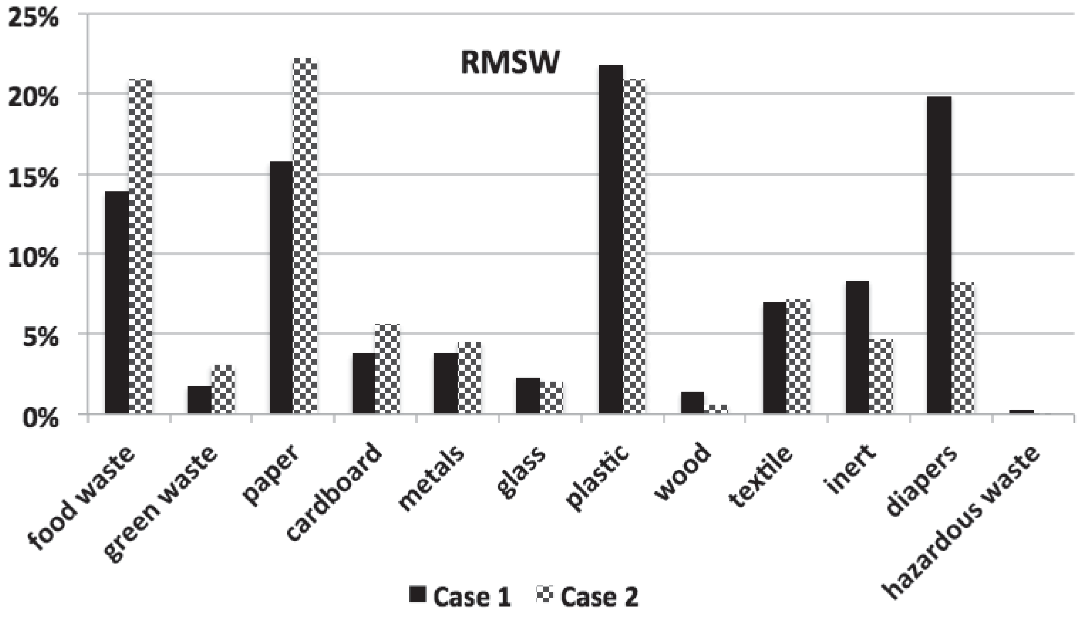

Figure 3 RMSW composition

For the material recovery balance, the fractions considered for recovery are reported in Table 1. Also the efficiency of recovery of these fractions in different plants is reported in the same table (FW and GW were considered to be recovered as compost). The data were selected from the scientific literature (Ionescu et al., 2013; Rada and Ragazzi 2013). For the Take-Back-Programs (TBP) only the fractions with high calorific value were considered and used in this research (paper and cardboard, plastic and wood).

Table 1 Efficiency of the waste recovery fractions

Waste Fraction	Paper and cardboard	Plastic	Green waste	Wood	Food waste	Metals	Glass	Sweeping	Bulky
%	85	60	60	85	40	90	95	60	68

3 Results and discussion

From the analysis emerged that the RMSW is in first class for chlorine and for mercury, so it can be considered as combustible SRF, but the problem is its LHV, for both the cases. The LHV is near 15 MJ/kg, but in order to be classified as combustible SRF, achieving the Italian rules requirements, the RMSW composition must be improved with residual materials with high LHV from the recycling lines (TBP) or/and with worn tyres. In this way the obtained combustible SRF can have the following classes (LHV, Cl, Hg): 3(2),1(2),1(1).

Taking into account the obtained results and the waste management planning, in the *fist case study* a laboratory analysis of RMSW that is sent to the landfills was developed.

This RMSW was analyzed taking into account the requests from the EU and Italian SRF legislation. The samples were collected in the last months of the year, in order to undestand also the implications of winter tourism. The results are reported in Table 2, together with percentage of population increase. It can be noticed that the increase of inhabitants worsen the LHV of RMSW, also because the quantity of food waste increases. Moreover it must be taken into account that a certain variability of data depends on the method of sampling of RMSW: the quarter method was used in order to obtain a laboratory sample of few kg, starting from 1 ton of RMSW.

Table 2 RMSW characterization as SRF

	SRF request	**November**		**December**		
		RMSW				
		12% equiv. inh	5% equiv. inh	65% equiv. inh	35% equiv. inh	21% equiv. inh
Residue 105°C [% p/p]	-	69.73	86.07	52.82	57.67	50.37
Ash [% p/p s.s.]	-	30.02	17.73	24.06	12.16	38.09
Moisture [% p/p]	-	30.27	13.93	47.18	42.33	49.63
LHV [MJ/kg]	≥15	**10.3**	**14.2**	**6.1**	**9.1**	**7.7**
Total Cl [% p/p s.s].	≤1	**3.17**	0.60	0.39	0.34	**1.58**
Sb [mg/kg s.s.]	50	**277.4**	19.7	2.7	**133.8**	**114.8**
Ar [mg/kg s.s.]	5	2.3	2.1	1.1	2.3	2.3
Cd [mg/kg s.s.].	4	1.4	<1.0	<1.0	<1.0	<1.0
Co [mg/kg s.s.]	18	4.1	2.0	2.9	<1.0	4.0
Total Cr [mg/kg s.s.]	100	93.7	64.8	75.6	19.0	81.1
Mn [mg/kg s.s.]	250	**667.5**	97.8	**852.2**	132.5	**278.6**
Hg [mg/MJ]	≤0.03	<0.02	<0.02	<0.02	<0.02	<0.02
Ni [mg/kg s.s.]	30	**70.4**	**46.8**	**51.5**	14.2	**59.6**
Pb [mg/kg s.s.]	240	200.0	13.3	**283.5**	73.6	118.5
Cu [mg/kg s.s.]	500	**20130.0**	**740.0**	60.4	**3221.0**	**25870.0**
Ti [mg/kg s.s.]	5	<1.0	<1.0	<1.0	<1.0	<1.0
V [mg/kg s.s.]	10	9.1	6.9	6.4	5.4	10.0

In Figure 4 the recovered fraction for both case studies is reported. Also the fractions used in order to improve the quality of the SRF produced from RMSW + fractions from TMB are presented. It can be noticed that only with the recovery of materials from selective collection in different recycling plants, the target of 50% is not achieved; in both cases the percentage is near 45%.

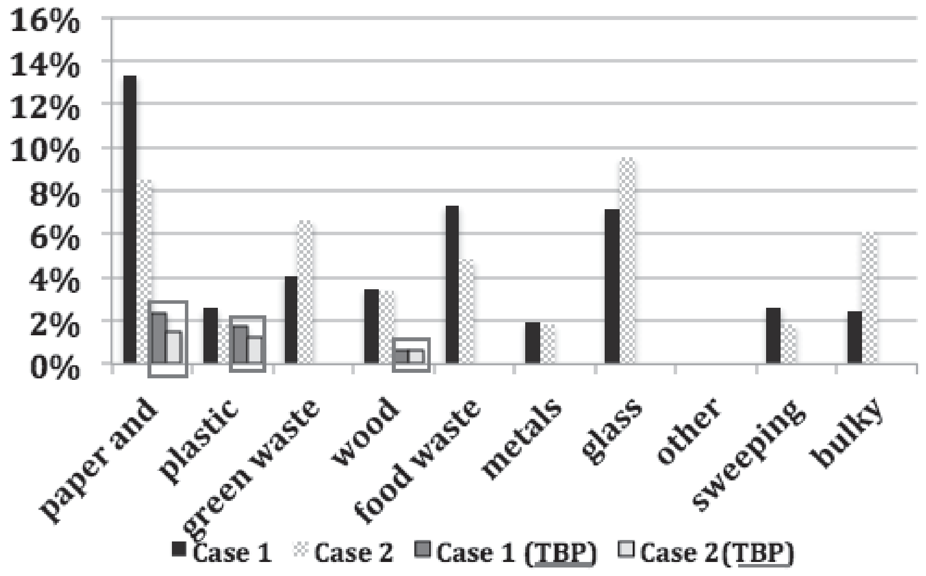

Figure 4 Recovered fractions

In both cases only with the TBP (about 4%), the combustible SRF cannot be obtained. Only with a small addition of worn tyres (3% in the first case and 11% for the second one) the combustible SRF class 3, 1(2), 1 can be achieved. For improving the LHV class from 3 to 2 the percentage of worn tyre in the final mix must not overcome 50%, as requested by the EU legislation. The percentage needed for the both case studies is 37% and 41% respectively. Without TBP the percentage of worn tyre needed for the achievement of combustible SRF class 3 and 2 increases with 2-3% points.

In Figure 5 the LHV (MJ/kg)) of SRF obtained only from RMSW, of SRF obtained from RMSW + Fractions form TBP, and the two combustible SRFs obtained with worn tyres addition are reported.

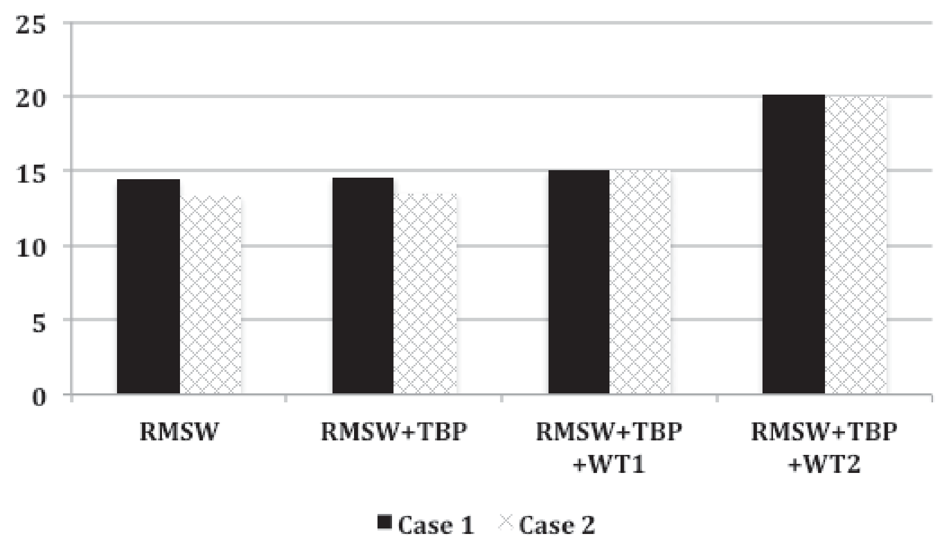

Figure 5 LHV dynamics

However it must be taken into consideration that for classifying the improved RMSW as SRF or combustible SRF also some mechanical grinding/shredding must be performed.

Regarding the 50% recovery, this target is achieved only with the thermal treatment of produced SRF. The recovery of the fractions selectively collected does not cover this target because in the real recycling plants the residues from these processes are high.

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Case study of an MBT producing SRF for cement kiln co-combustion, coupled with a bioreactor landfill for process residues

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Abstract

The research focuses on the performances of a traditional single stream MBT for SRF production suitable for co-combustion in a cement kiln. Bio-drying of the residual waste is followed by mechanical refining in order to fulfil the quality requirements by the cement kilns. The residues arising from the mechanical refining section are landfilled in a nearby bioreactor-landfill, where landfill gas is collected for electric energy recovery. A detailed mass balance of the system is presented, followed by a Life Cycle Assessment.

Keywords

landfill bioreactor, LCA, SRF, cement kiln, co-combustion

1 Introduction and framework

The paper builds up from previous experiences on Mechanical-Biological Treatment (MBT) technologies applied to the residual waste focused on energy recovery from the residual waste (Consonni et al., 2005a and 2005b). A huge literature exists on this topic, which can be summarised in the following key findings:

- production of Solid Recovered Fuel (SRF) in MBT plants is the preferred option when industrial plants suitable for its co-combustion are available at a reasonable distance, and when Global Warming Potential is targeted with high priority
- such plants, which encompass cement kilns and coal-fired power plants, need to be state-of-the art facilities, equipped with Best Available Techniques (BAT)
- some concerns might arise for the pollutants for which the abatement technologies available in the industrial plants are not as effective as those installed in traditional Waste-to-Energy plants

- the energy and environmental effectiveness of WTE plants treating the Residual Waste (RW) in competing with SRF co-combustion is strongly driven by electric and thermal energy production efficiency of the former.

The abovementioned considerations were confirmed by a detailed LCA study carried out on the most important Italian experience of SRF production and co-combustion in a coal-fired power plant (RIGAMONTI ET AL., 2012). The present research is devoted to a similar assessment, where two major differences are:

- SRF is co-combusted in a cement kiln fed with petcoke
- The MBT plant is coupled with a landfill, where the residues are disposed and where landfill gas is collected following a landfill bioreactor management approach, which allows for an enhanced performance of the anaerobic degradation process and a higher (and quicker) landfill gas yield.

2 Materials and methods

2.1 Description of the system

In the analysed system, the residual waste collected in an Italian Province characterised by high level of source separation is delivered to a MBT plant operating under the single stream concept (Fig. 1). After a simple bag opening operation, the whole mass of RW is bio-dried aerobically for 12-15 days. The weight loss amounts to 26% on average, split between the highly biodegradable waste fraction and the moisture. The bio-dried material enters a mechanical refining section, aimed at producing a high quality SRF for utilisation in cement kiln. Ferrous and non-ferrous metals are removed at this stage, together with the chlorinated plastics (PVC), thanks to an optical sensor. Residues separated from the first screen are disposed in a landfill, located in the same site of the MBT plant, managed as an activated bioreactor, with complete sealing and leachate recirculation to improve biogas production (Fig. 2). Standard engines are then used to produce electric energy, following a simple landfill gas cleaning. Landfill gas collection efficiency was assumed equal to 90%, the rest being released to the atmosphere.

Ferrous and non-ferrous scraps are shipped to some recycling plants for secondary production, while SRF is delivered to a cement kiln for co-combustion, substituting petcoke.

The cement kiln is a state-of-the art facility, with cyclone preheater and precalciner, equipped with an alkali-bypass in order to allow for high thermal substitution rate with secondary fuels which also contain a certain amount of chlorine. Urea is used to control NO_x emission, while flue gas dedusting is carried out with a fabric filter.

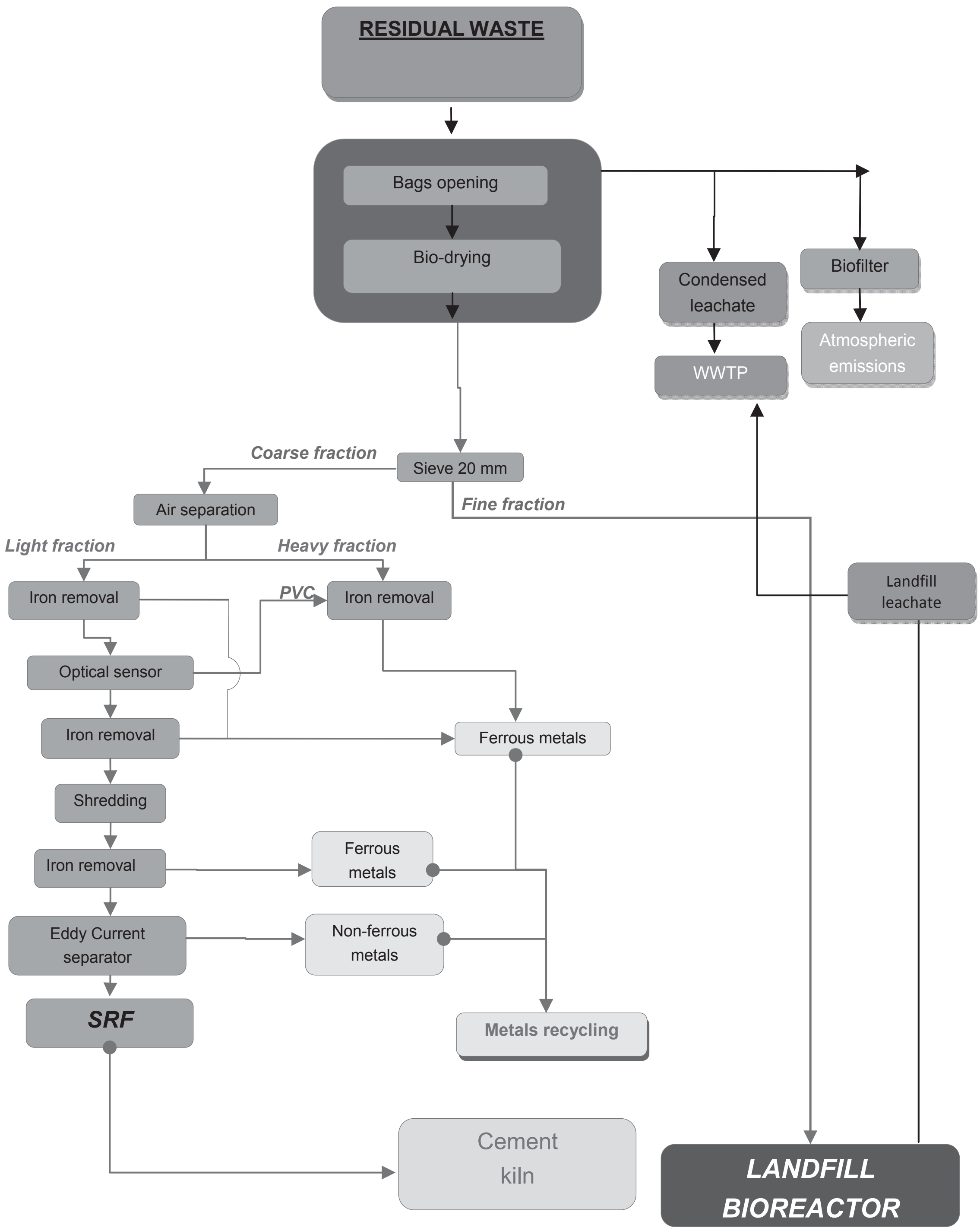

Figure 1 Layout of the MBT plant

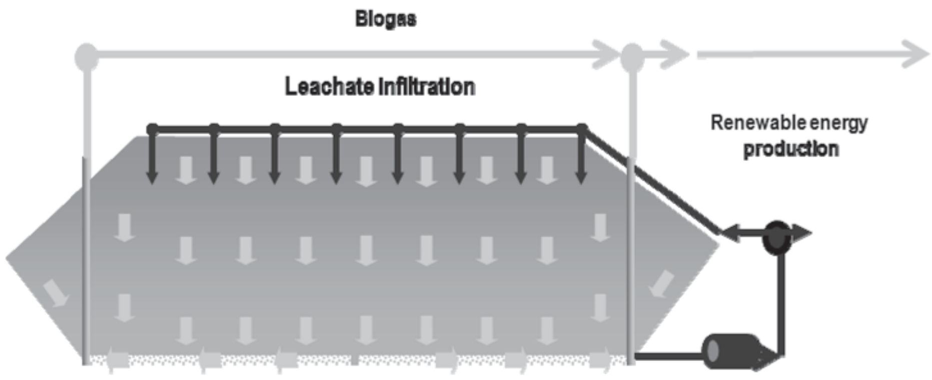

Figure 2 Scheme of a bioreactor landfill

Fig. 3 reports the mass and energy balance of the whole system, included avoided products and energy, based on the year 2013 data. These are the main inputs/outputs for the Life Cycle Assessment. It worth noting that the amount of electric energy produced from the biogas obtained from landfilling the MBT residues (3377 MWh) is very similar to the energy consumption for running the MBT plant itself (3446 MWh). Obviously the timeframe of such consumption and production are completely different because the former actually takes place in one year, while the latter is obtained in the following 8 years, but when steady-state operation is reached (as it is the case for the analysed plant) we can affirm that the biogas production will allow for a nearly complete self-sustainment of the MBT plant operation.

The effects of SRF utilisation for co-combustion in the cement kiln are shown in Fig. 4. Savings are obtained in terms of fossil CO_2 emissions, because of the lower content of fossil carbon in SRF compared to petcoke, of the life-cycle and transport of petcoke (which is delivered to the plant by a combination of trans-oceanic freight and train) and of urea used for NOx abatement in the kiln. The positive effect of SRF co-combustion on NOx formation is well known; in this specific situation, and based on the analysis of the plant operational data with and without SRF utilisation, such a benefit is not reflected in a lower NOx emission during co-combustion, but rather in a decrease of the urea feeding rate needed to keep the same concentration at the stack. A similar analysis was performed for the other atmospheric pollutants, measured during baseline and co-combustion operation, and it turned out that the concentrations are not affected by the SRF thermal substitution rate. Then in the LCA no variation was assumed to take place at the stack for all the pollutants but CO_2.

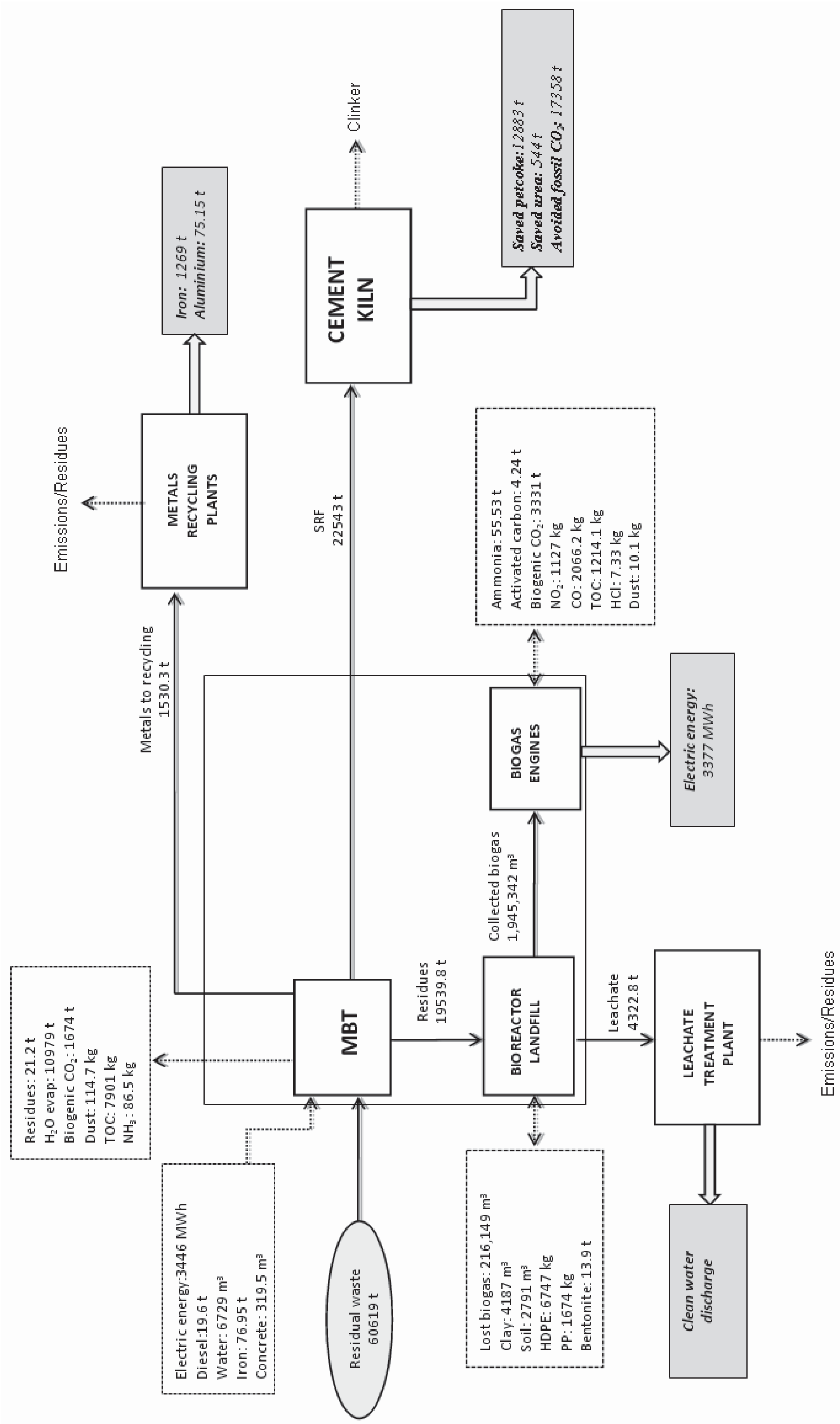

Figure 3 *Mass and energy balance of the system on a yearly basis*

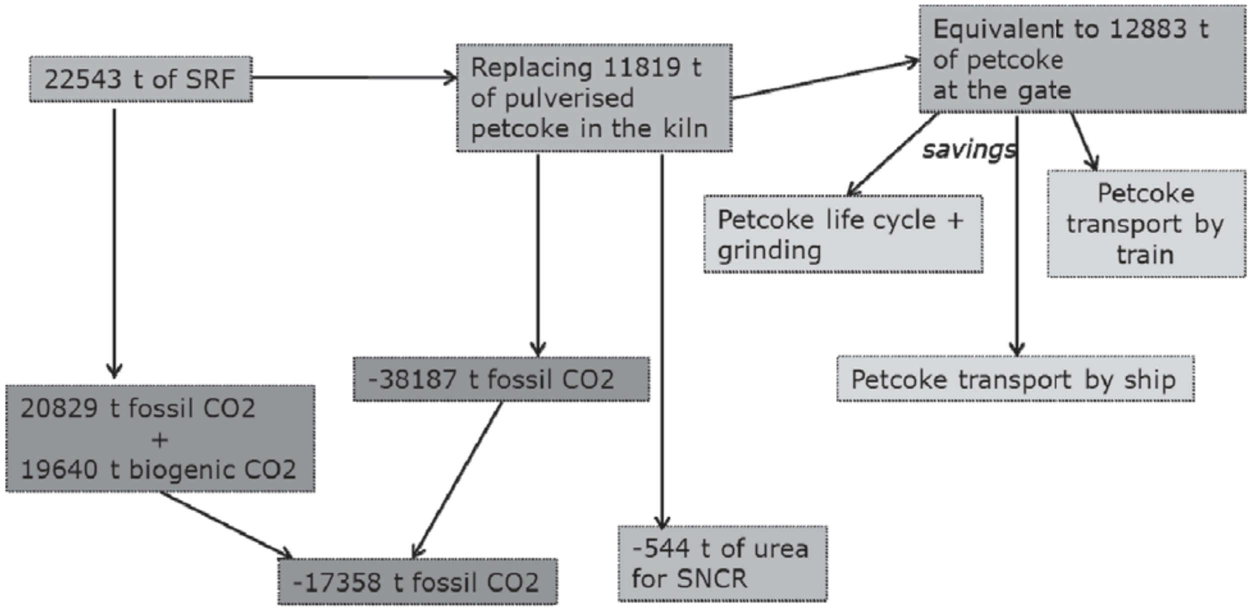

Figure 4 Effects of the utilisation of SRF in the cement kiln, according to a 26.5% calorific substitution

2.2 Life Cycle Assessment

The life cycle assessment of the system was carried out following the "ILCD 2011 Midpoint" characterisation method (EUROPEAN COMMISSION, 2012), complemented by the Cumulative Energy Demand (CED) indicator (HISCHIER ET AL., 2010). The Simapro 8 software was used to perform the calculation, and ecoinvent dataset was used for all the processes where primary data were not available.

The functional unit of the study is one tonne of residual waste delivered to the MBT plant, and the zero-burden hypothesis was assumed (EKVALL ET AL., 2007). All input/output data refer to year 2013, while the sole exception of electric energy produced from the landfill gas. This is actually originated by the amount of MBT residues generated in 2013, but it will be produced during a 8-years timeframe.

The system boundaries include all the systems described in Fig. 3, as well as the transport of SRF from the MBT plant to the cement kiln, of the metals to the recycling plants and of the leachate to the waste water treatment plant (WWTP). The modelling approach is attributional, with multifunctionality problems solved by means of expanding the system boundaries. Secondary materials and recovered energy substitute for the current average primary production.

3 Results and discussion

Overall results of the Life Cycle Assessment are reported in Tab. 1, with Fig. 5 showing the contributes of each process. Most of the indicators are negative in sign, which means that the savings are higher than the burdens. This is particularly relevant for the GWP and for the CED, as expected, mainly because of the saved petcoke in the cement kiln. Results positive in sign arise for human toxicity (cancer effects) and for the freshwater ecotoxicity. For both indicators, the positive contribute is due to the ferrous metals recycling, and in particular to the waterborne emissions of Chromium VI from the landfilled slags (NESSI ET AL., 2014). This is a well-known issue within the LCA community, and further studies are currently being carried out for a better comprehension of the phenomenon, and for the existence of possible biases.

The results for most of the impact categories are primarily affected by the cement kiln operation, where the use of SRF allows for the substitution of petcoke. Ferrous metals recovery is also relevant, but mainly for the abovementioned reason. The MBT plant and the nearby landfill for process residues play a marginal role, while the energy recovery from biogas is not negligible for some indicators.

Table 1 Life Cycle Assessment results for the whole system. All values are referred to the functional unit (i.e. 1 tonne of residual waste at the gate of the MBT plant)

IMPACT CATEGORY	UNIT OF MEASURE	
Climate change	kg CO_{2eq}	-437
Ozone depletion	kg $CFC11_{eq}$	-0,00011
Human toxicity (cancer effects)	CTUh	8,37E-05
Human toxicity (non-cancer effects)	CTUh	-1,49E-05
Particulate matter	kg $PM_{2.5eq}$	-0,18
Photochemical ozone formation	$kgNMVOC_{eq}$	-1,09
Acidification	molc $H+_{eq}$	-2,34
Terrestrial eutrophication	molc N_{eq}	-3,36
Freshwater eutrophication	kg P_{eq}	-0,06
Marine eutrophication	kg N_{eq}	-0,27
Freshwater ecotoxicity	CTUe	714
Land use	kg C deficit	-2974
Water resource depletion	m^3 $water_{eq}$	-0,47
Mineral and fossil resource depletion	kg Sb_{eq}	-0,003
Cumulative Energy Demand	MJ	-14248

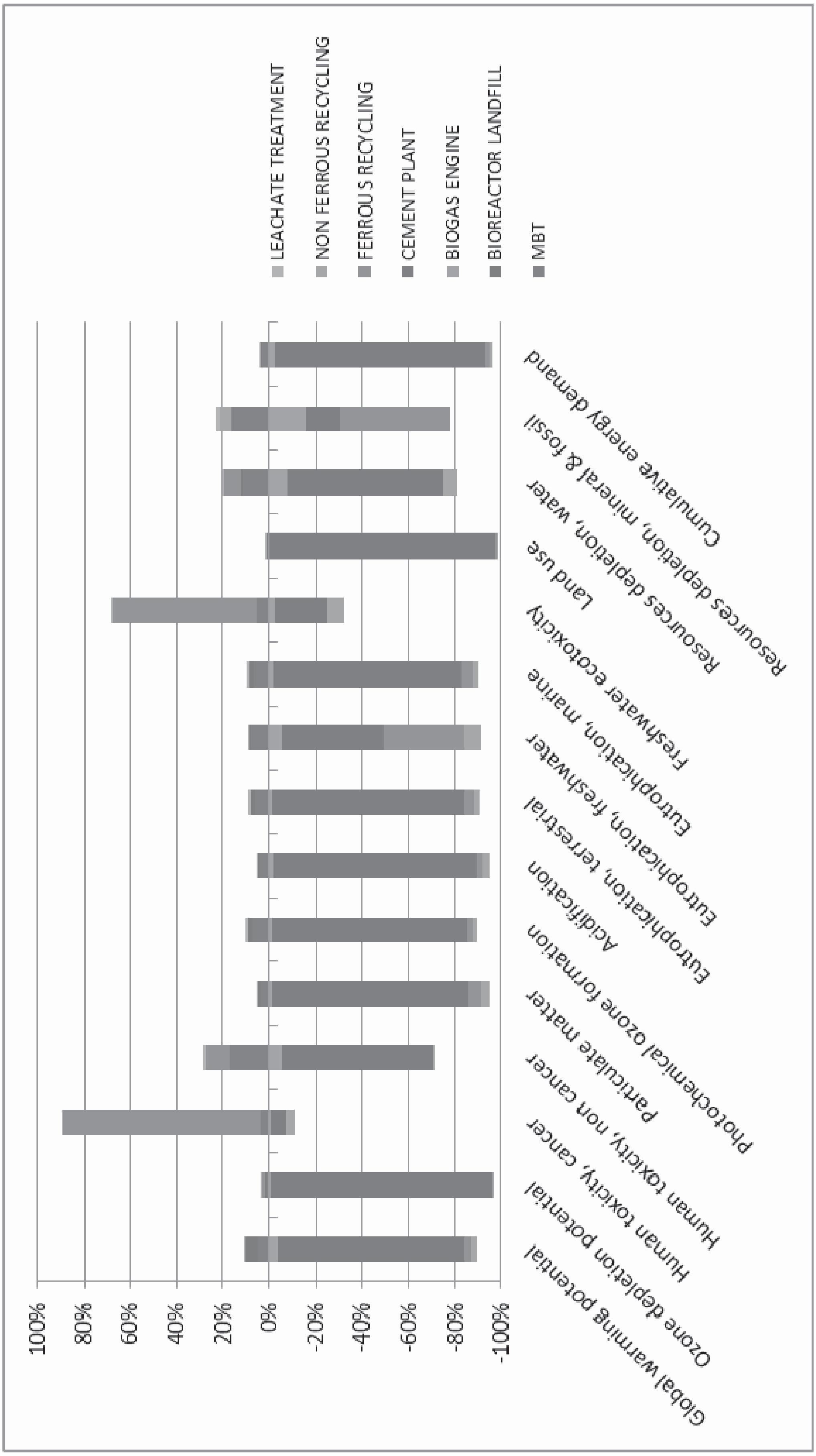

Figure 5 Contribution of the main process units of the system to the overall results

The breakdown of the different pollutants contributing to the Global Warming Potential is depicted in Fig. 6. Nearly all of the contribution is due to the fossil CO_2 balance at the stack of the cement kiln, with the other pollutants contributing to a very minor extent, including the methane released from the landfill. In order to give a complete picture of the actual CO_2 emissions from the system, also the biogenic fraction has been reported in the graph, which obviously is not accounted for in the determination of the total GWP. Biogenic CO_2 emissions arise from the bio-drying process, from the landfill gas engine exhaust, from the CO_2 contained in the non-collected landfill gas and from the biogenic fraction of SRF when co-combusted in the cement kiln. In any case, even if including such contribution, the system would result in an overall CO_2 saving.

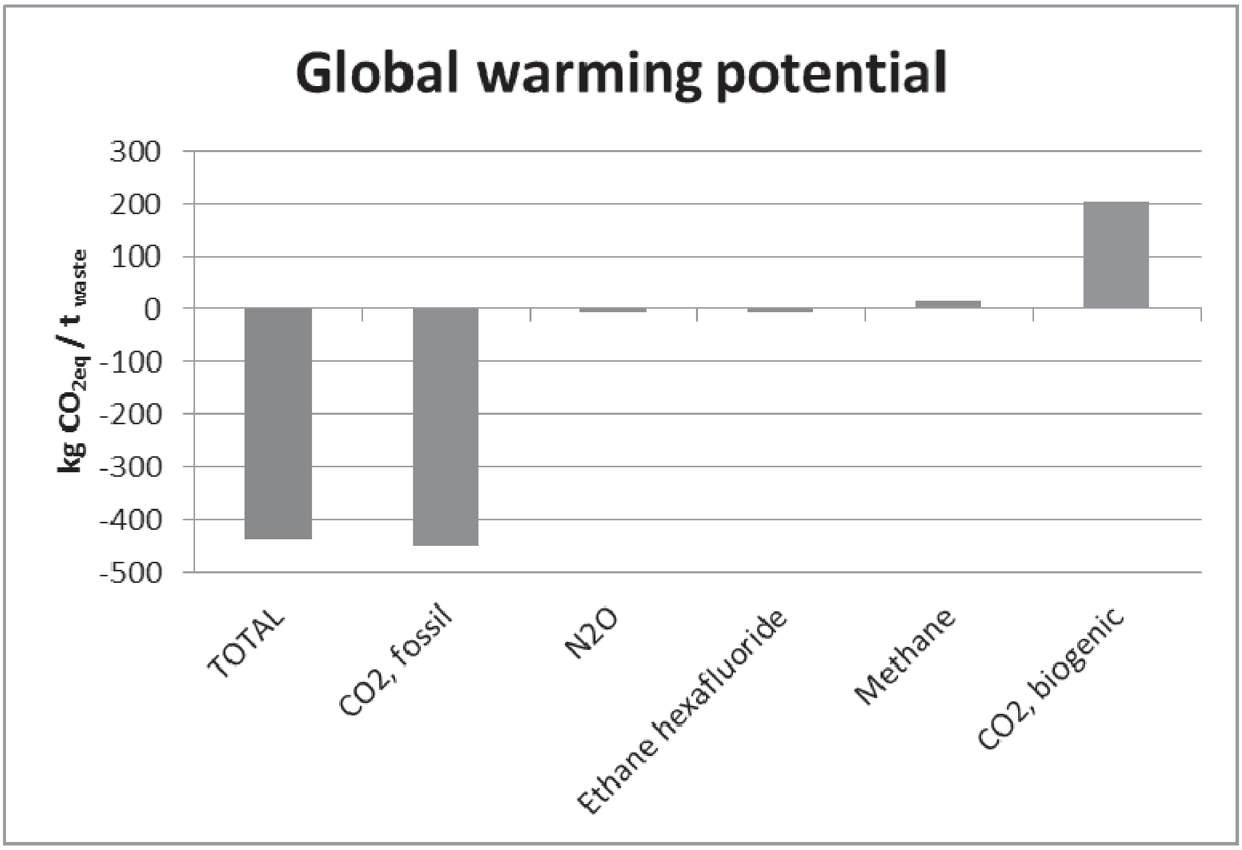

Figure 6 Contribution of the different pollutants to the GWP indicator. Biogenic CO_2 is reported separately and not included in the total

The described residual waste management system has proven to be energetically and environmentally effective, with most of the impacts being more than compensated by the savings. This is thanks to petcoke displacement at the cement kiln, metals recycling at the MBT site and enhanced biogas recovery and utilisation at the bioreactor landfill. Moreover the operation of the MBT plant might reach a steady-state situation where the electric energy produced from the landfill gas allows for the self-consumption of the MBT itself. Such an approach might then be replicated in similar situations, provided that a state-of-the-art cement kiln is available for co-combustion.

4 Literature

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Latest North American Perspective on Integrated Solid Waste Management

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Abstract

This presentation will provide an overview of integrated solid waste management in North America. It will then focus extensively on the current state of solid waste management, material recovery, waste to energy (WTE). It will provide insight on the current practices in place and the results achieved in the material and energy recovery. Further it will discuss the current trends followed by perception as to what lies ahead, the expectations and the opportunities.

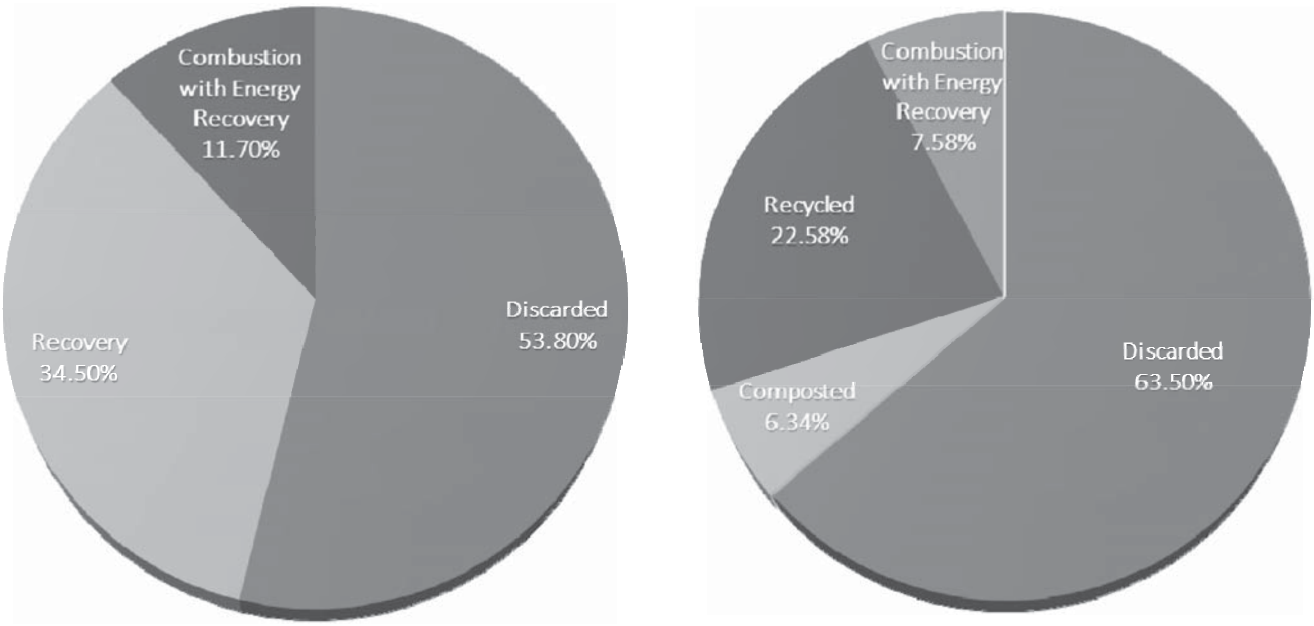
Keywords

North America, municipal solid waste; integrated waste management; recycling; disposal; waste-to-energy; resource recovery; conversion technologies; materials recovery.

1 Municipal Solid Waste in the United States of America

Mindfulness to solid waste issues in North America has been changing over the course of the last 40 years. Instead of being considered as having no value, industry, policymakers, and the greater public are becoming increasingly aware that waste has meaningful value for both the recovery of materials and the generation of energy. This awareness that waste is composed of multiple commodities has had a positive impact on public attitudes toward recycling and source reduction, though there is still a long way to go before North America reaches comparable levels of recycling and waste reduction with communities throughout Europe. Regardless of the inherent difficulties in measuring source reduction, it is positioned at the top of United States (U.S.) Environmental Protection Agency (EPA)'s waste management hierarchy, and has resulted in materials substitution and changes in packaging design in addition to changes in practices both in the home and at work to reduce waste. Waste managers provide services to meet waste management needs now deemed important and manage budgets, which are a growing percentage of a jurisdiction's budget. Planning has moved beyond anticipating next week's issues to getting public services ready to take on the challenges of another generation—and increasingly, to awareness of the need to create integrated, sustainable solid waste management systems.

There are two sets of data on the amount of waste generated and the disposition of it in the U.S. One is from the EPA and the other is from the Earth Engineering Centre (EEC) at the Columbia University in the City of New York. The latest data from the EPA estimates the total generation of municipal solid waste (MSW) around 251 million of US short tons in 2012, while EEC reported 389 million US short tons of MSW being generated in the 2011 (Figure 1). EEC reported that disposal was as high as 64% of total waste generation, based on reports from waste disposal facilities. Analysis of these differing results continues to encourage the industry to more accurately measure rates of disposal and recycling. (SHIN, 2013)



a. U.S. EPA Estimates, 2012 b. EEC Columbia University, 2013

Figure 1: Disposition of the MSW in the U.S

EPA also looks into the composition of the MSW as generated and as disposed in the US. The largest fraction by far is the paper and paperboard comprising 27 percent of the total generated MSW followed by food scraps, yard trimmings and plastic comprising 15 percent, 14 percent and 13 percent accordingly. The food waste is the largest fraction in the disposed MSW comprising 21 percent. (EPA, 2012).

In 2005, the EPA made a significant change to their Waste Management Policy, modifying the waste management hierarchy to more accurately reflect the importance of the recovery of materials and energy from the waste stream. Prior to 2005, the hierarchy placed source reduction at the top, followed by recycling, and then landfilling and incineration as the bottom tier. The 2005 change modified the hierarchy to source reduction, followed by recycling (with a 35% national goal established), followed by incineration/thermal processing with energy recovery (WTE defined as renewable), followed by landfilling and incineration (without energy recovery). This acknowledgement of the value of the energy potential of waste is important, and has supported the recognition of energy produced by WTE facilities as renewable. 32 states, the District of Columbia, and two territories now define WTE as renewable energy under various statutes and regulations (ERC, 2012).

2 Management Practices

Over the last few decades, the generation, recycling, composting, and disposal of MSW have changed substantially. While solid waste generation has increased from 3.7 to 4.3 pounds per person per day, between 1980 and 2012, the recycling rate has also increased – from less than 10 percent of MSW generated in 1980 to about 35 percent in 2012 as reported by EPA. Disposal of waste to a landfill has decreased from 89 percent of the amount generated in 1980 to about 54 percent of MSW in 2012, in the significantly more than 1,900 highly engineered and regulated sanitary landfills in the U.S. (EPA, 2012).

The introduction of regulations and requirements for environmentally-conscious disposal were a catalyst for the waste and recycling industries in the U.S. and Canada, and began to change both attitudes and practices regarding materials management. In 1970, the nation relied almost entirely on local scrap yards to provide the infrastructure to receive and prepare materials, primarily metals, for recycling. Today, there are greater than 580 material recovery facilities (MRFs)[1] in the U.S. having an estimated total daily throughput greater than 91,000 tons per day that process a wide range of recyclable materials for re-entry into industry as raw material feedstock for new products. These facilities vary widely throughout the nation, with respect to the materials they process and the technology and labour used to sort materials. Today, we also collect and process yard debris at as many as 2,300 composting facilities around the U.S. In the last couple of years significant interest has aroused for the anaerobic digestion of food waste that resulted in 20 commercial plants operating in the U.S. Over 50 percent the nation's population now lives in states where legislation has discouraged the disposal of yard trimmings in the trash. (THEMELIS & ARSOVA, 2015)

Residential recycling collection services have been increasing since their initial introduction in the 1970s. Communities have added single stream collection of source separated recyclables where no sorting is required by the generator, i.e. all recyclables are put together in the same container. By 2010, more than 9,000 kerbside recycling collection programs were reported. For residents without kerbside collection, drop-off centres collect residential recyclables. One report estimated that more than 20,000 communi-

[1] MRFs are also known as 'clean MRFs' since they process source separated recyclables as compared to 'dirty MRFs' which process mixed waste for separation of recyclables and possibly for composting or fuel feedstocks.

ties have drop-off centres, including some communities that likewise have kerbside collection. In 1970, only 6.6 percent of MSW was recovered for recycling, which rose to 9.6 percent in 1980 and 16.2 percent in 1990. Over the last decade, recovery of recyclable materials from MSW has increased from 69.3 million tons in 2000 (29 percent of total generation) to over 85 million tons in 2010 (34.1 percent of generation). (EPA, 2011) Lately, this national recycling rate has levelled off, after major increases in the 1990s when many communities built or expanded their recycling infrastructure. Much of this plateau can be attributed either directly or indirectly to economic factors. The economic recession in the U.S. and budget pressures on state and local governments have resulted in their inability to sustain high degrees of public education, resulting in less consumer participation in recycling programs, especially in the growing number of multi-family housing complexes and in communities that do not offer single stream recycling collection. Many public places and offices do not offer recycling, even though the amount of beverage containers and other recyclables is a significant percentage of the waste stream in parks, event venues and offices.

The modern MRFs processing recyclable materials have expanded in size, number, and operational flexibility. Currently there are three different types of MRFs in the US. Mixed waste processing facilities -“Dirty MRFs”- are the oldest type processing mixed MSW and separating the recyclables. A dirty MRF accepts a mixed solid waste stream and selectively separates recyclable materials through a combination of manual and mechanical sorting. The leftover fraction – “residue” is either landfilled or processed into a refuse-derived fuel for combustion with energy recovery.

The processing of mixed waste gives opportunity for communities to recover additional recyclables from the waste stream missed in kerbside recycling separation, and Dirty MRFs can co-locate with single-stream recycling MRFs, WTE, or composting facilities to maximize their impact. Many of these Dirty MRFs are developing systems for separation of organic materials from the mixed waste stream for use in anaerobic digestion, other organics processing facilities, or potentially a fuel for large coal-fired or solid fuel-fired boilers or cement kilns.

The “clean” MRFs operating in the U.S. accept recyclable materials that have already been separated from municipal solid waste at the point of generation by either residential or commercial sources. These MRFs operate as either dual stream, where containers come in as a pre-segregated stream from paper, or as single stream, taking a mixed incoming container stream (typically ferrous metal, non-ferrous metals, glass, PET, and HDPE) and a mixed paper stream (typically OCC, ONP, etc.). The number of dual stream MRFs in the U.S. grew as kerbside recycling programs to 228 plants operating in 2012, and single stream MRFs have undergone the same growth in tandem with the growth in popularity of single stream kerbside recycling collection programs to 263 plants operational in 2012. (BERENYI, 2012) Single stream collection programs often result in a larger total amount of recyclables set-out at kerbside and therefore processed and diverted, though the quality of materials separated at a single-stream MRF may be lower than it is under a dual stream system, often due to contamination of paper by broken glass and plastics. (GERSHMAN, 2008) In 2012, Americans recovered approximately 65 percent of the generated paper, approximately 58 percent of yard trimmings, approximately 34 percent of metals) (EPA, 2012).

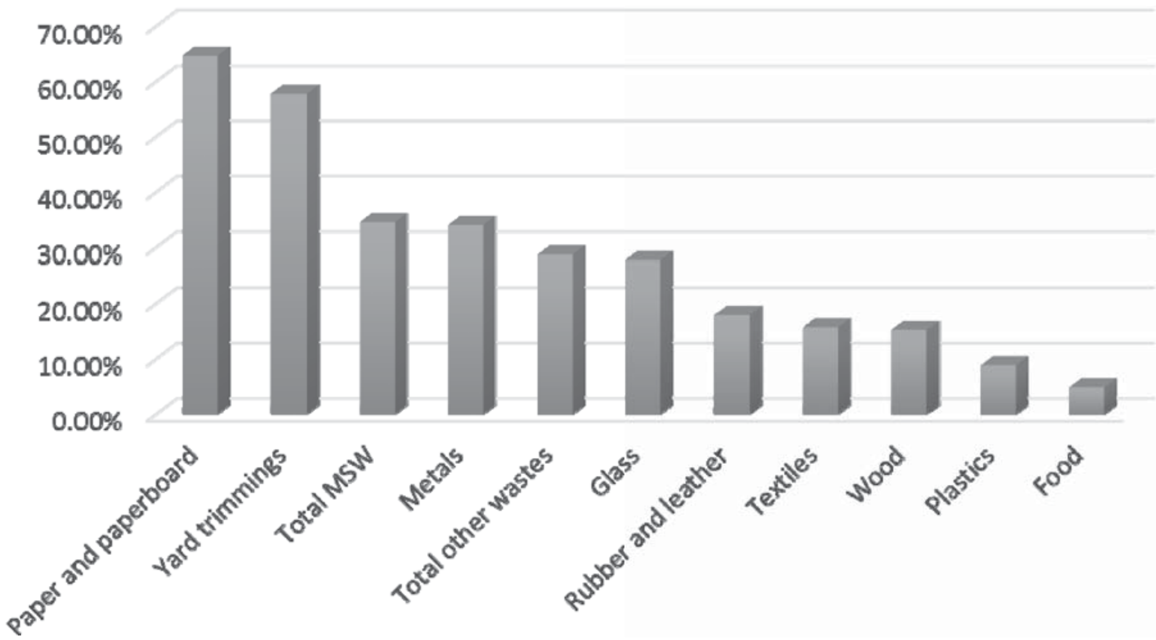


Figure 2 Recovery of Material Types as Percentage of Generation (EPA, 2012)

In terms of recycling, the collection, processing and remanufacture of recyclable materials clearly have important economic and environmental benefits. Additionally, recycling creates jobs and increases revenues that benefit U.S. communities and their residents. The U.S. hosts over 55,000 recycling and reuse establishments that employ approximately 1.1 million people generate an annual payroll of $37 billion and gross $236 billion in annual revenues. (R.W. BECK, 2009)

3 System Economics

In the U.S. today, there are many factors that affect the real costs and revenues for solid waste management. Most citizens do not often consider the costs of collection and disposal, but rather look at waste management as a basic municipal service, provided for a simple fee, or often “free”. Laws and regulations in a particular jurisdiction, the population in the area and the ability or inability to gain efficiencies of scale, how much control the local government has over collections (in some areas collection is provided from the “open” market where the resident may choose their waste hauler), politics regarding waste management issues, sites available for facilities, financing available to waste service companies for new equipment, the conditions of waste supply contracts, and other “hidden” costs (including costs stemming from unexpected changes in market conditions, changes in waste stream composition, landfill post-closure fees, and other costs) all have an impact on the cost of collection and disposal, and may vary significantly within the same region of the Country.

Ranges for collection services (without disposal or processing charges) can range from $10 to $40 USD per month per household for solid waste service, and $2 to $4 per month for recycling and yard waste collection. Commercial waste is often charged on a per month per box basis, and may include a separate pass-through cost for disposal charges. While a 2 cubic yard box serviced once per week may cost $60 to $140 per month, a 6 cubic yard box, also serviced once per week, might cost $130 to $280 per month.

The market for recyclable materials also has an impact on the costs for collection and disposal services. One ton of kerbside-collected residential single-stream recyclables has a value, once processed of over $150 per ton in many areas of the country, a value which has increased significantly over the last decade, and may possibly be $20 to $40 higher if container redemption values can be accrued by the MRFs, as in California. The rising value of recyclable materials, in tandem with rising costs for fuels and collection service, creates a strong incentive for many communities to strengthen their recycling and diversion programs.

The average tipping fee on the WTE plants in the U.S. is around $68 per ton while the landfilling fee varies from less than $20 per ton average in Idaho to more than $100 per ton average in Massachusetts (Figure 3).

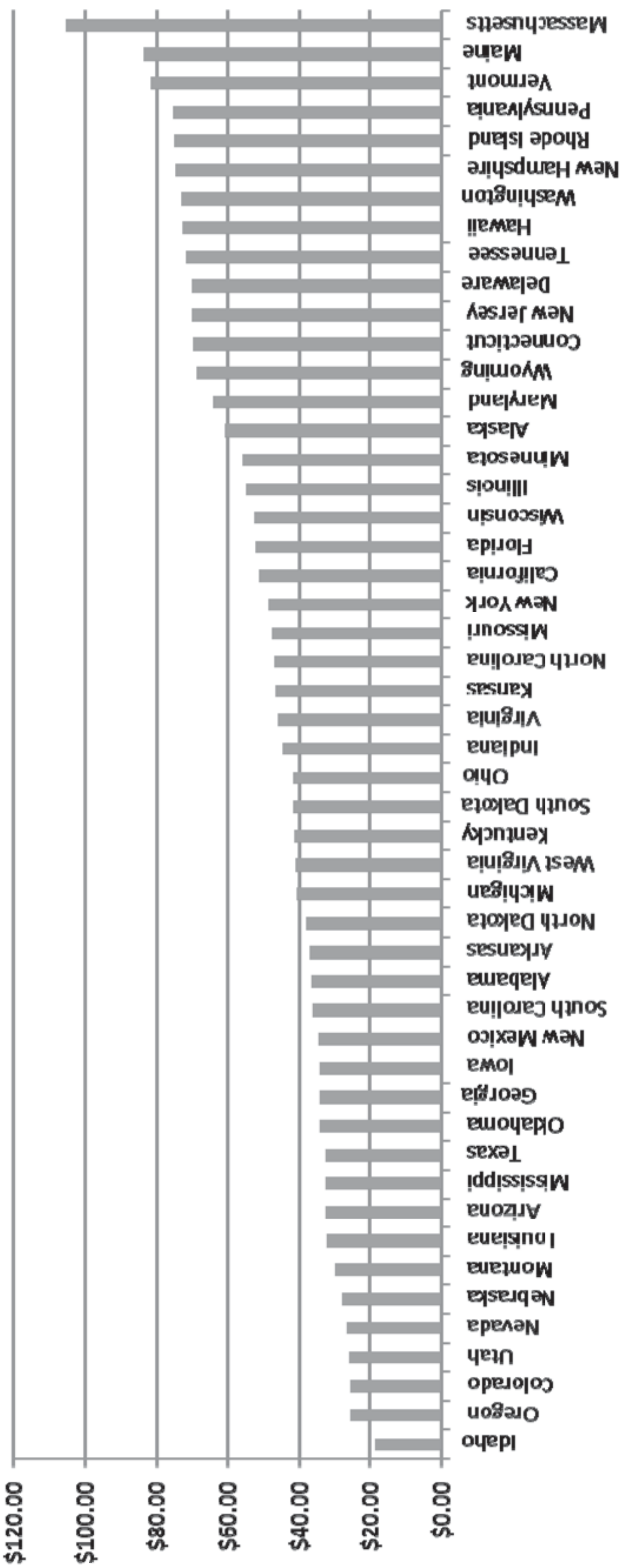


Figure 3 Average Price Per Ton At Each State's Largest Landfills (Waste and Recycling News 2012)

4 Review of the Established and Emerging Technologies for MSW Processing

4.1 WTE plants in the U.S.

Along with recycling and composting, waste is converted to beneficial use for recovery of its energy content, about 50% the potential heating value of coal on a per-ton basis or a barrel of fuel oil. Burning MSW with energy recovery, generally steam or electricity, (WTE) has matured right into a safe, effective and environmentally acceptable technology. The proven, basic methods of MSW combustion technologies include mass-burn/waterwall combustion, mass-burn/starved air combustion, refuse-derived fuel/dedicated boiler and refuse-derived fuel/fluidized bed, or using RDF as a fuel in existing coal-fired utility boilers, solid fuel-fired industrial boilers, or in cement kilns.

The path from the 1970s to the present has been a tumultuous one for the development of WTE in the U.S., as environmental, economic, land use, and community pressures have affected municipal attitudes toward WTE in relation to landfilling and recycling. Frankly speaking, energy has not been valuable enough while landfill capacity has become plentiful and a much less expensive disposal choice. After the Resource Recovery Act of 1970, the creation of a waste “hierarchy” and reaction to the newly identified “garbage crisis” shifted focus toward beneficial use of waste, and the opportunity of electricity production with WTE facilities. Collection of waste at kerbside became a more widespread practice, and municipalities that had a new burden of disposal in permitted facilities wanted to take advantage of the then current tax laws for accelerated depreciation, energy tax credits and tax-exempt financing for facilities. These opportunities fuelled many public-private partnerships for the development and construction of WTE facilities across the country. In the late 1990s, there were some 150 WTE projects in development in the U.S.

Today, there are 84 WTE plants operating in 23 states, handling approximately 12 percent of our waste stream and generating significantly more than 14.5 million megawatt hours of electricity per year (Michaels, 2014). There is only one plant under construction in the U.S., Palm Beach County, FL (under construction); and one in Canada in Durham/York (under construction).

Table 3 Facilities by Technology Type (Michaels, 2014)

Technology	Number of Facilities
All Facilities	84
Mass Burn	64
RDF	13
Modular	7

4.2 Emerging Technologies

In the last couple of years anaerobic digestion (AD) has gained significant interest in the U.S. that have resulted in 20 commercially operating plants. It has become the fastest emerging technology for organics waste treatment in the U.S. with more than 10 new plants under development at the moment. Leaders on the U.S. market with most operational AD plants are Harvest Power, Quasar Energy Group and Zero Waste Energy. (Themelis & Arsova, 2015)

In recent years, advanced thermal conversion technologies, such as pyrolysis, gasification, and plasma arc have presented additional possibilities for the conversion of waste into energy and valuable fuel products such as biodiesel or ethanol. Through heating waste to produce a synthetic gas (syngas) that then has the possibility of being co-fired, these technologies have demonstrated effective at facilities in Europe, Asia, and Canada. There are multiple configurations of gasifiers and pyrolysis systems, differentiated by the use of wet or dry feed, gas flow direction, and use of air or oxygen, and these systems are capable of converting 70-85 percent of the carbon in the feedstock to syngas. Though versions of these technologies have been used by the electric power industry to generate energy throughout the world from fossil fuels for over the past 35 years, with 19 gasification plants in the U.S. Currently there is only one gasification plant located in Canada processing RDF from MSW from the City of Edmonton. It is an Enerkem project with capacity of 10 million gal per year of ethanol.

5 Trends, Expectations, and Opportunities for the Future

Current trends in the solid waste management in the U.S. are focused on higher recycling rates and increased material recovery rates before the energy recovery by the means of thermal processing. Diversion of the food waste, especially from commercial sources, as the biggest fraction that currently goes to the landfills in the U.S. is the main focus of many states. Four have already instituted organic waste disposal bans and are working on developing legislative and financial support for development of more processing facilities, anaerobic digestion and composting. AD is the leading technology with the biggest number of plants under development.

Second important trend to notice is the interest in mixed waste processing and implementation of the concept of the Mechanical Biological Treatment (MBT) from Europe. The drivers for this trend are multiple and include the “one bin for all” approaches, the added recycling benefits over the single or dual stream recycling, the need for preparation of feedstock for the thermal technologies, etc. The used of mixed waste processing, especially in older systems, however, is experiencing public acceptance challenges. The Medina County, Ohio, mixed waste processing facility, recently reported achieving a recycling rate of only four percent and the County has discontinued the facility operation.

Contrary to the increased interest in material recovery and AD plants the interest in combustion WTE plants has been diminishing and resulting in the trend of closing plants around the U.S. Fifteen years ago, there were 97 operating facilities and today there are 84 operating WTE facilities across the U.S. Recent developments in the industry indicate that some additional WTE facilities may close, as evidenced by recent announcements about the Wheelabrator North Broward WTE and New Hanover WASTEC facilities facing closure.

Low landfill tip fees and low wholesale energy pricing contribute to this trend in the U.S. NIMBY (not in my backyard) proponents and a growth of the Zero Waste, or ”zero waste disposed” community has also affected public opinion and acceptance of these facilities. The “zero waste disposed” trend has gained a significant amount of traction lately, encouraging increased recycling and extended producer responsibility as ways to divert waste from disposal at landfills, and concurrently, at WTE facilities.

The U.S demonstrates a need to manage wastes in a more sustainable manner, including increasing efforts to reduce the amount of waste generated and boosting our recycling rates for residential and commercial materials. Current legislative initiatives are a step in the right direction; The Waxman Markey Bill-American Clean Energy and Security Act of 2009 (ACESA) (H.R. 2454, 2009) indirectly promotes recycling as a means to address global warming, and Executive Order 13514 – Federal Leadership in Environmental, Energy, and Economic Performance (2009) (Federal, 2009) calls on government agencies to study their greenhouse gas emissions and set targets to reduce them by 2020. In addition, the Executive Order establishes a 50 percent recycling goal, 50 percent diversion of non-hazardous solid waste by the end of 2015 and using paper containing a minimum of 30 percent post-consumer content. Unlike the 20 countries throughout Europe that levy landfill taxes (many taxing wastes at EUR 30 per tonne, EUR 50 per tonne, or higher), there is no national landfill tax or fee. Many states and local governments collect fees and taxes on the disposal of solid waste, but it is rarely higher than a few USD, and with an average landfill tipping fee rate of $49.27 per ton in 2012 for MSW, economic pressures of current rates not sufficient to deter landfilling in many areas region and allow WTE to be cost competitive (gate rates at WTE facilities throughout the nation commonly range from $65 - $100 per ton).

Communities throughout the U.S. need to work collaboratively to exceed state-by-state recycling and waste diversion goals, while encouraging use of the remaining waste for its energy value; and establishing economic incentives to encourage the domestic use of recyclable resources. Failure to act will result in a continuation of fragmented policies, recycling plateaus, and too much waste transported and buried in landfills that get further and further away from where waste is generated in the first place. Continuation of recycling industry demand for more paper, aluminium, and plastics will help to support increase of the amount of waste sent to mixed waste processing, and will help communities to raise recycling rates and divert materials for energy recovery. Looking to the future, as landfill capacity in the U.S. remains plentiful (though not all states have local access to capacity), greater emphasis on recycling and support for WTE facilities and facilities that recover energy, chemicals, and other materials from the waste stream will need to be continually bolstered by legislation that places value on moving up the waste management hierarchy, and providing more sustainable, productive methods for management of MSW.

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Integrated Waste Management System including Waste-to-Biofuels in Western Canada

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Abstract
The City of Edmonton provides integrated and sustainable waste management services for residents and for the commercial sector. These services are both economical and mindful of the environment. Up to 60 per cent of residential waste is currently diverted from landfills at the Edmonton Waste Management Centre. This is mainly achieved through recycling and composting processes. Edmonton's goal is to further raise that diversion rate to 90 per cent. Two projects play a key role in achieving this goal: a High Solids Anaerobic Digestion Facility and the first of its kind Waste to Biofuel and Chemicals Facility. These two projects will be described in more detail in this paper.

Keywords
Waste Diversion**, Integrated Solid Waste Management, Waste Processing, High Solids Anaerobic Digestion**, Refuse Derived Fuel, Waste to Biofuel, Ethanol

1 Context

The City of Edmonton provides integrated and sustainable waste management services for residents and the commercial sector. These services are both economical and mindful of the environment. At the Edmonton Waste Management Centre (EWMC) the City and its industrial partners operate a variety of recycling, research & development, and processing facilities for various waste streams. Currently the City is able to divert up to 60 per cent of the residential waste stream from landfill. This diversion rate is accomplished through recycling, municipal waste composting, and waste reduction activities, such as home composting, grass recycling, and reuse activities.

The integrated waste management system of the City of Edmonton is the result of the implementation of a thirty-year strategic plan developed in 1993. This plan focuses on diverting waste from landfill and the generation of products and energy from these waste materials. This plan was conceived as a result of having the only City operated landfill start to reach capacity in 1989 and being unable to find a new site to replace it. The active life of the City's landfill was initially extended but it has now been closed since 2009.

The initiation of a curbside recycling program in 1988 and the construction of a Materials Recovery Facility (MRF) at the EWMC in 1999, were able to extend the life of the existing landfill. Since 1988 City employees and contractors have been collecting blue bags/boxes of mixed recyclables such as paper, cardboard, plastics, metals and glass. This material is processed at the MRF, which is currently able to handle about 55,000 tonnes of recyclable material on an annual basis. Over 90 per cent of Edmontonians voluntarily participate in the City's recycling programs.

2 Processing and Organics Management

Since the year 2000 the organic fraction of residential and some commercial waste is composted in the Edmonton Composting Facility (ECF). This facility is currently processing about 125,000 tonnes per year of residential organics and about 10,000 dry tonnes of digested biosolids from the City’s Waste Water Treatment Plant. After curing in windrows and mass beds systems, about 60,000 tonnes of quality compost is produced and marketed annually.

Before composting the organic portion of the municipal waste (MSW), the waste is sorted and separated at the Integrated Processing and Transfer Facility (IPTF). At the pre-processing stage unwanted and bulky items are removed manually. Further separation is achieved through two 50’ (15 m) long and 12” (3.7m) in radius trommel screens, which sort out the smaller 2” (5 cm), 2” to 9” (5 to 23 cm), and larger 9” (23 cm) fractions. The 2 to 9” fraction is further separated into a 2” to 5” (5 to 13 cm) and 5” to 9” (13 to 23 cm) fraction through disc screens. The two smaller fractions (<2” and 2” to 5”) which include the majority of the organic portion, is conveyed to the ECF after remaining metals are removed. Figure 1 depicts the pre-processing phase of the IPTF in more detail.

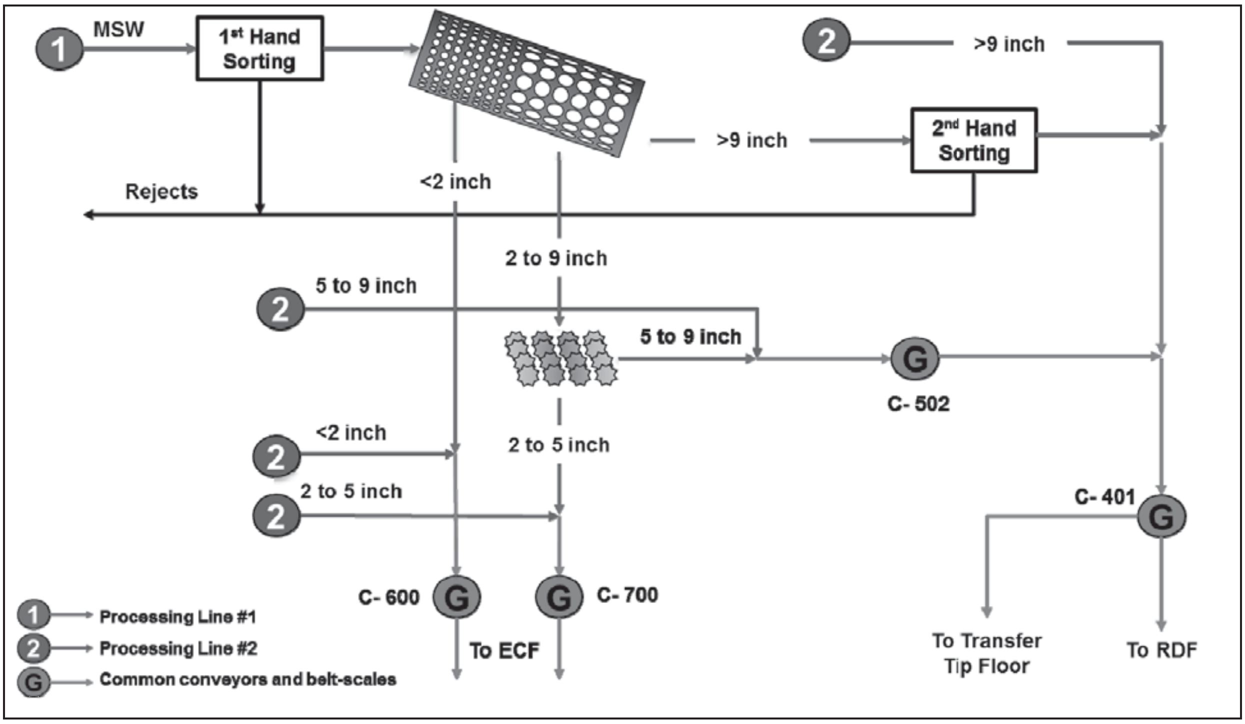

Figure 1: Pre-processing phase in the Integrated Processing and Transfer Facility (IPTF)

To manage the increasing amount of waste generated in Edmonton, mainly caused by the rising population (Edmonton welcomed about 60,000 new residents in the last two years), and to deal with seasonal over capacity at the ECF, the City is currently in the process of constructing a High Solids Anaerobic Digestion Facility (HSADF). The annual throughput of the HSADF will be 40,000 tonnes of residential and commercial organics and the facility is expected to generate 10,663 MWh of gross electrical and 40,800 GJ of gross thermal energy per year from the utilization of biogas generated in the process. In addition, on an annual basis, it is expected to produce about 20,000 tonnes of quality compost and reduce greenhouse gas emissions by 42,600 tCO_2e. Only a portion of electrical and thermal energy generated will be used for the operation of the HSADF itself. The excess power will offset internal demand at the EWMC and the excess heat will be beneficially used for drying or heating purposes.

The City is currently in the process of selecting a technology vendor and a construction contractor for this project. The current schedule foresees the HSADF becoming operational in the third quarter of 2017. Figure 2 shows a rendering of the HSADF and its integration with the IPTF and ECF.

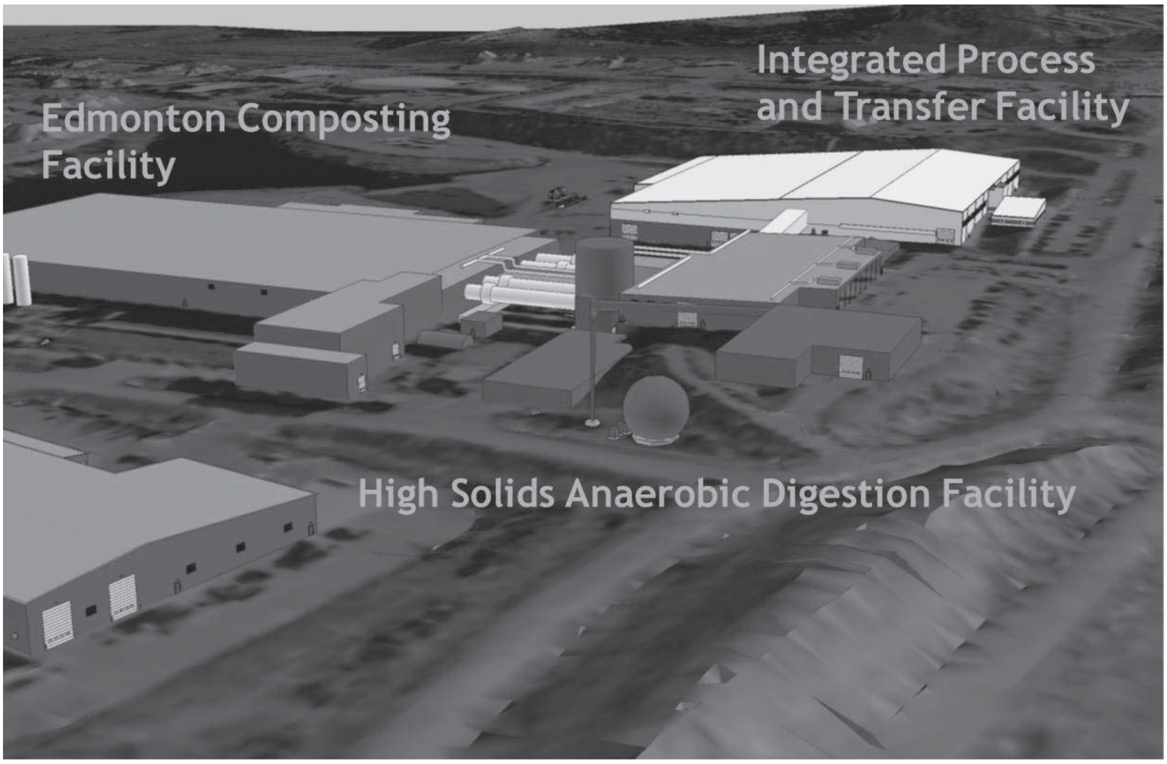

Figure 2: Rendering of the High Solids Anaerobic Digestion Facility

3 Refuse Derived Fuel Production

The material that is larger than 5'' (13 cm) in size after the pre-processing stage of the IPTF is further converted into a Refuse Derived Fuel (RDF) product. This is achieved in the RDF Phase of the IPTF. For the ensuing Waste-to-Biofuels process the material needs to be shredded and homogenized to achieve the required physical and chemical specifications. After an initial shredding step, ferrous metals, fines, heavies such as glass and stones, and non-ferrous metals are removed before the RDF material is shredded once more to a final particle size between 1 and 2" (2.5 and 5 cm).

In 2012 a complete RDF line by Vecoplan was installed and in 2016 a RDF dryer will be added to achieve the necessary and homogenous moisture content in the RDF material. On an annual basis 100,000 dry tonnes will be produced and conveyed to the neighbouring Waste to Biofuels and Chemicals Facility owned and operated by Enerkem.

4 Waste to Biofuel Project

By the year 2002, the City started investigating additional ways to further divert and process the remaining 40 per cent of the waste stream that could not be recycled or composted. The need to develop processes complementary to the already existing recycling and composting infrastructure at the EWMC was identified. The project was steered towards thermal conversion technologies, simultaneously reviewing and evaluating traditional waste-to-energy technologies, as well as new emerging conversion technologies such as gasification and pyrolysis processes.

Through this process the City chose Enerkem, which is a waste to biofuels and green chemicals company. Enerkem's flexible and innovative proprietary technology platform promised to be the most compatible with the City's current and future needs. As a result, Enerkem built a facility at the EWMC that will convert the municipal waste into a synthetic gas ("syngas") and then into fuels (ethanol) and green chemicals (methanol). The Company's ability to clean and condition its syngas made it one of the few companies capable of converting the waste into fuels through a clean and efficient manner.

Enerkem developed and continues to optimize its technology at its pilot plant in Sherbrooke (Quebec, Canada) and industrial demonstration facility in Westbury (Quebec, Canada). The Edmonton waste to biofuels project was publicly announced in June 2008, construction started in 2012, and the facility is currently in commissioning stage.

Once the Waste to Biofuels and Chemicals Facility is fully operational, the City will be able to further increase the residential landfill waste diversion rate from its current 60 per cent to 90 per cent. Figure 3 presents the anticipated waste flow at the EWMC to achieve 90 per cent residential waste diversion from landfill.

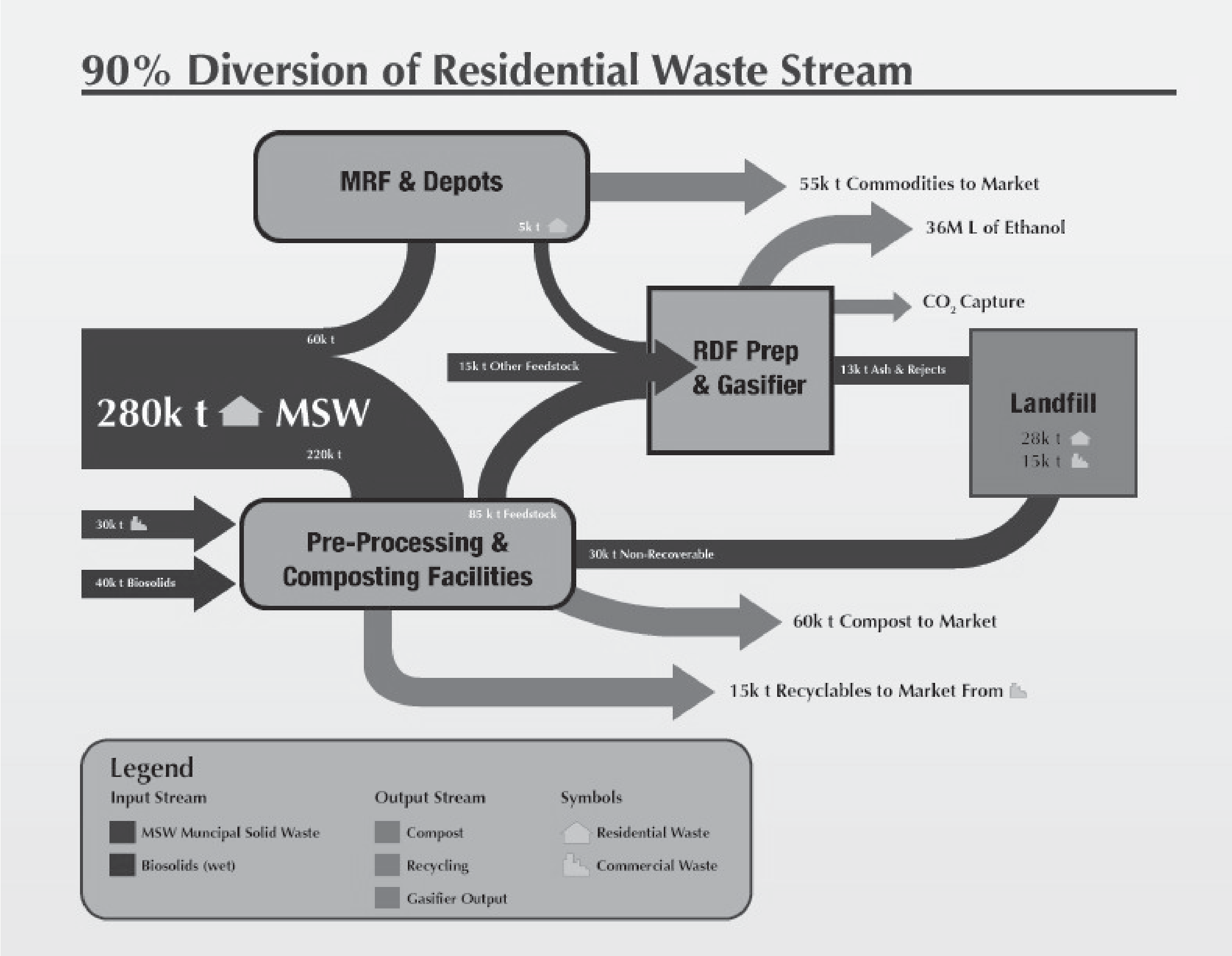

Figure 3. Material flow to achieve 90 per cent residential waste diversion from landfill

Following preparation at the IPTF, the RDF feedstock will go through Enerkem's thermo-chemical technology platform. The process involves relatively low temperatures and moderate pressures, as well as advanced chemistry, using industry-proven catalysts. It uses less energy than it produces, and uses minimal water in a closed-loop system. Enerkem's core process is based on a state-of-the-art gasification system coupled with a proprietary gas cleaning and conditioning process. The platform consists of three distinct steps: gasification of residual biomass/ wastes; cleaning and reforming of synthetic gas (syngas), and; conversion of a conditioned syngas into methanol and ethanol. The Facility will produce annually 38 million litres of methanol and ethanol from 100,000 dry tonnes of RDF processed. The process schematics are shown in Figure 4.

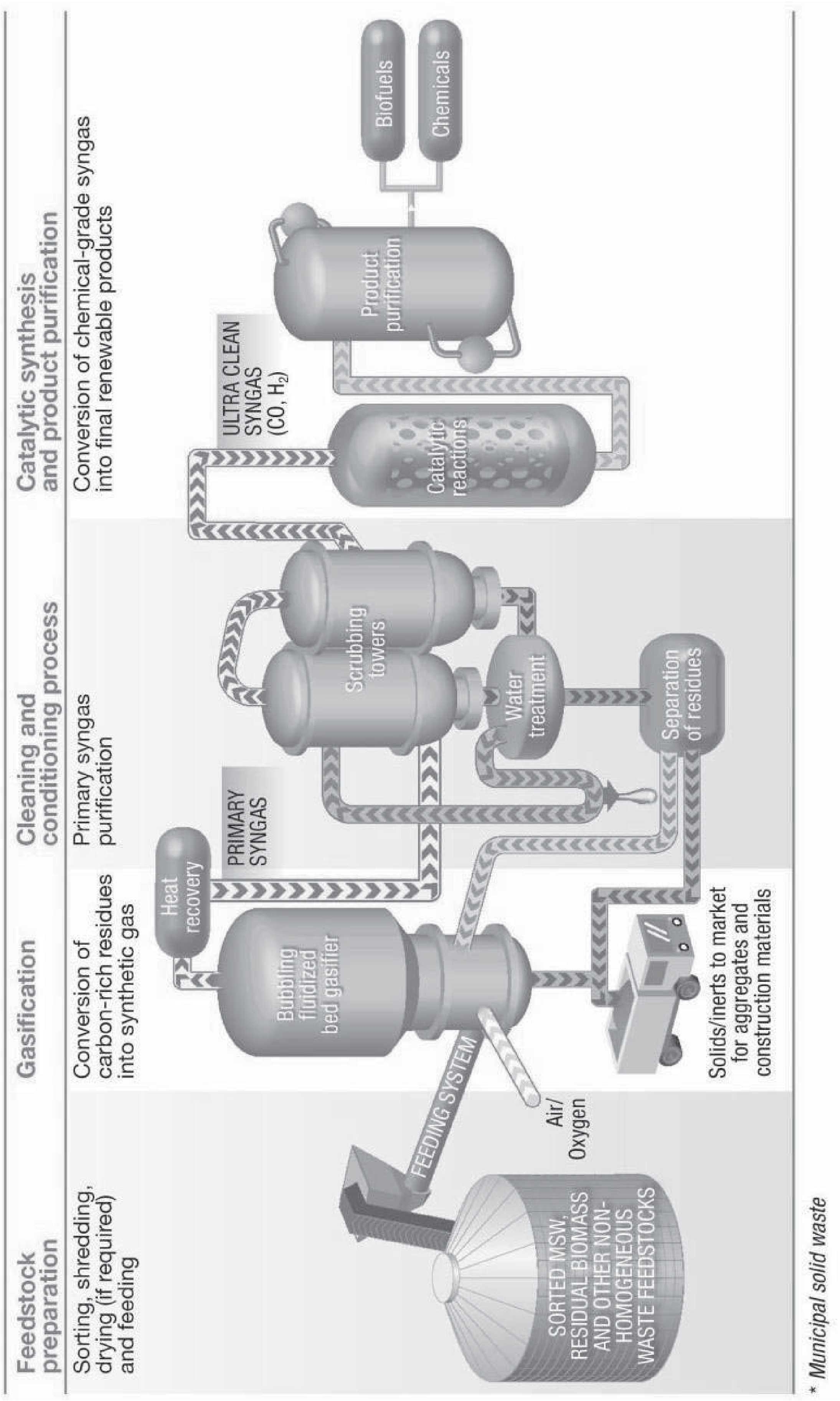

Figure 4: Schematics of Enerkem's low severity thermo-chemical process

5 Conclusion and Outlook

A long-term plan to focus on waste diversion and the generation of products and energy from waste materials was developed by the City of Edmonton in 1993. Since then recycling and composting facilities were established to increase residential waste diversion rates up to 60 per cent. As waste generation and population continue to increase, two new projects are currently underway. A High Solids Digestion Facility which will process organic waste materials to produce renewable energy in the form of heat and power, high quality compost, and will significantly lower greenhouse gas emissions. A first of its kind waste to biofuel project will convert the non-compostable and non-recyclable waste into a refuse derived fuel (RDF), which will then be gasified and the resulting synthetic gas will be converted into methanol and ethanol. These initiatives will maintain and increase the City's ability to manage waste in a sustainable manner and help achieve the goal of diverting 90 per cent of the residential waste from landfill.

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Landfill mining option: MBT role and landfill potential danger

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Abstract

The use of landfills for the disposal of municipal solid waste (MSW) has many technical and regulatory limits. An interesting solution is to recover the bales that have been previously stored in a landfill. After specific mechanical biological treatments (MBT), the contents of the bales can be used to produce a solid recovered fuel (SRF) that can be used for energy purposes. The possibility of producing SRF fuels from a landfill in northern Italy has been studied and is presented in this paper. The MSW extracted from the landfill, the bio-dried material produced by the waste hypothetically treated in a plant for bio-drying, and the SRF obtained after the extraction of inert materials, metals and glass from the bio-dried material have been characterized. Assessed the waste nature, the potential environmental impact of dioxin release from a possible landfill fire has been analysed, applying the Austal2000 model system.

Keywords

bio-drying, mechanical biological treatment (MBT), co-combustion, compressed bales, dioxins, landfill fire, landfill mining, modelling, solid recovered fuel (SRF).

1 Introduction

The European Union (EU) legislation puts landfills in the last place in the waste management hierarchy and in the first places material and energy recovery together with a highly efficient decrease in the landfill of biodegradable materials. In recent years the focus on landfill reclamation has increased, also referred to as landfill mining.

Landfill mining (LFM) involves the excavation, transfer, and processing of buried material taken from an active or closed (generally unlined) landfill (Hogland et al., 2004). After waste excavation, the conditioning treatment can take place either directly on the landfill or in a mechanical biological treatment (MBT) plant.

“Bio-drying” is an MBT approach that exploits the biological reactivity of the waste in order to produce a material with an improved lower heating value (LHV) thanks to the moisture reduction. Either with or without some post-treatment, this material can be considered as a solid recovered fuel (SRF), which can be used for energy production in industrial plants (Muller, 2009; Rada et al., 2014b).

The SRF definition was introduced in Italy by the Italian Decree 205/2010. Its classification system for SRFs in based on limit values for three important fuel properties: LHV, chlorine and mercury. With the Ministerial Decree no. 22/2013 only some SRF types can achieve 'End of Waste' status and that also under specific conditions. This new SRF in Italy was named "combustible SRF". In Table 1 the SRF classification characteristics (in red "combustible SRF").

Table 1 SRF classification characteristics (in red "combustible SRF")

Classification property	Statistical measure	Unit	Classes 1	2	3	4	5
Lower heating value	Mean	MJ/kg	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3
Chlorine (Cl)	Mean	%	≤ 0.2	≤ 0.6	≤ 1.0	≤ 1.5	≤ 3
Mercury (Hg)	Median	Mg/MJ	≤ 0.02	≤ 0.03	≤ 0.08	≤ 0.15	≤ 0.5
	80th percentile		≤ 0.04	≤ 0.06	≤ 0.16	≤ 0.3	≤ 1.0

Baling technology is a promising temporary storage method of MSW. It is currently applied in several places in the world so that many environmental risks (e.g. unpleasant smells, leachate formation, hazardous landfill gas, etc.) are prevented (Ozbay and Dormusoglu, 2013). The MSW from bales after various pre-treatments can be adopted for the production of SRF that can be used for energy purposes.

Another important issue, in addition to energetic one, occurs in favour of recovery. Heaps of waste materials having high organic fraction and/or high calorific value are at a considerable high risk of fires; these are commonly used, even though the associated risks are known (Stenis and Hogland, 2011). Materials stored only for a short period also pose a substantial risk of fires. Similarly, employing baling as a storage technique does not eliminate the risk of fires. Plastic wrapping around the bales produces a high flame-spread rate (Nammari et al., 2004), and bales can easily catch fire from adjacent fires.

Unlike the case of other industrial processes, the atmospheric emissions from open fires cannot be controlled either by setting emission limits or by using air pollution control devices. As a result, the impact of open burning on air quality is many times greater than that of controlled combustion (Stenis et al., 2011; Atencio et al., 2013; Wiedinmyer et al., 2014). Fire incidents can pose serious health risk for the population residing in the vicinity of storage sites. One of the most important reasons is that fires are the source of persistent organic pollutants (POPs) such as dioxins, furans (PCDD/F) and/or polychlorobiphenyls (Fiedler et al., 1990; Rada et al., 2006; Kulkarni at al., 2008).

The aim of this paper is to present the results regarding the possibility of producing SRF and combustible SRF, from a landfill located in northern Italy, where the waste is placed in cylindrical wrapped bales. The authors also analysed the potential environmental impact of dioxin release from a possible fire in the proposed landfill.

2 Materials and methods

A real case study of a landfill from the North of Italy was used, in which a wrapped bales system had been used since the late 1990s, while awaiting the construction of an incinerator. Due to the high level of selective collection (SC) efficiency, the quantity of residual waste (RMSW) has now decreased strongly, making its incineration not financially viable (Rada, 2013). SRF production and usage is the new strategy proposed for the waste management in the province where the case study is located (Rada and Ragazzi, 2014).

The considered landfill covers a land area of approximately 38,600 m^2, with a maximum filing height of approximately 18 m. The waste is placed in cylindrical wrapped bales, piled on top of each other. The average height and diameter of the bales are both 1.20 m, the average volume is 1.4 m^3, and the average bulk density is 0.7 t m^{-3}. The cylindrical bales are produced by a single mechanical press which shreds, compresses and plastic-wraps the MSW. The shredded material is pressed and fixed with an HDPE plastic net. When the press opens, the bale is transferred to the wrapping unit, which is separated from the compression unit but integrated into the same machine. The bale is then wrapped with LDPE film (Figure 1). Once the bale is removed, a new cycle begins.

Figure 1 a) HDPE plastic net wrapping b) LDPE film protection

The bales have a good compression resistance and high elasticity. In the chosen landfill 404,000 wrapped bales have been placed, with a total of 384,608 t_{RMSW}. The landfill was in operation between 1999 and May 2014, and contains only RMSW. The waste came from two different communities: community 1 (C1) (waste delivered between 1999 and 2011) and community 2 (2C) (waste delivered between 1999 and 2014).

In order to classify the waste extracted from the landfill and hypothetically treated into SRF or combustible SRF, their LHV, chlorine and mercury were determined using the following data:

- landfilled waste (t_{RMSW});
- average composition of RMSW;
- LHV of RMSW fractions (Schiavon et al., 2014);
- average density, volume and packing weight of a waste bale;
- percentage of chlorine for each fraction (Rada et al., 2014a; Ragazzi and Rada, 2012);
- Mercury value for each fraction (Rada et al., 2014a; Ragazzi and Rada, 2012).

The RMSW extracted from the bales was also hypothetically treated in a bio-drying plant in order to obtain the SRF required by the Italian law.

Further to the waste characterization, the study also aimed to investigate the dispersion of dioxins emitted by a possible landfill fire. For this purpose Austal2000 was utilised, a freely available atmospheric dispersion model based on a Lagrangian particle model for simulating the dispersion of air pollutants in the ambient atmosphere (Janicke, 2002; Janicke and Janicke, 2003).

The model was applied for a 5.36x5.10 km^2 region, its centre being the stack of the landfill. The period of the application was a full calendar year (2013) which, in the framework of the current study, was considered sufficient for presenting the variability of the meteorological conditions of the region with satisfactory accuracy. 8 days is the supposed lasting of fire, hypothetical time required to burn all deposited waste, and two are the simulations made. In the first one the fire was hypothesized at the beginning of January (first 8 days) while, in the second one, it was supposed in July (first 8 days). Two different scenarios were chosen because they are characterized by different atmospheric stability and, therefore, by different capacity to disperse pollutants.

The source, constituted by the landfill, was simplified with a rectangle with an area of 0.04 km^2. Since it is not realistic to consider a simultaneous burn of the whole landfill, the original source was divided into four identical parts, which start one after the other two days later. Annual mean of concentration and annual mean of deposition were considered in this study.

3 Results

Table 2 shows the RMSW extractable from the chosen landfill and classified as SRF from the three main parameters. Results were obtained by taking into account the fractions characterizing each year of disposal and hypothesizing that the composition of the wrapped waste was stable (Andreottola et al., 2001). Of course, in real cases, the classification as SRF needs the inclusion of a homogenizing stage.

Table 2 SRF class of LHV, chlorine and mercury

	Waste					
	Community 1			Community 2		
	LHV	Cl	Hg	LHV	Cl	Hg
2004	4	1	1	4	1	1
2005	4	1	1	4	1	1
2008	4	1	1	4	1	1
2009	4	1	1	3	1	1
2010	4	1	1	3	1	1
2011	4	1	1	3	1	1
2012				4	1	1
2013				4	1	1

The RMSW placed in the chosen landfill is in the first class for chlorine and mercury, thanks to selective collection, and can thus be considered as combustible SRF, however the problem is its LHV. For the RMSW from community 1, the LHV is always in class 4, therefore the SRF cannot be accepted as a combustible SRF. For the RMSW from community 2, a combustible SRF was only obtained between 2009 and 2011, after which the results worsened because the food waste increased and the packaging decreased.

The above results are related to the hypothesis that SRF would be obtained only through bale extraction, shredding and homogenization. A more technological approach could be based on the construction of a more complex plant, based on the principle of bio-drying. The results for the bio-dried material produced from the RMSW hypothetically treated in a bio-drying plant, and considered as an SRF are shown in Table 3, which also reports the results for SRF obtained after the extraction of inert, metals and glass from the bio-dried material. This post-treatment exploits the characteristics of the bio-dried material, which makes the above-mentioned extraction easier.

Table 3 SRF class of LHV, Cl and Hg: bio-dried waste and SRF from the bio-dried waste

	Bio-dried waste						SRF from the bio-dried waste					
	Community 1			Community 2			Community 1			Community 2		
	LH	Cl	Hg	LHV	Cl	Hg	LHV	Cl	Hg	LHV	Cl	Hg
2004	4	1	1	4	1	1	4	1	1	3	1	1
2005	4	1	1	3	1	1	4	1	1	3	1	1
2008	4	1	1	4	1	1	3	1	1	3	1	1
2009	3	1	1	3	1	1	3	1	1	3	1	1
2010	4	1	1	3	1	1	3	1	1	3	1	1
2011	4	1	1	3	1	1	3	1	1	3	1	1
2012				3	1	1				3	1	1
2013				3	1	1				3	1	1

For community 1, the LHV class was 4 (and 3 for 2009 because of the increased packaging), thus the SRF cannot be accepted as combustible. For community 2, the waste in 2008 was slightly anomalous because the class decreased more than in previous years because there were many materials with low LHV, such as green waste and inert materials, and few materials with high LHV, such as hazardous and composite waste.

For community 2, the LHV class is always 3, thus the SRF can be accepted as combustible SRF. For community 1, only the SRF produced from the waste from 2008 can be considered as combustible SRF. Previously the LHV is lower because of the percentage of food waste.

Figure 2 shows the PCDD/F deposition map obtained with the Austal2000 dispersion model, assuming a fire in the first eight days of January. It represents the deposition caused by the 8-days long event, averaged on 365 days. The analysis shows that the higher deposition values are on the landfill and nearby. Moving away from the landfill, the deposited PCDD/F amount decreases. Lower value are on the western side of the landfill. The deposition values are 0 pgTEQ $m^{-2}d^{-1}$ to 19,930 pgTEQ $m^{-2}d^{-1}$. Most of these values exceed alarmingly the proposed deposition guide value of 1.4 pgTEQ $m^{-2}d^{-1}$ (Schiavon et al., 2013), value calculated starting from the diet of people living in an Alpine region of Italy and from the WHO guide value for the Tolerable Daily Intake (TDI).

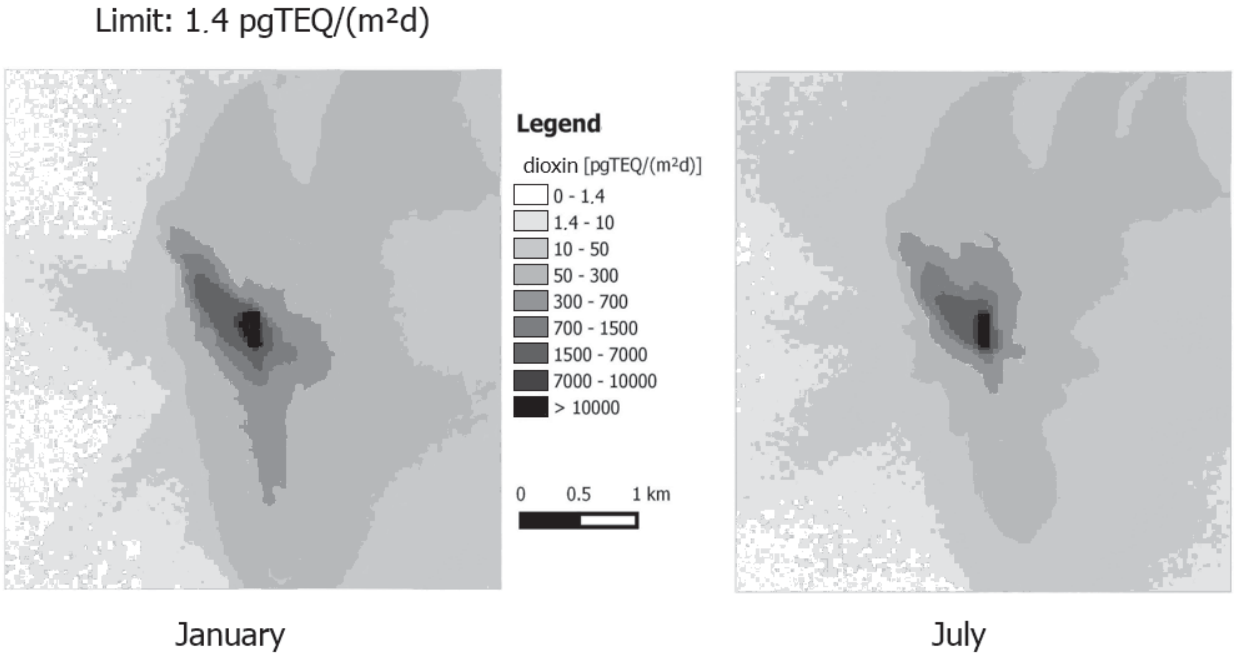

Figure 2 PCDD/F deposition map (fire in the first eight days of January and of July)

January and July have different atmospheric stability; the simulation with fire in July is less burdensome because the air turbulence is greater, therefore the deposition values are lower, between 0 pgTEQ $m^{-2}d^{-1}$ and 14,410 pgTEQ $m^{-2}d^{-1}$ (Figure 2). The estimated production of dioxin from the stored bales of the chosen landfill, considering an 8-day long fire, is about 0.035 kgTEQ.

On July 10, 1976, the rupture of a bursting disc on a chemical reactor in Seveso (Italy) resulted in the highest known residential exposure to PCDD/F. According to the Agency for Toxic Substances and Disease Registry's estimates, about 1.3 kgTEQ were emitted. Even today there are Seveso's accident effects; the potential dioxin emission from the chosen landfill would have devastating environmental consequences.

Figure 3 shows the PCDD/F concentration map obtained with the dispersion model Austal2000, assuming a fire in the first eight days of January. It represents the concentration caused by the 8-days long event, averaged on 365 days.

The analysis shows that the higher concentration values are on the landfill and nearby. Moving away from the landfill, the concentration of dioxin amount decreases, in accordance with the deposition results. The concentration values are 0 pgTEQ/m^3 to 76.85 pgTEQ/m^3.

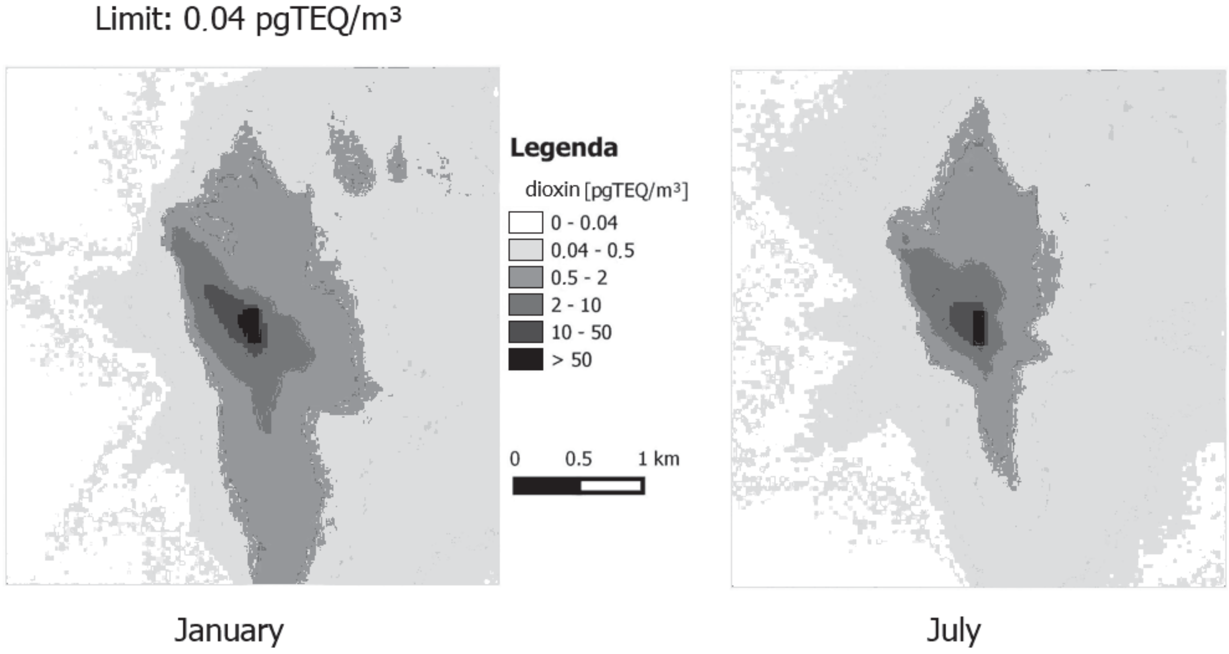

Figure 3 PCDD/F concentration map (fire in the first eight days of January and of July)

The Italian legislation requires dioxin limits only for soils to reclaim (D.Lgs. 153/2006), not for air. To make comparisons and evaluations the value proposed by National Technology Advisory Commission of 0.04 pgTEQ/m^3 can be used (ARPA Umbria, 2010). This guide value is exceeded in most of the domain; nearby the landfill the limit value is exceeded up to 2,000 times.

Despite the reduced dimension of the domain, the dispersive action of wind is clear in the simulation of July. Indeed the concentration values are lower, between 0 pgTEQ/m^3 and 54.63 pgTEQ/m^3 (Figure 3). The western area of the landfill is the exception related to the wind direction.

4 Conclusions

Landfill mining entirely with waste processing and recycling may be an alternative to landfill aftercare as well as a way of preventing pollution and recovering huge areas through land recycling. Energy recovery by incinerating excavated waste fractions with a sufficient calorific value seems to be technically feasible, and fits in with the targets of land recovery.

Our results show that the RMSW in the chosen landfill is in the first class for chlorine and for mercury, and thus can be considered as combustible SRF, however the problem is its LHV. The LHV is too low and thus the waste excavated must be treated in a bio-drying plant and inert waste, metals and glass must be removed. This leads to a material with a high LHV thus meeting Italian regulations for SRF.

Another conclusion of the present investigation is that the chosen landfill is a potential source of dioxin, which should not be underestimated.

The simulations with Austal2000 showed that the PCDD/F guide values, for deposition and concentration, would be exceeded alarmingly.

However, a consideration on the potential danger represented by the chosen landfill should be made, along economic and environmental assessment, if landfill mining were considered as possibility.

Anyway, for the chosen case study, the municipality together with the environmental agency included the possibility to recover the landfill in the last Waste Management Plan. In particular they included the possibility to construct a MBT plant for SRF production.

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Landfill mining in practice: Dismantling of the old dump Kössen / Austria

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Landfill mining in der Praxis: Rückbau der Altablagerung Kössen / Österreich.

Abstract

This case study presents in its first part a hands-on assessment of the content of a former landfill which was operated between 1920 and 1985 and accepted all municipal waste streams generated in a predominantly rural environment with tourism as a main economic factor. The assessment was performed – according to the principle "let´s replace assumptions by knowledge" – prior to the complete removal of the landfill content (volume about 50.000 m^3).

The second part gives an overview on the excavation and separation works itself which have been triggered by flood events in summer 2013 (Kössen, a small town located on a river emptying into Chiemsee in Bavaria was the municipality mostly affected by this flood in Western Austria).

Inhaltsangabe

Als Tribut an den Hochwasserschutz wird eine 1920 bis 1985 betriebene Müllkippe „zerlegt und verräumt". Es handelt sich um eine typische ehemalige Universal-Abfallsenke einer Tiroler Gemeinde, gelegen an der Grenze zu Bayern (nächstgelegene Ortschaft: Reit im Winkl) direkt gegenüber der Einmündung eines Bachs in einen Fluss, welcher als Tiroler Ache 25 km weiter in den Chiemsee mündet. Der Beitrag beschreibt in seinem ersten Teil bereits 2008 durchgeführte Erkundungsarbeiten und in der Folge die eigentlichen Rückbauarbeiten (bestehend aus Aushub, Siebung und tlw. händischer Sortierung) eines Volumens von etwa 50.000 m^3, welche durch ein Hochwasserereignis im Sommer 2013 ausgelöst wurden (Kössen war mit 300 evakuierten Einwohnern und hunderten bis ins Erdgeschoss überfluteten Häusern die am stärksten betroffene Gemeinde Westösterreichs). Zum Zeitpunkt der Tagung „Waste-to-Resources 2015" wird das Projekt abgeschlossen sein; es können somit endgültige Ergebnisse präsentiert werden.

Keywords

Landfill mining, Deponierückbau, mechanische Abfallbehandlung, Hochwasserschutz. Landfill mining, landfill reconstruction, mechanical waste treatment, flood protection.

1 Project background and overview

The former landfill "Auwirtslacke" is located in Kössen, a Tyrolean municipality directly on the river Kitzbüheler Ache (in Germany: Tiroler Ache) which flows into Chiemsee, a large lake in Bavaria. It was operated for all kinds of municipal solid waste between end of World War I and the mid 1980ies without whichever emission control.

As a part of mayor flood protection measures in the area it was decided to remove the entire landfill (volume about 50.000 m^3) in order to give the river more space. The excavation works which are followed by screening and sorting the entire landfill content started in July 2014 and are scheduled to be finished in May/June 2015.

2 Exploration phase

In order to have a sound estimate on disposal cost before starting the excavation works a complex assessment on the physical landfill content and its composition to be expected was performed, consisting of

- *the evaluation of historical data* (which turned out as relatively fruitful compared to similar cases)
- *interviews* with former operating staff and finally
- *the digging of trenches* – total length about 800 m, distance between trenches 10 and 15 m – on the entire surface down to the landfill body´s bottom.

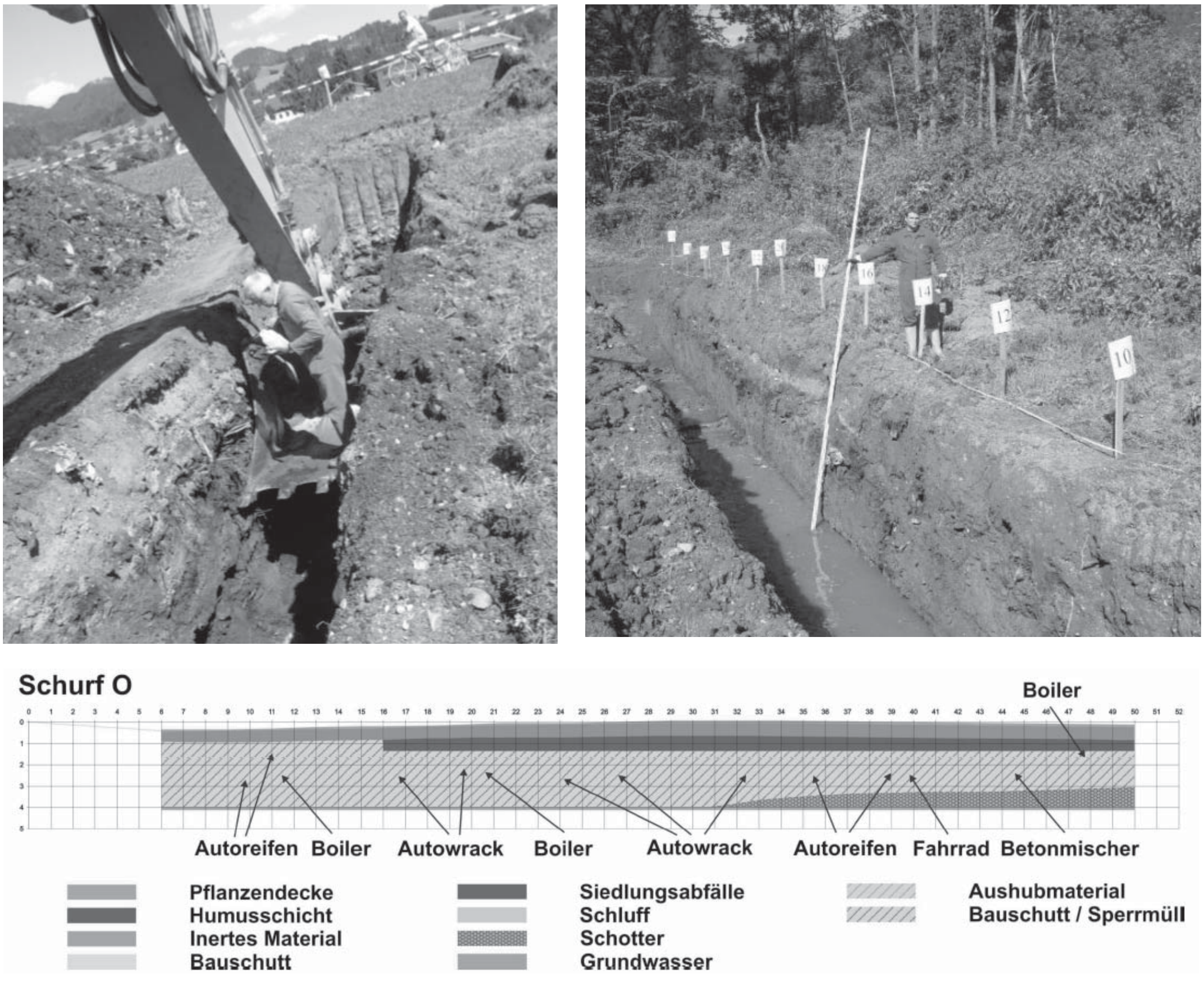

Figure 1 Digging of trenches with sampling (left photo) in order to receive an overview on contaminants as well as volume proportions by documenting measures of single layers

The achieved data gave a good picture on the landfill´s composition which provides not only an indication about expectable disposal cost, but also on the way subsequent excavation works have to be organized. As a particular question the one on the date of final landfill closure (which in such cases often matters in legal terms – who will bear which cost ?) could be answered by finding certain items which allow a clear judgement on its earliest disposal = latest closure date (eg. food and beverage packaging with readable shelf dates, refer to Figure 2).

By way of summarizing the dump´s content can be described as mainly inert materials (excavation, construction and demolition debris) "contaminated" with relatively small amounts of municipal solid waste the putrescible components of which have been largely eluted into the nearby river due to the impact of high groundwater levels over a long period. A significant portion of scrap metal was to be expected since the site served in its last operational decade (1975 – 1985) for disposing of bulky waste only, and car wrecks (for which recovery in Austria was commenced in the late 1970ies).

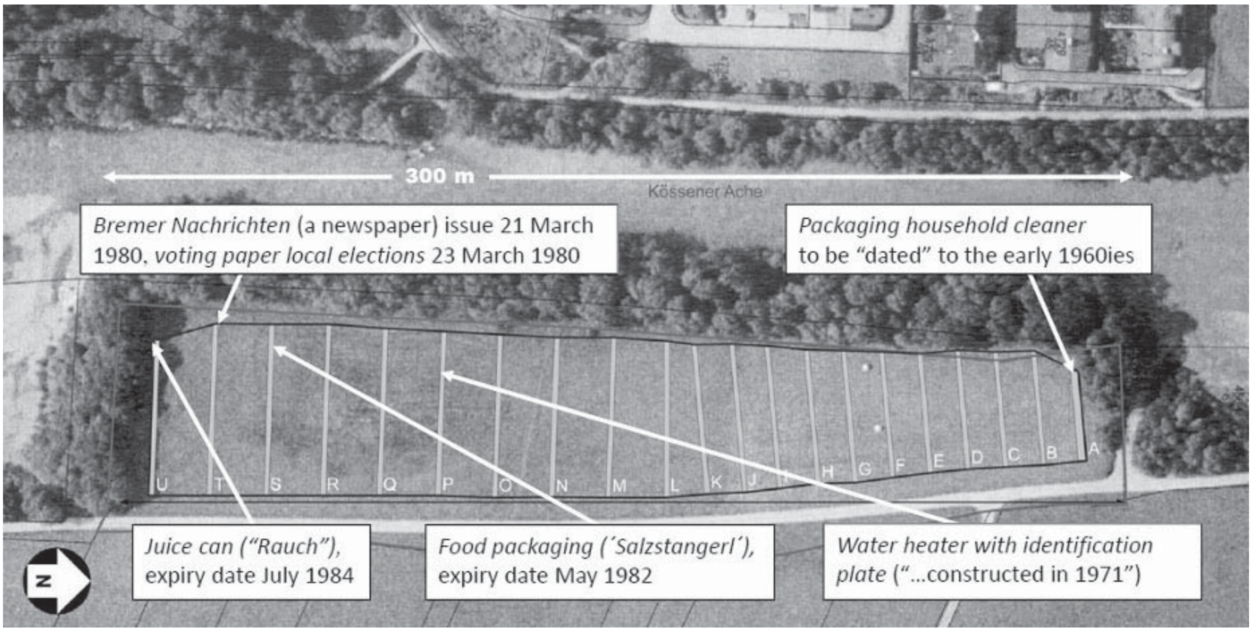

Figure 2 Former Kössen landfill: Survey on the entire location and typical „age tracers" found during the assessment (the numbered bars indicate the before-mentioned trenches)

3 The entire excavation and ´dismantling´ phase

Trigger for a decision to remove the entire dump inventory (with the aim to create space for the two watercourses to join inside their banks even at high water levels) was a major flood event in June 2013. Since landfill regulations in place in Austria and related cost considerations forbid a plain "transfer" to another landfill (or whichever other disposal) an entire "dismantling" was necessary, i.e. to separate inert materials from not decomposed domestic waste components such as wood, glass, plastics and scrap metal.

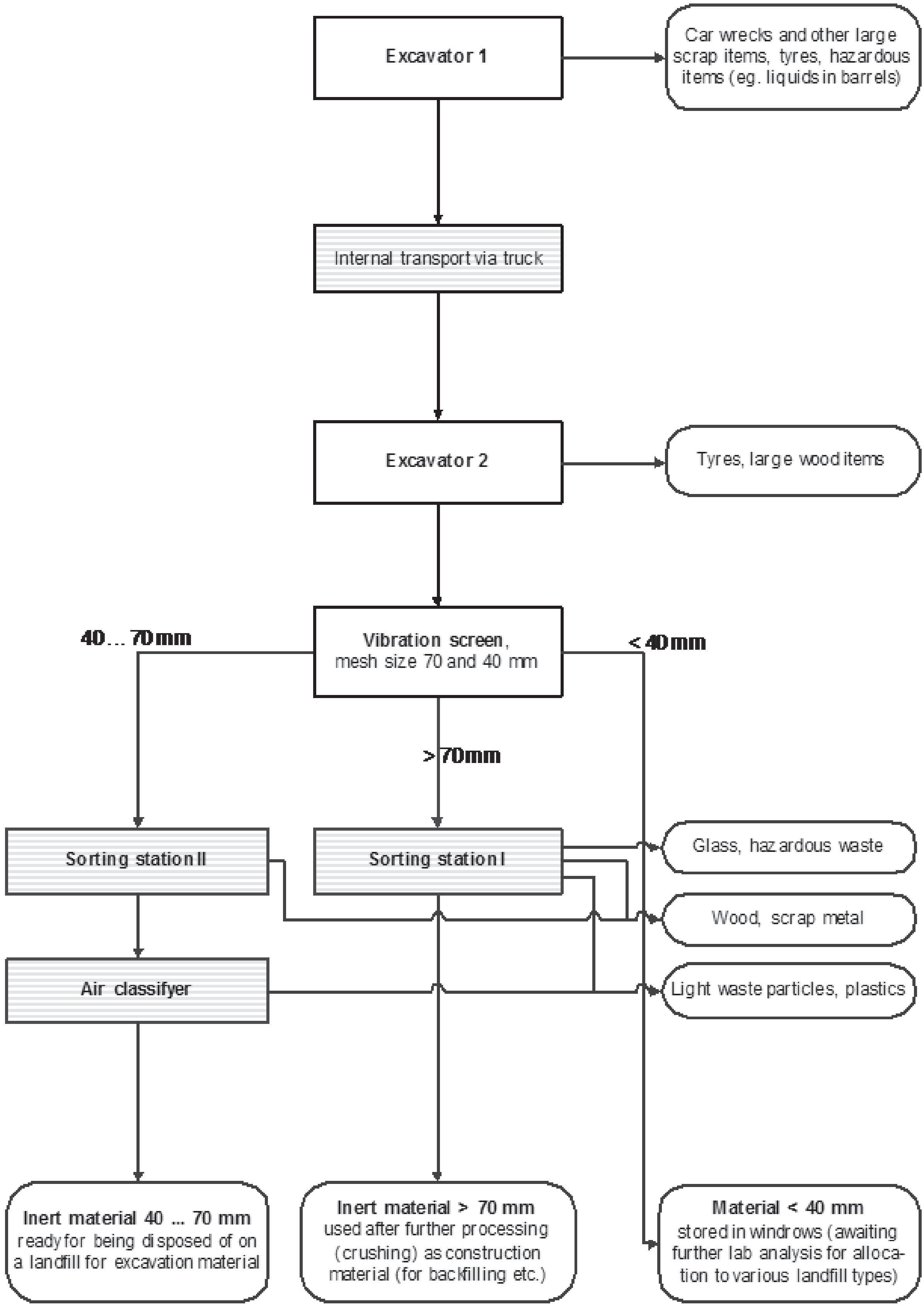

Figure 3 Landfill mining Kössen: Process flow sheet

For a flow sheet of the applied separation process it is referred to Figure 3; the core unit – a vibration screen with two mesh sizes, 40 and 70 mm and manual sorting of its overflow – is shown below.

Figure 4 Core unit applied for dismantling the dump´s inventory: a vibration screen producing a fine fraction (leaving the screen right hand side, windrows visible in background), a fraction 40 … 70 mm (left) for further processing via air classifier, and > 70 mm out of which the fractions wood, glass, scrap metal and plastics/MSW are sorted manually.

4 A few data on cost

At the time of writing this report – the works commenced in July 2014 and will be concluded in May 2015 – total project cost including disposal and related transport efforts is estimated with 1,25 – 1,5 m €.

Manual operations (mainly handpicking of the screen fractions > 70 and 40 … 70 mm) were performed by asylum seekers, mainly from Syria and African countries (note that in Austria the employment of asylum seekers by public entities – the project is carried out by the Municipality – in activities for the public welfare is legally settled at a state-wide payment). Without this contribution (i.e. when applying local wage levels for about 5,500 working hours) total cost would have increased by 10 %.

About 5 % of the total cost could be compensated by revenues (marketing two qualities of ferrous scrap and various non-ferrous metals, for prices refer to Table 1).

Table 1 Revenues / cost (negative values) for relevant fractions, transport ex works included

Fraction	Revenue / cost per ton	Comment
Non-ferrous metals	€ 600	Average revenue for a mixture of stainless steel, aluminium, copper (massive parts, motors, cables), lead (waste pipes, car batteries), and brass
Ferrous metals, quality 1	€ 148 [1]	Items with a strength larger than 6 mm
Ferrous metals, quality 2	€ 133 [1]	Mainly vehicle wrecks and parts thereof (eg. wheels)
Glass	€ 0	Bottles, manually separated into white / coloured
Wood	- € 25	Thermal utilization
Tyres	- € 80	Thermal utilization (cement industry)
Domestic waste	- € 101	Delivered to a WtoE facility (distance about 400 km)
Oil/water emulsions	- € 108	Oil spillage (mixed with excavation): About - € 300
Inert material > 70 mm	€ 0	Secondary construction material (after crushing)
Inert materials < 70 mm	- € 3 … 30	Depending on landfill category, and distance

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[1] Price level 7/2014 which dropped until 3/2015 by € 40 (application of a contractually defined price index)

Compost-like material or thermal valorization – impact on MBT Plant economics and environmental aspects – Case studies in Portugal and UK

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Abstract

The paper focuses on the utilisation of the solid product from the biological treatment stages of three MBT Plants which treat the organic fraction of MSW by means of wet mechanical pre-treatment units followed by anaerobic digestion. The experiences of two MBT Plants in Portugal (CVO Valorlis and CVO Suldouro) which produce compost-like material are contrasted with the experiences at the MBT Bredbury Parkway (UK) which, by drying the digested solids, produces a RDF with low calorific value for further use in thermal valorisation. The impact of these two different approaches on the operating costs for the treatment of the digested solids as well as the environmental aspects for both valorization paths is discussed.

Keywords

MBT Plant, MSW, BTA® Process, wet anaerobic digestion, wet pre-treatment, digestate treatment, composting, compost-like material, digestate drying, low calorific value RDF.

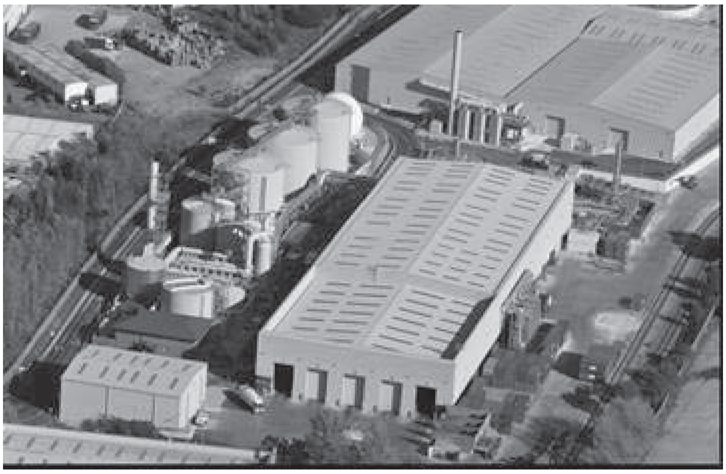
1 Introduction

This article describes and compares two different ways to treat the dewatered digestate from an anaerobic digestion facility for the Organic Fraction from residual Municipal Solid Waste. At the Bredbury Parkway MBT the dewatered digestate is dried to >50% DS in order to be used as low calorific value RDF, while at the CVO Suldouro and the CVO Valorlis the dewatered digestate undergoes a composting step in order to obtain a compost-like material that can be used for certain agricultural purposes.

2 MBT Bredbury Parkway

2.1 Plant description

Bredbury Parkway MBT treats 100,000 tonnes per annum of residual municipal solid waste. It is an MBT-AD facility that generates refuse derived fuel (RDF), recovers metals and produces an organic rich fraction that undergoes anaerobic digestion. The biogas produced generates electricity via combined heat and power (CHP) engines with the waste heat being used to dry the dewatered digestate to make a low calorific value (CV) RDF.



The process consists of mechanical pre-treatment (MPT) which separates the waste based on size. The incoming waste is shredded and after metals recovery and reject removal the oversize (>60mm) fraction forms the high-CV RDF, while the undersize fraction (<60mm) forms the organic rich fraction for anaerobic digestion

Figure 1 Bredbury Parkway Aerial View

The facility treats around 100,000 tpa (design capacity) generating around 35-40,000tpa of organic rich fraction from municipal solid waste (OF MSW). The organic rich fraction is processed in BTA® Waste Pulpers and BTA® Grit removal System (GRS) to generate an organic substrate for AD treatment.

The mesophilic AD system consists of a sludge buffer tank (SBT) followed by three mesophilic AD tanks, each of 4,100m³ capacity, operated in parallel. The SBT and AD tanks use BTA® gas mixing, with additional mixing in the SBT provided by a low level jet mixing system. The MPT operates five and a half days per week (Monday to Friday 16h/day, Saturday 7 h/day) generating feed to the SBT, while the AD is operated 24/7, being fed from the SBT. The CHP system generates electricity at around 1.2MW and waste heat from the CHP engines is used for heating the digesters and in a dryer to dry the dewatered digestate.

Typical waste feed composition to the pulpers is shown in the table below. The BTA pulping and sludge thickening system is controlled to generate a substrate of 6-8%DS (system maximum design is 12.5%DS) and the AD tanks operate at 4-5%DS. Typical hydraulic retention in the AD system is >25 days.

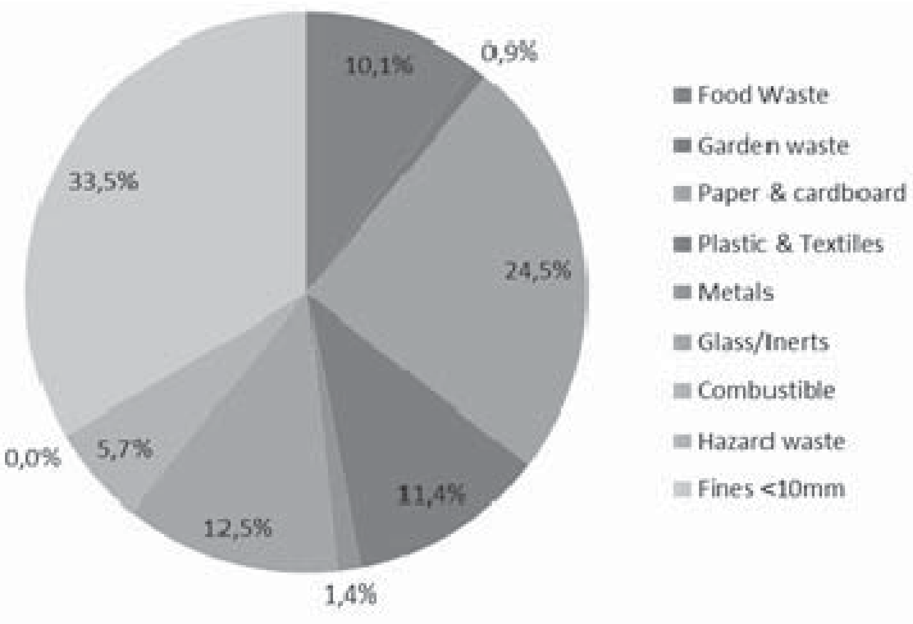


Figure 2 Bredbury Parkway typical pulper waste feed composition (indicative values)

2.2 Further processing steps for dewatered digestate

After adding about 3.5 kg of polymer per tonne of solids, the digestate from AD is dewatered in decanting centrifuges to around 32 %DS, of which the volatile content is about 45%. This sludge is then dried to >50 %DS (using waste CHP heat) to become low CV RDF. The Sevar dryer is a two pass system: dewatered digestate from the cen-trifuge is conveyed into the dryer feed hopper, the digestate is then conveyed through the dryer, which operates at around 80°C and has a residence time of around 60 minutes.

Figure 3 Bredbury Parkway Digestate Dryer

2.3 Product and final use

The dried digestate (low CV RDF) is typically 53 %DS with a NCV of 5 MJ/kg. It forms around 23% of the total RDF produced by the facility. The high CV RDF fraction which is typically 63% of the total RDF, comes from the oversize waste processing line (mainly paper and plastics) (NCV ~12.5 MJ/kg) and the remaining 14% (also high CV) comes from the de-watered lights recovered as part of the BTA pulping process (NCV ~11 MJ/kg).Both RDF streams (high and low CV) are transported by rail to a thermal power station (TPS, which is essentially a waste incinerator with CHP) that generates electricity and heat for industrial use by Ineos Chlor.

3 CVO Valorlis and CVO Suldouro

3.1 Plant description

Both VALORLIS - Valorização e Tratamento de Resíduos Sólidos, S.A., and SULDOURO - Valorização e Tratamento de Resíduos Sólidos Urbanos, S.A., belong to the EGF holding, which with 11 companies in total treats 65% of the MSW produced in Portugal.

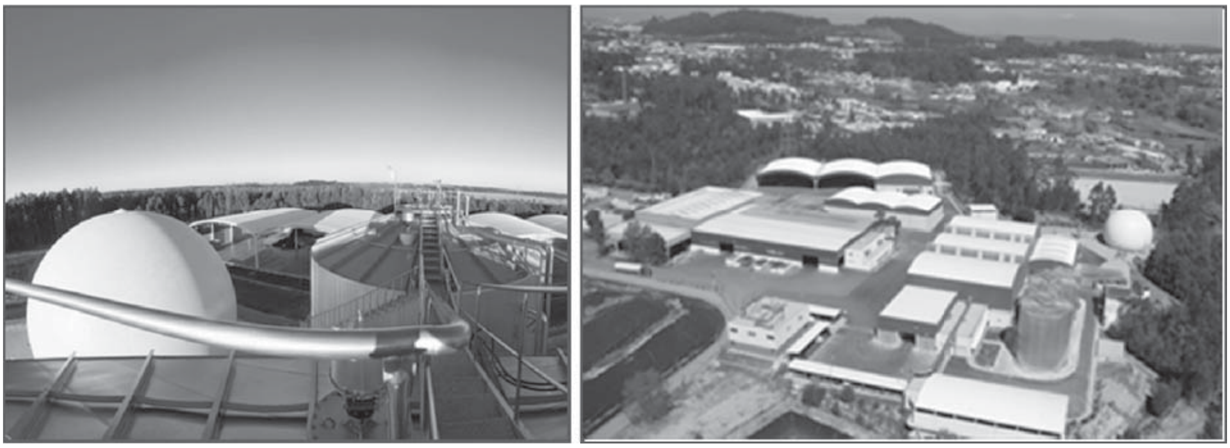


Figure 4 CVO Valorlis (left) and CVO Suldouro (right)

The Central de Valorização Orgánica (CVO) Valorlis, was started up in 2010 and in 2014 treated 60,000 tonnes, which is approx. 20% above the nominal capacity of 50,000 tonnes/year. After the mechanical pre-treatment, approx. 25,000 tonnes/year of organic rich fraction from MSW (OF MSW) are further processed in the wet mechanical pre-treatment. Started up in 2011, the CVO Suldouro is slightly smaller with a nominal design capacity of 43,000 tonnes/year MSW. In 2014, a special focus was given to the recovery of waste packages, processing in the mechanical treatment and sorting plant resulting in a facility throughput of approx. 58,000 tonnes, generating about 12,900 tonnes of OF MSW. OF MSW was originally generated from the underflow stream, <80 mm from a drum sieve; however, after an extension of the mechanical pre-treatment system with optical and ballistic separators at both facilities, recovered organics are now also obtained from the overflow stream (>80mm).

The OF MSW is further treated in an anaerobic digestion line according to the BTA® Process as described above. After the wet pre-treatment, the organic suspension is digested in the mesophilic range in two reactors of 2,000 m³ at Valorlis and 2,250 m³ at Suldouro, with a nominal hydraulic retention time of 18 and 25 days respectively (in 2014: 26 days and 50 days). At both CVOs, digestate from the AD process undergoes the solid-liquid separation step using screw presses

In 2014, approx. 3,350 tonnes of dewatered digestate were obtained at Valorlis and 2,865 tonnes at Suldouro. For a polymer consumption of about 5 g/kg DS the average dry matter content was around 30-34% DS and the VS content was in the range between 49– 55%.

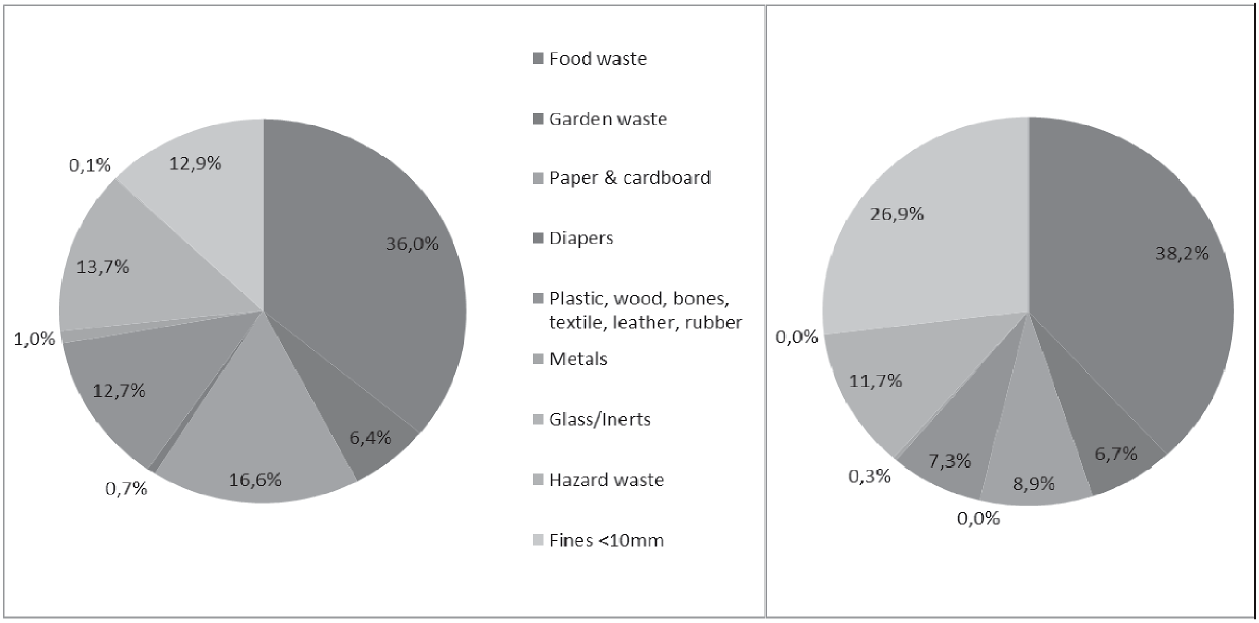


Figure 5 Composition of OF MSW in Valorlis (left) and Suldouro (right). Data from sorting analysis during start-up and acceptance tests

3.2 Further processing steps for dewatered digestate

Due to its high homogeneity and low content of impurities the dewatered digestate is a good substrate for further composting. The dewatered digestate is mixed with additional structuring material in order to allow for better aeration. The structural material is a blend of fresh wood chips and rejected material (wood chips >10mm) from the refining step.

At the CVOs, the composting process is divided into two steps. In pre-composting, the material is treated in an enclosed hall in boxes with forced and controlled aeration. This stage is designed to sanitise the raw compost and takes four weeks with the compost being turned once. After pre-composting, the material is transported by wheeled loader for post-composting in covered aerated trapezoid windrows. Post-composting takes around 60 days, giving a total retention time in the composting process of 12 weeks, as requested in the tender. The compost is screened using a mobile sieve of 10 mm to recover structure material.

Figure 6 Composting boxes for the pre-composting phase and post-composting hall

3.3 Product and final use

The composting of the AD digestate generates around 2,050 tonnes/year of compost-like material at Valorlis and 1,500 tonnes/year at Suldouro. Unlike the UK, under Portuguese legislation the production of compost-like material is not automatically forbidden due to the waste source (MSW). The operating licenses of the CVO Suldouro and CVO Valorlis facilities stipulate the compost quality monitoring requirements and frequency, as indicated in Table 1.

To get authorization to sell the compost it is necessary to submit an application including compost characteristics and composition, its effects in plants grown, and public health and environmental impacts. These tests were made in soil and with fast-growing crop plants (lettuce in the Valorlis test). Soil samples were taken and analysed before and after the compost addition, to verify whether heavy metals migration occurs. The same tests were made to the crop plants. The effect of compost in the crop plant growth was measured by weight/hectare. The tests made with VALORTERRA® compost (compost produced in Valorlis) concluded that i) the addition of compost in the soil improves the crop plant growth, ii) there is no migration of heavy metals to the soil, and iii) that there is no migration of heavy metals to the crop plant.

The permission to sell VALORTERRA® is valid for 5 years. Suldouro has recently finished the tests and submitted them to achieve two further years of license to manufacture the compost-like material under the name AGROVIDA®.

Four different classes are considered according to Portuguese legislation (Portaria 1322/2006): Class I: for agriculture crops for human consumption, Class II: for agriculture crops for animals for human consumption, Class IIA: for orchards, vineyards, fruit trees or olive groves, Class III: for gardens and landscaping.

Table 1 Control frequency of compost according to operational permits

Parameters considered in operational permit	Controls (n° per year)
Anthropogenic inert materials, boron, cadmium, calcium, chrome, conductivity, copper, humidity, lead, nitrogen, magnesium, mercury, nickel, pH, phosphorous, organic mass, potassium, sodium, stones > 5 mm, volumetric mass, zinc	4
Escherichia coli; Salmonella spp	4
Maturation degree, maturation temperature (ºC)	4
AOX, LAS, DEHP, NPE, PAH, PCB, PCDD/F	1

Table 2 shows the classification of the parameters of the obtained compost-like material at both MBT Plants. While for anthropogenic inert materials a classification under Class II would be possible, due to the levels of some heavy metals (mainly copper and zinc) the product is classified under Class IIA, which allows its application as "corretivo orgánico" that can be used in orchards, vineyards, fruit trees and olive groves.

Table 2 Classification of compost-like material at CVO Valorlis and CVO Suldouro

	VALORLIS				SULDOURO			
	Compost				Compost			
Parameter	Class I	Class II	Class IIA	Class III	Class I	Class II	Class IIA	Class III
Cadmium (mg/kg)	0.7	**1.5**	3	5	0.7	**1.5**	3	5
Lead (mg/kg)	100	150	**300**	500	100	150	**300**	500
Cupper (mg/kg)	100	200	**400**	600	100	200	**400**	600
Chrome (mg/kg)	**100**	150	300	400	100	**150**	300	400
Mercury (mg/kg)	**0.7**	1.5	3	5	0.7	**1.5**	3	5
Nickel (mg/kg)	**50**	100	200	200	**50**	100	200	200
Zinc (mg/kg)	200	500	**1000**	1500	200	500	**1000**	1500
Antropogenic inert materials (%)	0.5	**1**	2	3	0.5	**1**	2	3
Stones >5mm (%)	**5**	5	5	-	**5**	5	5	-
Salmonella spp.	**None in 25g**	None in 25g	None in 25g	None in 25g	**None in 25g**	None in 25g	None in 25g	None in 25g
Escherichia Coli (NMP/g)	**1000**	1000	1000	1000	**1000**	1000	1000	1000

While most of the compost AGROVIDA® in Suldouro has been used in the municipalities' green areas, some is also sold to vineyards and blueberry production. The compost VALORTERRA® is sold to private companies in the vineyard sector. Furthermore, Valorlis exchanges this compost-material for garden waste from municipalities. This allows cost savings for structure material, the only cost being for the rent of a mobile shredder. This idea is also persuasive for the municipalities to collect and segregate garden waste to aid recovery.

4 Comparison of operation costs

4.1 MBT Bredbury Parkway

The Bredbury Parkway MBT-AD facility is one of five major facilities constructed by Costain as part of its contract with Viridor Laing for the Greater Manchester Waste (GMW) Project. The facilities are designed to treat over 500,000 tpa of residual waste. Part of the overall GMW project includes the provision of RDF to the Ineos Thermal Power Station. Details of the operating costs are not available, however no fossil fuel is used to dry the de-watered digestate and there is a gate fee payable for its disposal as low CV RDF at Ineos.

In the wider UK market, data published by WRAP (http://www.wrap.org.uk/content/wrap-gate-fees-report-detailed-2014) provides typical gate fee data for MBT and EFW plants:

Table 3 Comparison of UK gate fees for MBT and EFW plants

Facility Type	Average Gate Fee (£/tonne)	Gate fee range (£/tonne)
MBT	84	25 – 104
EFW (MSW)	94	62 – 112
Landfill (non-hazardous) Includes £80/tonne landfill tax	102	89 – 130

4.2 CVO Valorlis and CVO Suldouro

Table 4 gives an overview of the relevant operating costs for the composting step at the CVO Valorlis and the CVO Suldouro, equating to 30.4 €/tonne dewatered digestate feed at CVO Valorlis and 39.4 €/tonne dewatered digestate at CVO Suldouro. With 12,000 € (CVO Valorlis) and 3,780 € (CVO Suldouro) the revenues in 2014 for the sale of the compost-like material were rather small compared to the operating costs. Yet, no costs had to be foreseen for the disposal.

4.3 Impact on other parts of the MBT Plants

Table 5 gives an overview of the differing spatial requirements for the drying and composting methods for dewatered digestate treatment described above.

The space requirements for the composting option are much larger than for the drying option. However, it should be noted that for both MBT plants in Portugal the nominal retention time in the post-composting area is 60 days ensuring a total retention time of the composting process of 12 weeks. This retention time was requested in the tender, although a shorter retention time would also suffice to meet the quality requirements, significantly reducing space requirements.

Table 4 Overview of operation costs for composting phase at CVO Valorlis and CVO Suldouro

Parameter	**Operation costs [€/year]**		**Comments**
	Valorlis	**Suldouro**	
Electricity	22,706	24,990	including costs for exhaust air treatment
Diesel	13,000	8,000	
Structure material	10,000	22,500	Valorlis: costs for mobile shredder
Lab analyses	1,600	3,640	
Reports and studies to obtain licences	10,000	6,650	Valorlis: costs to obtain permit of 5 years; Suldouro: costs for the permits for 2 years
Man power	27,000	32,000	
Maintenance costs (M&E)	17,500	15,000	
Sum Operation Costs	**101,806**	**112,780**	

Table 5 Comparison of spatial requirements for drying and composting treatment methods

Parameter	**MBT Bredbury Parkway**	**CVO VALORLIS**	**CVO SULDOURO**
Dryer area	10 m x 25 m	--	--
Pre-composting	--	42 m x 34 m	30 m x 43 m
Post-composting	--	55 m x 34 m	64 m x 43 m
Refining & Storage area for product and structure material	Container storage only	52 m x 34 m	50 m x 25 m

One of the main reasons for the two-stage composting step was to reduce the impact on the exhaust air treatment system, as only the pre-composting hall is connected to it. At the CVO Valorlis the exhaust air stream from the composting is mixed with the stream from the reception and pre-treatment hall. The ratio is about 30:70%. Due to the layout restrictions in Suldouro, it was necessary to consider a separate exhaust air treatment line for the dewatering and composting area. The costs for the additional power consumption for the exhaust air treatment are already included in the power consumption figures above.

At Bredbury Parkway the exhaust air from the dryer is treated with the rest of the extracted air from the MPT process in a caustic scrubber and recirculating biofilter system before discharge to atmosphere. The biofilter uses inert lava rock as the support media for the odour destroying microbes and has a design life in excess of 25 years. Once acclimatised the operation of the dryer has no significant impact on the operation of the odour control system as the dryer is designed to operate continuously apart from regular cleaning.

The Bredbury Parkway facility is operated under an Environmental Permit which identifies several point source emission locations and sets relevant emission limit values that must be tested annually. The odour control system discharge stack and the CHP engines exhaust stack are two of the identified locations.

4.4 Environmental impact

The compost-like material obtained at the CVO Suldouro and CVO Valorlis allows substitution of fertilizers or soil improvers.

The low CV RDF from Bredbury has a positive calorific value and therefore contributes to power generation as part of the TPS, which generates electricity (~100MW electrical at full load) and heat for use on the Ineos chemical site, displacing fossil fuels. The TPS operates under an Environmental Permit and is compliant with the Large Combustion Plant Directive (LCPD, 2001/80/EC). The electricity generated by the Bredbury MBT-AD facility from the combustion of bio-gas qualifies for Renewables Obligation Certificates (ROCs) giving a significant in-crease in the monetary value of the power generated. Typical ROCs value is ~£45/MWh and ‘green’ energy from AD qualifies for double ROCs (ie ~£90/MWh).

5 Transferability of concepts

5.1 MBT Bredbury Parkway

As for the use of the digestate from Bredbury Parkway as compost-like material it must be pointed out that it will never be compliant with either PAS100 or PAS110 (UK compost standards) as it is not derived from source segregated material. Requirements from

PAS100 lay between Class I (chrome, mercury, nickel, zinc, anthropogenic inert materials,) and Class II (cadmium, lead, copper) according to the Portuguese legislation. The compost-like material obtained does not fulfil these requirements. Similar as in Portugal it does not meet the requirements of these higher classes. Therefore, possible outlets are more restricted. However it is noted that in another MBT Plant based on the BTA® Process in the UK, Reliance Street (also part of the GMW project), an ABPR (animal by-products regula-tions) compliant compost-like product is obtained that can be used as landfill cover but not as a 'compost'.

5.2 CVO Valorlis and CVO Suldouro

Under the EU Proposal for End-of-Waste Criteria on biodegradable waste subject to biological treatment passes, it will not be possible to use compost-like material from Municipal Solid Waste for agricultural purposes, but only for landfilling or landscaping, therefore its application is limited. Alternative possibilities through thermal valorization are limited in Portugal as no Energy from Waste (EFW) plants exist, however there are cement plants with a limited capacity to receive RDF. The market for RDF derived from dried digestate from the CVOs in Portugal is very limited as there is enough high calorific RDF produced from industrial and commercial waste in Portugal and alternatively the cement plants can get it for free from other countries.

6 Summary

Two different ways for the treatment and valorization of the dewatered digestate from anaerobic digestion plants for OF MSW have been presented. While at Bredbury Parkway a thermal valorization as low CV RDF is the preferred option, leading to important savings of fossil fuels, at the two Portuguese plants show that material valorization as compost-like material under a strict testing and certification programme is possible. It can be further seen that there are, in both cases, limitations to other valorization paths. In order to ensure the financial viability of mechanical biological waste treatment facilities it is important to allow for different treatment and valorization methods.

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National Waste Policy in Brazil: its repercussion after 4 years

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Abstract

After 20 years, in 2010, was published the national waste policy that was based on principles found in Europe and Germany, as well as the hierarchy of procedures concerning sustainable solution for the problems associated with the waste management, focusing the resources preservation and climate protection. After 4 years publication we can observe a slowly movement, slowly doesn't mean small when we consider the giant waste market that Brazil represents, expecting for 2016 around 15 billion euros turn over in waste management where 80 % is done by private sector. Although the good news, Brazil still have 42 % of waste final disposal being done at wild landfill and their remediation represents also an interesting market. To change traditional practices we need to open a multidisciplinary discussion integrating multiple market segments to enable the design of tools for the implementation of sustainable management of municipal solid waste.

Keywords

Waste, Management, Treatment, Recovery, Secondary Market.

1 Global challenges

The amount of solid waste produced by populations is not only related to the level of wealth reflected in the economic ability to consume, but also to the values and habits of life, determining the degree of disposition for the realization of consumption. Prior to the concern about the proper disposal of waste, in order to reduce damaging effects of improper disposal or for desirable reuse, recycling, composting and energy recovery, every effort should be put into actions for not producing waste.

The background of the waste recovered is based on:

- The increment of global GDP, resulting in higher consumption and greater demand for food.
- The increase in demand for fossil fuels, primary resources, expanding the use of elements from the periodic chain.
- The increase in emissions of greenhouse gases.
- Landfills contribute significantly: they represent 8 to 12% of the entropic emissions.
- The emissions (liquid and gaseous) in the landfills are active during 30 to 50 years.
- The increase on the price of secondary resources, as well as in the price of energy and the demand for compost, are also motivations for waste recovery.
- Directly connected with Brazil, we have also the dependence of our energy matrix on climate change.
- The compulsory application of technologies promoted by legal frameworks result in the rationalization of costs.

To change traditional practices, we need to open a multidisciplinary discussion, integrate the multiple market segments to enable the design of those for the implementation of sustainable management of municipal solid waste (MSW). The discussions range from technologies in the form of fermentation, composting, recycling, energy recovery, to the supply of information, advise on the introduction of a sustainable waste management and also engineering and scientific content, as well as relevant aspects for implementation of projects, such as financing, environmental licensing, monitoring and other aspects of the market.

2 Brazilian Waste Management

2.1 General Information

The quantity of solid waste generated in Brazil was over 380 kg per person per year. From the more than 5,565 cities in Brazil, almost 60% have initiatives of selective collection, but only 16% of the cities have the service implemented. Although the selective collection started in the 80s, no more than 2% of the waste is recovered.

The very high proportion of the organic fraction is typical for emerging market economies, and the consequence is very low calorific values. The biotechnologies play an important role as a solution to minimize environmental impact.

Table 1 Waste Characterization (1)

Organic fraction	51,4 %
Paper, carton, tetrapak	13,1 %
Plastics	13,5 %
Metals	2,9 %
Glass	2,4 %
Others	16,7 %

(1) IPEA 2012

The quantity of solid waste generated in Brazil in 2013 totalized 76 million tons, 4.1% more than the previous year, where from the total collected waste, higher than the 3,7% of population growth rate. The 42 % of the generated waste ended up in inadequate places, such as wide dumps.

The urban cleaning services had turn over of 8 billion euro in 2013, meaning 38,00 euro /person/y, representing only 20 % of the international costs and mostly of these expenses are supported directly by the municipal budget, where 40% of them are covered by some type of waste fee, instead based on generation is based on square occupied area. According to a study of the IBAM and SEDU/PR, in many municipalities urban cleaning can consume up to 15% of the municipal budget.

Table 2 Waste Market Panorama 2013

Waste generation in Brazil (2)	Ca. 76 million tons per year
Waste generation per capita (2)	380 Kg/inhab./year
MSW collection service (2)	90,4 %
Selective collection INIATIVE (2)	62,0 %
Final disposal in sanitary landfill (2)	58,26 %
Jobs private operators (2)	332.000
Jobs informal sector (MNCR 2011)	800.000
Number of cooperatives (IBGE 2010)	1175
Cost for the urban cleaning services (2)	38,38 euro/person/year

ABRELPE 2013

2.2 Secondary Resources

2.2.1 Compost

Actually, public policies at all federal instances promote the application of compost through the rule of reduction at least 30% of organic waste at the landfill during the next 4 years.

In 2008, there were 211 composting plants installed in 3,8 % of the Brazilian cities, meaning that around 5% of urban organic solid waste was composted. The organic compost has a selling price from €30 to €50 per ton. Actually, several projects are contracted by municipalities to process from 50 to 350 tons per day of municipal solid waste through mechanical and biological plants using composting technology or fermentation combined with composting. Actually is commercialized per year 20 million tons of fertilizer and from that 8 % is organic.

The tendency is increase the composting implementation, in spite of the difficulties inherent in the process such as: absence of selective collection and separation at source, lack of qualified personnel for the installation and maintenance of composting plant in large scale, lack of investment and technology suitable for collection and compost process. In addition, the compost market has to be developed because the vast majority of projects carried out in the past were not successful and the product obtained was of low quality and very contaminated with inert, which ended up creating a lot of resistance to the compost purchase by Brazilians rural producers.

2.2.2 Refused Derived Fuel (RDF)

The interlinking of the market demands for energy as a result of serious energy crisis that we are experiencing caused by fall of oil value in the international market combines with the very low level in the reservoir in the Southeastern region, without greater expectations of rehabilitation in short-term, makes the focus is directed to the search for alternative sources of energy. The thermoeletric energy is being commercialized under the value of 250,00 euro per MWh demonstrating the potential market for sustainable energies.

It is understood that the generation of RDF is part of the strategy of the cement market in Brazil, which wants to modify its common energy matrix from 15 to 30% to RDF, as an energy source within the next five years.

The RDF expected price goes from zero to €15 - 20 per ton, it is growing and moving the market to the waste recovery. Through the MBT plants is possible to rescue 50 % of the waste as RDF.

2.2.3 Biogas

The generation of biogas from the landfills and fermentation plants has been promoted extensively by the federal government since 2012, including the opening of research channels that have already landed €100 million in research at 17 projects.

There are already 5 projects contracted for the implementing of dry fermentation in large scale. In accordance with the ABRELPE survey, Brazil currently has 22 projects that provide recovery of energy from landfill biogas, which is equivalent to an installed capacity of 254 MW.

2.2.4 Recyclables

There are over 2,000 companies operating the recycling sector, where most act on informality, as deposit and the organization of scavengers.

Regarding the organization of scavengers, they are actively engaged in the formal sector through, IBGE 2008, 1175 cooperatives representing almost 130,000 persons, but more than 400.000 people is active informally (IPEA 2013), through the collection and sorting of waste.

As a comparison, the normal urban cleaning services hire over 330,000 people. It means that there are in total over 1.5 million people working in waste management in Brazil.

The average sales price for the recyclable material is € 200 per ton of mixed materials.

3 Waste Policy Repercussion

Evaluating extremely criticizes the repercussion of the national policy of solid waste due that has determined a time limit of 4 years for the municipalities to improve their waste management systems to fulfill the new prerogatives, we observed sensitive change but of extreme importance for the market.

During the first 2 years of publication of the legal standard, a series of contracts in PPP modalities were signed contemplating technologies extremely complex as incineration until fermentation plants and other techniques such as sorting of recyclable materials and extensive systems for composting. However, in arising-of economic analyzes compromised and even in energy prices lower than expected, it was identified a change in the profile of acquisition of the market where were given priority for techniques more simplistic such as the recycling of materials.

Currently, we have a new market orientation where is evidenced the implementing of mechanical-biological treatment plants having as emphasis on production of RDF to supply the new demands of the cement industry. In this scenario, we have a sector based on quest for operational excellence dictating the new rules for an industry accustomed to practices of low complexity such as collection and landfill. This partnership represents a change of paradigm, not only to introduce a new feature to the secondary market of waste but basically by ensuring the professionalism of a market accustomed to high profitability in the short term but which are no longer resonance when there are legal requirements for waste recovery. Even trespassing these discussions, we have the participation of peripherals actors such as public prosecutor, financing banks, environmental agencies and the community, pressing the market to offer its services in accordance with the assumptions of the law.

In general, it is observed that the law published in 2010 has already led to a series of changes in the sector that created a positive agenda for encouraging waste sector to look for capacity building for promoting waste valorization and social inclusion but also to look for the waste recovery as a new business.

4 Conclusion

Much has already been done; however, there is still much to be done for the strengthening of the waste recovery. It is necessary, among other initiatives, create incentives in the form of taxes subsidies and financial lines to ensure access to machinery and equipment, create and support campaigns to encourage the use of secondary resources and to promote capacity building with focus of this new market.

It is necessary to find an effective solution to the great challenge of the moment: ensure a management and a suitable destination to materials discarded by society. The solutions are already widely known, being the main: the elimination of "wild dumps"; the implementation of waste recovery plants and sanitary landfills for their rest; the realization of systems of selective collection and establishment of systems of reverse logistics based on producers' responsibility. Several social groups already established parameters, and follow the way to enable the equation of various situations and the interaction of the main people involved, public or private, for the solution of problems caused by solid waste. The Brazil, in spite of having one of the more advanced law on the theme, still lacks an institutional development and prioritization of this issue, through the commitment of the society, which did not understand the risks of their omission.

5 Literature

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Finep and its role in Urban Solid Waste Management in Brazil

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Abstract

Providing good solid waste management (SWM) services continues to be a major challenge in most developing countries. In Brazil, due to lack of organisation and/or financial resources, activities such as collection, transportation, processing, treatment and disposal, which were at the responsibility of municipalities, are being outsourced to private companies, in an attempt to soothe public budget constraints and enhance the quality of the services. However, given the low economic feasibility of the current technologies in Brazil, the country remains a long way from ensuring sustainability in this sector. In this context, the Brazilian Innovation Agency (Finep) has sought to assist companies in promoting innovation in SWM, either by backing low-interest loans or granting economic subvention for the acquisition of goods, services and labour. The results, though still modest, are encouraging.

Keywords

Waste-to-energy · Solid Waste Management · Innovation · Sustainability

1 Introduction

The proper handling of solid waste is one of the main challenges facing large urban centres in the beginning of this new millennium. The problem is even more critical in developing countries, where relevant deficits in the financial and administrative capacity of municipalities are clearly present (EPA, 2010). This adds itself to the lack of observance, on the part of the industrial sector, of the legal framework currently in force, corroborating with the inadequate disposal of solid waste and causing several social and environmental impacts. In Brazil, for example, despite the development of a more restrictive legislation and the efforts expended in all spheres of the government, the inadequate disposal of Urban Solid Waste (USW) is still present in all States of the country. According to the Brazilian Association of Urban Cleansing and Waste Management (ABRELPE), by 2013, around 40% of all Brazilian municipalities were still dumping waste in inappropriate places (ABRELPE, 2013).

In recent years, several initiatives have directed the actions of governments with regard to the management of urban sanitation services and the final destination of solid waste in medium and large-sized cities. In Brazil, particularly, an increase in the privatisation of formerly public services is clearly observed. Another noteworthy initiative, according to SCHNEIDER ET AL. (2013), are the so-called consortium solutions, where municipalities with areas better suited for the installation of operational units sign a cooperation agreement with their neighbours to receive their waste. Certain advantages for the host municipalities can be negotiated in this process, such as the exemption from the cost of leakage or some urban compensation.

As a result, significant improvements have been achieved in household waste collection in Brazil, mainly due to the outsourcing of activities and the development of inter-municipal solutions. According to the National Survey on Basic Sanitation (PNSB), the coverage of waste collection services in urban areas has increased from 79 percent in 2000 to about 97.8 percent in 2008 (IBGE, 2010). On the other hand, issues related to the final destination of solid waste in Brazil remain a long way from fulfilment. For instance, even though the final disposal of USWs in landfills has increased over the last few years, as depicted in Table 1, around half of the 5,564 Brazilian municipalities in 2008 still used dumps (IBGE, 2010).

Table 1 Final destination of solid waste in Brazil – 1989/2008

Year	Open air dump	Controlled Landfill	Sanitary Landfill
1989	88.2%	9.6%	1.1%
2000	72.3%	22.3%	17.3%
2008	50.8%	22.5%	27.7%

Source: Adapted from IBGE (2010, p. 60).

Another problem that must be dealt with is the fact that landfills in large cities are on their way to becoming saturated and cannot be expanded as before. Not only has the high degree of urbanisation increased waste production but it also has significantly reduced the quantity of areas of adequate size and characteristics for the implementation of new sanitary landfills.

In view of this, some municipalities have sought alternative solutions to the destination of waste, considered today the main bottleneck in the management process of solid waste in Brazil. In this context, the concept of the so-called Waste Treatment Centres (WTCs) has gained relevance. The WTCs comprise a set of integrated technologies, such as sanitary and industrial landfills, sorting centres, biological processing units, composting sites, energy recovery plants, among others, and aim to promote the treatment of several types of waste, avoiding pollution and minimising social and environmental impacts.

According to the Union of Urban Sanitation Companies of the State of São Paulo (SELUR) and the Brazilian Solid Waste and Public Sanitation Association (ABLP), the WTCs today consist in the safest, most modern and efficient solution for the treatment of solid waste from households and large producers (PwC, 2011). In practice, however, this initiative is hampered by the lack of maturity of the waste management chain, which does not yet have national reference centres available for the development of the new technological concepts and to aid in the definition of the most adequate technologies for each type of waste. Not only does this constitute a technical obstacle to the implementation of projects, but also generates a lack of confidence in decision-making on the part of the agents involved. In addition, the transfer of technology must be accompanied by intentional implementation efforts (transfer of skills, adaptation to the Brazilian climatic conditions and waste characteristics etc), which, in turn, require major investments.

In light of the above, and since SWM projects may well be inadequate on account of environmental requirements or have questionable economic outcomes, the role of public financing is of utmost importance to support the development of this sector and reduce investment risks. In this regard, the Brazilian Innovation Agency (Finep), a publicly owned company subordinated to the Brazilian Ministry of Science, Technology and Innovation (MCTI), has played an important role. Since 2012, when a specific nucleus was created within the Energy and Green Technologies Department (DENE), the portfolio of projects related to solid waste management has grown significantly, having closed the year 2014 with over R$ 555 million. The preeminence of this sector has also become evident with the publication of a specific public bid related to green technologies: “Inova Sustentabilidade”.

In the context of the above-mentioned situation, and taking into consideration the strong socio-environmental appeal of developing a sustainable waste chain in the country, this study aims to map and revise the innovative approaches of this sector in Brazil and to highlight the role of Finep in their continued development and implementation. It also suggests guidelines for future actions in SWM in Brazil. Besides this section, where we stated the main reasons and objectives of this work, the remainder of this article is organised as follows: Section 2 reviews the most relevant innovative initiatives in Brazil to the present day; Section 3 shows the advances achieved in the SWM sector since the last National Survey on Basic Sanitation (PNSB), dated 2008, and what is expected in terms of groundbreaking technologies in the following years; and Section 4 summarises the results with the aim of offering conclusions and proposals for future researches.

2 Technological Routes

According to the National Information System on Solid Waste (SINIR), for the greater part of the last decade, a large portion of the public policies for solid waste management was focused on the universalisation of garbage collection, neglecting the biggest bottleneck of SWM, which is the final disposal of the waste. The results could not have been any different: according to the last PNSB, one in every three Brazilian municipalities suffered floods between 2004 and 2008, and the main cause pinpointed was the inadequate disposal of waste in streets, avenues, lakes, rivers and streams (IBGE, 2010).

With the development of the legal framework of the solid waste sector, namely the National Basic Sanitation Policy – instituted in Law no. 11,445/2007 – and, mainly, the National Policy on Waste Management (PNRS) – instituted in Law no. 12,305/2010, and later regulated by Decree no. 7,404/2010 –, there has been significant changes. The current initiatives in the Brazilian solid waste sector, which aims at breaking the functional paradigm of previous decades, now focus on techniques for waste treatment and recovery rather than waste collection.

This session, therefore, gives a brief overview of the treatment techniques currently available in Brazil, highlighting (when possible) the participation of the Brazilian Innovation Agency (Finep) in the development of such technological routes.

2.1 Sanitary Landfills

Despite not being a method of treatment in strict terms, sanitary landfills play an important role in Brazil, since they are the most common practice for waste destination in the country (SINIR, 2012). Coupled with the large availability of space in the country, the dissemination of landfills in Brazil is mainly due to the fact that they are simple to implement and can handle a wide variety of waste streams, from household waste to Health Services Waste (RSS).

Another important issue is the attractiveness of the landfills from the economic viewpoint. According to a study conducted by the Getúlio Vargas Foundation (FGV) in 2008 at the request of the Brazilian Association of Solid Waste Treatment Companies (ABETRE), for a landfill that receives around 2,000 tons per day (a load equivalent to the waste production in Curitiba – capital of the State of Paraná –, in 2013), and an estimated revenue of R$ 46.81/ton, an Internal Rate of Return (IRR) of 20.42% p.a. is estimated. The result is quite significant when compared to the Brazilian short-term rate (SELIC) at the time (on average 12.5% p. a.) (FGV, 2008).

Despite the aforementioned advantages, the National Policy on Waste Management (PNRS) discloses a prospect of decline in the use of sanitary landfills since, according to the new legislation, they should only receive waste that cannot be treated/recovered using other treatment techniques, as per article 3, item XV, in law 12,305/2010. This is mainly attributed to the purpose of landfills, which is the final destination of the waste when there is no space for further treatment. It is also worth highlighting that the implementation of landfills requires large tracts of land and can incur significant environmental impacts, such as contamination of groundwater and aquifers, slippages of slopes and explosions due to the accumulation of methane.

2.2 Composting

PEREIRA (2014) considers versatility as one of the main advantages of composting. Since composting techniques may vary from simple processes in open spaces and with little machinery, to highly automated plants in confined areas, this technological route has found widespread application in Brazil, regardless of the climatic conditions or the gravimetric characteristics of the waste.

In addition, it can be argued that the organic composts that result from composting techniques are more difficult to be carried away by rainwater, since the presence of organo-minerals permits better fixation in the soil. The Public Prosecutor’s Office of the State of Paraná (MPPR, 2013) also highlights other advantages in the use of this fertiliser, such as lesser temperature variation of the soil and controlling effects on a number of plant diseases and pests.

On the other hand, it is worth mentioning the possibility of odours emissions, which is especially harmful when the system is located next to populated areas. The large area demanded by this technology also constitutes an important restriction, in the case of extensive systems. Finally, the difficulty to decompose certain materials, such as leather, rubber and wood, and the low-applicability when the input material is of mixed origin are also seen as major drawbacks of this method.

Although the technology itself is of easy implementation, there is ample space for Research and Development (R & D) with regard to new composting techniques and solutions for different climatic conditions and waste characteristics, aiming for higher efficiencies in waste treatment and recovery. By this token, Finep has supported a number of innovation projects related to composting techniques over recent years.

2.3 Anaerobic Fermentation

In brief terms, following CASSINI (2003), the anaerobic digestion/fermentation can be viewed as a complex biological stabilisation process, in which a consortium of different microorganisms, in the absence of molecular oxygen, promotes the transformation of complex organic composts into simpler products such as methane and carbon gas.

The main advantages offered by the anaerobic processes, according to FRICKE ET AL. (2007) are: lower carbon dioxide emissions; efficient use of the energy stored in the waste; and the lengthening of the lifetime of landfills, due to the reduction in the volume of waste products requiring disposal.

DE CAMPOS (2013), in turn, underscores that the main disadvantage of anaerobic fermenters is their reduced flexibility with respect to heavy materials, requiring periodical maintenance and cleaning of certain elements.

It is worth noting that there are two methods of anaerobic digestion (wet fermentation and dry fermentation) and both routes have already been extensively funded by Finep. Nevertheless, in line with the national trend observed in recent years, the number of projects involving dry fermentation processes has increased substantially. In addition, despite the apparent scope for benefits concerning discontinuous operations (batch process), continuous solutions remain more popular in Brazil than batch digesters. This is expected to change in the near future, since the latter are not only easy to design, but are also relatively low in cost (compared to continuous fermenters) and suitable for almost all organic wastes (fraction size up to 80 mm).

2.4 Mechanical Biological Treatment

According to FRICKE ET AL. (2007), the Mechanical Biological Treatment (MBT) has gained considerable importance in Europe since the second half of the 1990s. In Germany, for instance, this category is responsible for treating approximately 25% of the total waste of the country. There are several MBT techniques, comprising different arrangements of mechanical, physical and biological treatment stages. Yet, the main objectives are usually the same: the separation and pre-treatment of the different components of the waste and their subsequent reutilisation in place of new materials (energy or industrial input), treatment and disposal.

FRICKE ET AL. (2007) also mention some secondary objectives, such as: the separation of recyclable materials into ferrous and non-ferrous materials and the preparation for subsequent processing of raw materials, e.g. usage of Civil Construction Waste (CCWs) as aggregates for concrete and asphalt production, gravel, sand, flint and construction stones.

In Brazil, in spite of the low maturity of the MBT technologies, several initiatives have already been carried out. The Brazilian Innovation Agency, for instance, disposes of MBT projects in different regions of the country. In this regard, some of them have already gone beyond the initial development stage. The vast majority, however, have not yet been implemented on a large scale.

Another point that is worth emphasising is that, unlike how the technology is employed in Germany, MBT plants in Brazil are intended for all waste streams, i.e., they are also designed to treat organic fractions and dry materials that are generally treated using other technological routes in Germany.

The most daring projects not only involve large-scale industrial plants (with a treatment capacity exceeding 1250 tons per day) but also intend to establish research and education centres near the facilities, as in the case of Jundiaí (São Paulo).

2.5 Biogas recovery

The gas produced by landfills contributes considerably to the increase in greenhouse gas (GHG) emissions. According to the Brazilian Ministry of Environment (MMA), estimations of the global methane emissions produced by landfills vary between 20 and 70 Tg/year, while anthropogenic CH_4 emissions equals 360 Tg/year. This suggests that landfills can produce up to 20% of total methane emissions worldwide (MMA, 2013).

In the Brazilian case, according to the First National Inventory of Anthropic Greenhouse Gas Emissions, conducted by the Federal Government in 2005, the methane emissions from solid waste disposal sites in Brazil were estimated at 618 Gg in 1990, increasing to 677 Gg in 1994 (MCT, 2005).

Methane gas produced by landfills once collected can be used as an energy source, for instance. Generally speaking, 1.0 m^3 of biogas, with a concentration of 60% methane, has an energy content of 6.0 kWh, or 0.6 L of Fuel Oil. In addition, the collection of biogas contributes to the safety of landfills, inasmuch as it reduces the risk of explosions or fire.

In Brazil, three main sources of biogas are accounted for: landfills, sewage treatment plants and agro-industrial residues. As for Finep, the biogas portfolio, which comprises a total of R$ 170 million in projects already effectively contracted and a little over R$ 160 million resulting from projects in the final stages of contracting, mainly consists of projects related to biogas recovery from agro-industrial residues. Common examples of this specific kind of waste are: vinasse, sugarcane bagasse, poultry manure and animal carcasses. Finally, the major end-uses of biogas in these projects are: electric power generation in traditional Otto cycle engines or combined cycle systems; compressed natural gas for vehicles; and organo-mineral fertilisers.

2.6 Thermochemical routes

According to SCHAEFFER (2014), the term thermochemical conversion describes the conversion of energy which has been chemically stored through the influence of heat.

Three main routes are summarised under this term: combustion, gasification and pyrolysis. The difference between them resides mainly in the availability of oxygen for each process. In combustion, also referred to as incineration, the amount of oxygen is sufficient to promote the complete oxidation of the fuel, while the gasification comprises partial oxidation of fuel(s) and endothermic gasification of solid carbon. Pyrolysis, in turn, occurs in the absence of oxygen.

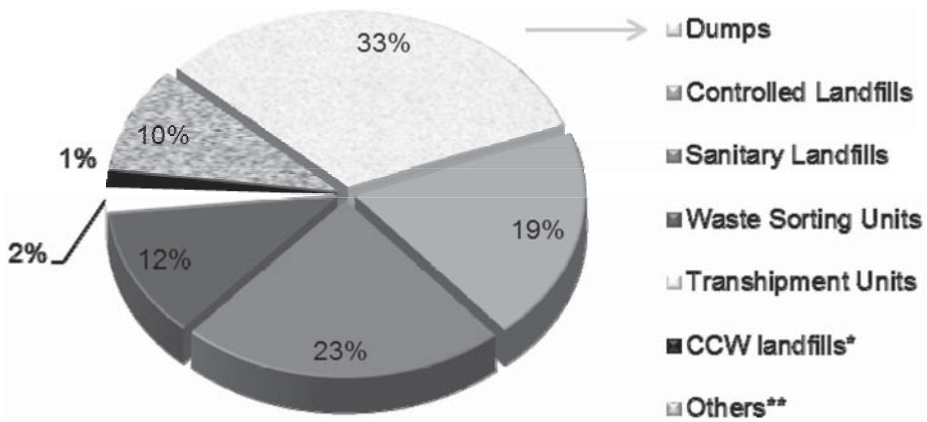
The products generated in the thermochemical conversion processes are also different. In combustion, the main product consists of an exhaust gas, which does not have any usable heat value. All the energy stored in the fuel is transformed into heat. Hence, only the heat contained in the exhaust gas can be used for the generation of electrical energy. As for the gasification, the fuel is transformed into a synthesis gas (known as syngas), a fuel gas that can be used for the production of liquid fuels – such as diesel, gasoline and hydrogen – or other chemical products such as high quality lubricant oils. The energy content of this gas, however, is inferior to that of the original fuel, due to the losses in the partial oxidation process.

The pyrolysis is akin to the gasification in the sense that the fuel is not completely oxidized. However, the former comprises different stages. The first stage comprises the grinding of the waste that should be previously selected. Then, the waste is sent to the pyrolytic reactor where the separation of the by-products occurs. According to SCHAEFFER (2014), the quantitative division of these fractions (solid, liquid and gaseous) depends on the temperature conditions and the retention time in which the pyrolysis occurs.

SCHAEFFER (2014) further argues that the gasification and pyrolysis technologies have not yet been fully established. This is mainly attributed to the cost of the investment and the high technological risk, which justifies the recent numbers in favour of combustion projects in Brazil. This situation, however, is expected to change in the near future, since the number of funding requests submitted to Finep containing gasification and pyrolysis projects has grown substantially over the years. The recent mobilization in favour of these technological routes is due, to a large degree, to the environmental appeal of reducing the emission of toxic substances, such as nitrogen oxides (NOX), dioxins and furans, which are typical by-products of the incineration, according to CONNETT (1998). Further, one may allege that the combustion needs a fairly homogenous material, with low humidity content and a considerably high calorific power to operate efficiently. Finally, it is important to mention that, in Brazil, for incineration plants with capacities over 40 tons/day, an Environmental Impact Assessment Study and an Environmental Impact Report (EIA/RIMA) are previously required, according to the CONAMA Resolution 1 of 1986.

3 Results and further steps

Recent years have witnessed unprecedented technological advances in alternatives for treatment and recovery of solid waste in Brazil. As depicted in Figure 1, waste processing units have gained prominence over the last few years, in comparison to the situation of 2008, when the last National Survey on Basic Sanitation (PNSB) took place. Furthermore, according to the National Secretariat of Environmental Sanitation (SNSA), the sharing of public and household waste processing units has become a common practice in the country (SNSA, 2014).



*Civil Construction Waste; ** Microwave or autoclave treatment units; Mass burning technologies; Industrial landfills; CCW recycling areas; Specific ditches for health services wastes; Composting units; Thinning and pruning services; and bulky waste processing facilities.

Figure 1 Composition of final urban solid waste disposal in Brazil as of 2012. Source: Adapted from SNSA (2014, p. 92).

It is indisputable to say that the major development in the Brazilian solid waste sector has been facilitated by the intensification of innovation. New, state-of-the-art technologies have been disseminated and national experts have gained mastery over many aspects, such as adaptation to different local environmental conditions and distinct waste gravimetric compositions. In this context, the Brazilian Innovation Agency (Finep) has played an important role. Apart from its noteworthy results in terms of innovation projects contracted in 2014 (as previously outlined in section 1), the company has demonstrated an unparalleled capacity to combine different financial instruments to increase public financing in the Brazilian solid waste sector. This became clearly evident when the agency coordinated, in 2013, the organisation of a specific public bid related to green technologies: “Inova Sustentabilidade”.

The bid, which originated from a joint effort between Finep, the Ministry of Science, Technology and Innovation (MCTI), the Ministry of Environment (MMA) and the Brazilian Development Bank (BNDES), proposed, among its key objectives, the promotion of Sustainable Production and Environmental Sanitation by means of innovative initiatives related to urban and industrial solid waste management.

The results of the "Inova Sustentabilidade" went far beyond expectations: the programme, which was originally intended to fund a total of R$ 2 billion in innovation projects, had an initial demand of over R$ 7.6 million. Upon completion of the qualifying phase, the programme had close to R$ 4.3 billion, distributed among 167 Business Plans (FINEP, 2014a). It is worth noting that, besides offering loans at subsidised interest rates and funding up to 90% of total project costs in some cases, the public bid also proposed the adoption of non-refundable instruments. These latter comprised economic grants for the acquisition of goods, services and labour, and financial assistance for cooperation agreements between Scientific and Technological Institutions and enterprises.

With respect to the solid waste sector in Brazil, it is worth stressing that, under the "Inova Sustentabilidade" framework, SWM projects accounted for a large portion of the total accepted for funding. For instance, the thematic line "Sustainable Production", which encompassed the majority of proposals (around 56% in value), covered two major sub-themes: Energy Efficiency in the Industrial Sector and Industrial Solid Waste. The second largest demand, in turn, came from the Environmental Sanitation thematic line (35% of the total accepted for funding), and most of its projects were related to the subtheme Urban Solid Waste. In addition, the programme's socio-environmental indicators strongly suggest that the companies have been focused on the reduction and adequate disposal of waste. According to the manager of Finep's Technology Department for Urban and Regional Development (DURB), Carlos Sartor, among the most representative indicators, six of them are closely related to waste reduction initiatives and another four to proper solid waste management (FINEP, 2014b).

In line with the global trend, solid waste management is now considered as a priority issue in the Brazilian public agenda. It is worth highlighting once again that the preeminence of this sector is mainly attributed to role of public financing in facilitating the transfer of technology and minimising the associated risks. Even so, there is still a long way to go. In this context, from the viewpoint of the agency's analysts, some alternatives rank as the most promising technological routes in the near future, such as drying, landfill mining and catalytic polymerization. To conserve space, these alternatives are not commented in this work. For further details on such technological routes, the interested reader is referred to OLIVEIRA AND FRADE (2015).

4 Conclusions

Since the enactment of Federal Law n. 12.305/2010, which set forth the National Policy on Waste Management (PNRS), the solid waste sector in Brazil has experienced substantial changes. By introducing concepts related to waste treatment and recovery and setting reasonable deadlines and penalties for enterprises to comply with Community Management Plans, the legal framework forced the waste industry to overcome inertia and seek efficient and effective solutions to solid waste management. The strategy seems to be working: over the years, the discussions concerning waste management in Brazil have shifted from conventional methods of waste disposal, such as open air dumps and landfills, to the development of large-scale Waste Treatment Centrals (WTCs).

In spite of the above-mentioned situation, much is left to be done. The demands of the Brazilian waste sector are yet to be fulfilled and the quest for innovative technologies and management systems that comply with the PNRS guidelines still goes on. In this context, the Brazilian innovation agency (Finep), assumes a strategic role. By backing low-interest loans and providing non-refundable grants or financial assistance for cooperation agreements with universities and other research institutes, the agency aims at sharing with the companies the costs and risks inherent to innovation activities. The results so far have been fairly positive: apart from the significant growth in projects related to solid waste management – over half a million in less than two years –, the company has demonstrated an unparalleled mastery of coordinating specific public bids/joint action plans related to energy and green technologies, such as "Inova Energia", "PAISS Agrícola" and “Inova Sustentabilidade”.

The main challenges for the next years lie in making several technological routes for waste treatment and recovery economically feasible in Brazil and in developing a highly qualified staff, capable of making rational decisions regarding the best treatment/disposal solutions for each facility’s needs and each waste stream. To that end, the participation of public funding agencies is of the utmost importance.

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MBT in Brazil – a solution for the current challenges

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Abstract

Brazil demonstrates advances in waste management, especially after the publication of the National Solid Waste Policy (NSWP), Law number 12.305, which requires a waste plan for each municipality, encouraging recycling and composting of waste. Still, the problem persists because of the lack of selective collection, lack of incentives to recyclers and collectors programs, as well as neglect of governments and the citizens. The likelihood of improvement is great, but will require much time and investment. The mechanical and biological treatment is then presented as a solution to meeting the goals in the treatment of waste in the short term. This work aims to analyze this technology and its application in the municipality of Rio de Janeiro, evaluating their advantages, disadvantages and limitations to this process.

Key words

MBT; MBT in Brazil; Mechanical and Biological Treatment; waste; waste management; recycling; waste to energy; waste to resource; urban waste.

1 Brazilian Scenario

The progress of humanity and the encouragement of increased consumerism have generated the supply and mass consumption products. A greater extent, so does the production of waste in the world, together with the scarcity of non-renewable resources in the long term, climate change, have diverted attention to environmentally sustainable practices involving waste management.

Brazil, the 6th largest GHG generator as country report Released COP17 (UNEP, 2011 cited PNRS, 2010), yet is in a more technical phase and less practical than the EU, but has important advances. His uncontrolled growth, social inequalities, great territorial dimensions, low education index and involvement of public management with environmental issues are their main challenges to pursue a management of municipal solid waste with better results.

According to the Brazilian Panorama waste (ABRELPE, 2012), we generate 76,387,200 tons of municipal solid waste (MSW) in 2013, representing an increase of 4.1% compared to the same indicator of 2012. This index is higher the population growth rate in the country in the period, which grew by 3.7%.

Still according to ABRELPE (2013), Brazil has 41% of its waste for landfills or controlled landfills, 58% landfill and a small portion to other types of treatment, then prioritizing the disposal compared to the other forms as the NSWP. For selective collection, only 3% of the collected dry waste is recovered from long process, compared to a target of 5%, effective for 2013.

Due to the large dimensions and poor income distribution, presents gravimetric index average waste in proportion to the poor countries, but in the big cities, the gravity is equivalent to the average of the rich, as shown by reports from the World Bank (2012), Bracelpla (2013) and CETESB (2013).

Social development is also an important point, since in countries like Brazil recycling is an activity that generates resources for social classes with lower purchasing power. In addition to operating in the production of consumer goods from waste, much of the recyclable materials back to the market due to the work of sorters, people with very low income, who are in this profession a form of survival.

Acoording to CEMPRE (2013), only 766 municipalities (14%) offer the selective collection service. This number represents 27 million people, 12% of the population. It´s also important to comment that 62% of these cities, cooperatives of garbage collectors are part of selective collection, 26% of cities the private companies and 52% of these only the city is responsible for the selective collection.

In 2010, entered into force on National Solid Waste Policy (NSWP), introduced by Law 12,305, establishing strategies and deadlines for the Brazilian sustainable development, reviews the hierarchy of priorities in waste treatment and imposes the reverse logistics system, and to treat the life-cycle of products and encourage the reuse, recycling of materials and composting of waste, eliminating the dumps and leaving foster landfilling, getting to this, only waste without a more favorable allocation to the environment and the economy of resources.

In addition to the above points, involves the scavengers organized in cooperatives and considers the selective collection as an instrument of policy.

This Policy has generated goals for waste management across the country, through the National Plan for Solid Waste, your principal document for the regulatory goals.

Among the principal goals, are those mentioned below:

- Elimination of dumps and controlled landfills by 2014;
- Keep the current municipal solid waste generation levels, taking as a reference the year 2008 (equivalent to an average rate of 1.1 kg / capita / day) with subsequent reduction;
- Reduction of 70% of dry recyclable waste disposed in landfills, based on national characteristics in 2012;
- Inclusion and empowerment the organization of 600,000 collectors of reusable and recyclable materials;
- Induce composting of the organic portion of MSW and power generation through the use of gases from the digestion of organic compost and gases generated in landfills (biogas);
- The development of solid waste plans is a condition for states (from 2012), the Federal District and the municipalities (from 2014) have access to the Union's resources or controlled by it, and so to benefit by incentives or financing of federal credit agencies.

After 4 years of its publication, presents developments mainly in the capitals of South and Southeast, but still many areas for improvement, especially in those factors, as shown in the following Table 1.

Table 1: Brazilian actual stage of NSWP

NSWP point	Actual stage	Observations
Eradication of dumps	17.4% of the volume generated for the dumps (Abrelpe, 2013).	Low level of commitment of Public Power in smaller cities.
Waste disposal, as the hierarchy in NSWP.	82.6% of the volume generated for the landfill and controlled landfills (Abrelpe, 2013)	Dry percentage of the allocation of the MSW based on selective collection. Low level of commitment of the government to encourage technologies for the treatment of organic percentage.
Selective Collection	Only 1.6% of the dry percentage is obtained from selective collection programs. The volume is 4% of the total volume of all recycled in the country..	Low coverage of selective collection; Low level of commitment of society and the Government; High logistic costs and investments involved.

Even with the National Solid Waste Policy in force, compliance with established goals will require a long time because it involves a drastic change of culture and needs of the population mainly of direct support of the government, generating greater involvement of technical manpower, allocation of significant grant, need for partnership between municipalities and continuity in projects, critical points of the Brazilian Public Management.

2 MBT Analysis

Thus, the MBT in the treatment of MSW presents itself as an important solution for obtaining short-term results, presented mainly solving the weaknesses in the process of selective collection and the disposal of organic waste (JUNIPER, 2005).

Even with high start-up investment for the plant installation, the MT is presented as technically and economically feasible solution, since recyclable waste have a high market value, without even requiring the collection of waste disposal fees, frequently used in EU countries, but still no social viability for application in Brazil (NASCIMENTO, 2014).

For the purposes of BT, there is still need for development of current technologies and market for the purchase of the compound to the search for economic viability (NASCIMENTO, 2014), as the level of efficiency for methane generation in anaerobic digestion is less than the found in the landfills with biogas generation (Valnor, 2010).

Currently, Brazil has 2 TMB units installed in São Paulo used to treat waste generated from the selective collection and a plant in the concession process for the treatment of MSW in the city of Rio de Janeiro.

Given the scarcity of national experience in this subject, the methodology used for the study was based on extensive literature review, using books, scientific articles and internet.

To define the scenario of the city of Rio de Janeiro and analysis of case studies were also conducted expert interviews and field research in Screening and Plants in operation.

Juniper (2005), through a study covering 80 plants in the EU, responsible for processing waste 8 million / year, also lists the main advantages in the use of technology, such as better use of dry waste for recycling, the reduction the volume of waste to final destination and moisture and volume of the organic fraction, the use of the organic fraction into compost or energy and reducing gas forming potential (greenhouse gas and odors at the landfill).

However, Stephanie (2011) presents technical, economic and environmental challenges evaluated in 61 plants in Germany, which add up to a total capacity of 6.4 million tons / year: high level of equipment wear, number of stops in production and contamination in the ballistic separator, representing the difference between the actual and planned with respect to time for maintenance and cleaning, number of people and energy expenditure, and a high variation of biogas production due to the discontinuous input substrate.

Also according to Stephanie (2011), the cost of using this technology is similar to the incineration spent in the EU: 100 Euro per tonne. The cost factor is presented as the main downside of the technology, which needs to be evaluated in detail for each type of MBT plant installed, comparing the investment involved with revenues from the sale of recyclables, compost, biogas and RDF (Refuse Derived Fuel), also used for generating electricity.

The NSWP establishes a new hierarchy for the recovery of waste, starting with the non-generation, reduction, re-use, recycling and treatment, leaving the final destination as the last stage.

In addition, both the NSWP as the National Plan for Solid Waste (still in approval) set goals to meet in the short term, as the closing landfills by 2014, the reduction of organic and dry waste to landfills, development of selective collection and need the development of regional plans of solid waste as a condition for access to the resources of the Union, or controlled by it.

Both Brazil, state and the city of Rio de Janeiro, region focus of this study, are still far behind with regard to meet those goals.

For the city of Rio de Janeiro, using the methodology of LINDON et. al (2004) to present the SWOT analysis, results as following Table 2.

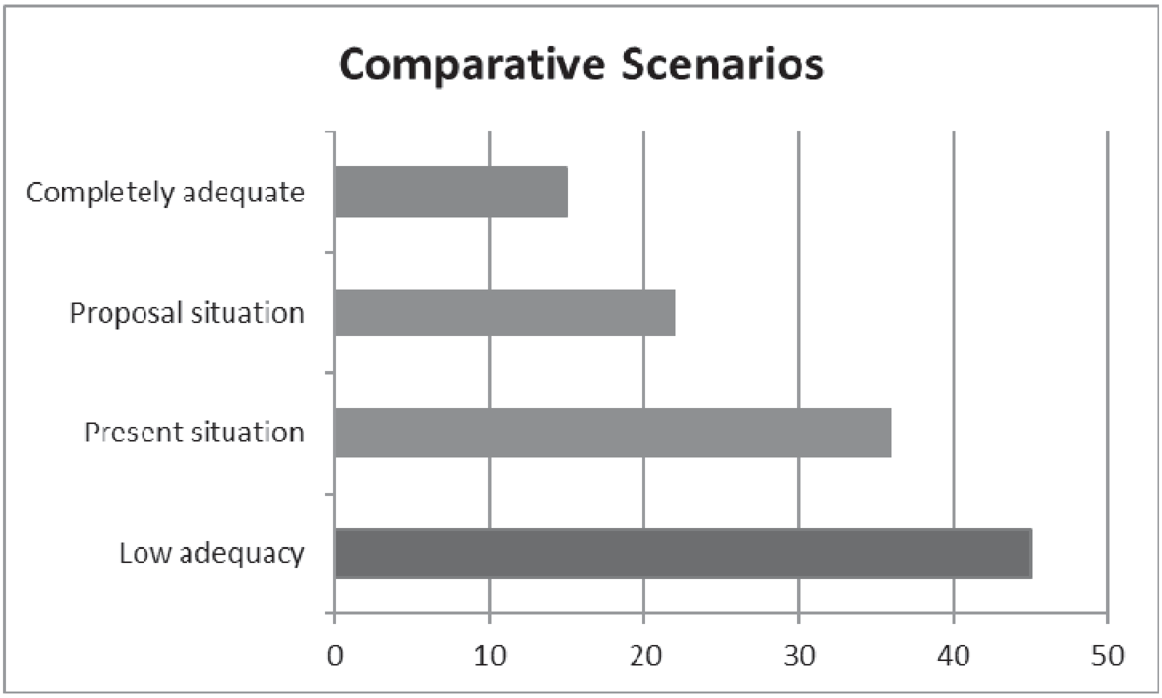
Table 2: SWOT analysis in the management of waste from the city of Rio de Janeiro

STREGHTS	WEAKNESS
Coverage of waste collection in all locations.	Recycling dependent on selective collection.
Ellliminations of dumps.	Low coverage of selective collection.
Biogas from landfills.	High logistic costs and investments involved for selective collection.
Published PMGIRSU/RJ and in progress..	Low level of knowledge of collectors.
Composed of marketing existence, although under.	Low level of responsability of collectors.
RDF of marketing existence, although under.	High volume of waste sent to landfills.
Visibility of the city compared to the other in Brazil.	Environmental impacts and representative costs involved to the large volume of waste sent to landfills.
	Not meet the waste disposal hierarchy as NSWP.
OPPORTUNITIES	**THREATS**
Increasing recycling market.	Lack of interaction between municipal managers.
New garbage sorting technologies with short-term return.	Lack of systemic view to the municipal managers.
Growing biogas and RDF market.	Public management without ongoing action between mandates.
Investment opportunities for new technologies.	Low level of involvement of the population.
Published NSWP and in progress.	High costs and investments involved in the implementation of
New market opportunities and jobs.	new technologies.
	High costs for the marketing of recycled materials.

Thus, the MBT is presented as an important solution for the city of Rio de Janeiro, with short-term results to mainly address the weaknesses in case of selective collection and the disposal of organic waste.

To analyze the application of this technology, to analyze the application of technology, we used the methodology used in NASCIMENTO (2014), comparing the current situation (90% of waste sent to landfill and 10% treated) with a proposed scenario (50% of the waste with the same treatment of the current scenario and 50% intended for UMBT), based on 15 critical success factors, resulting in the following Table 3.

The criteria for evaluation of each critical factor are defined as your fitness level environmental policies or according to the time required for the achievement of goals: Concept 1 - entirely appropriate environmental policies or service short-term goals; Concept 2 - partially suitable environmental policies or call the targets in the medium term; Concept 3 - low compliance to environmental policies or service long-term goals.



Graphical 1: Comparative Scenarios.

To obtain the final concept, the higher the total score will be the least appropriate scenario evaluated, according to the critical factors and hence the required environmental policies, as the Graphical 1.

Table 3 reports the results of the analysis of critical success factors for the comparative situations for waste management of Rio de Janeiro.

Table 3: Analysis of critical success factors for waste management of Rio de Janeiro, as NASCIMENTO (2014).

CRITICAL FACTORS	PRESENT SITUATION	PROPOSAL SITUATION	COMENTARIES
	Landfill + selective collection	MBT, Composting, FDR, AD	
Logistics costs	3	1	Number of vehicles 50% higher, at least to serve the same route in the selective collection and MSW; Need for screening units for shipment to final destination; More vehicles for sending waste to landfill.
Greenhouse Gas Emission	3	1	The increased flow of vehicles generates more greenhouse gases.
Technological investment	1	3	High investment in equipment for the MBT plant
Awareness on Investment	3	1	Continuous investment need for separating waste from the population
Volume sent to landfill	3	1	Increased waste sent to landfill, as only the Caju Plant has units for waste processing.
Cost of remediation of landfill post closure	2	1	With larger volumes sent to landfill, the treatment time after its completion will be higher.
Cost of manure treatment	3	1	By reducing the volume sent to the landfill, leachate production falls proportionally reducing its cost of treatment.
Duration of the landfill	1	3	With larger volumes sent to landfill, the length of time this will be higher. According to the quantities simulated this methodology, the length of time present 50% increase.
Biogas generation	2	1	Both the landfill as anaerobic digestion included in BMR plant can generate biogas, MBT plant being in smaller proportions.
Knowledge level required for operation	2	3	The MBT equipment requires more technical knowledge.
Political involvement level	3	1	Somente no início para o investimento em equipamentos.
Compliance with the recycling rate	3	1	The mechanical treatment unit can increase the volume of recyclable items in the short term. A material in the washing unit MBT plant can generate more items recovered for recycling.
Hierarchy of compliance for waste treatment	3	1	The MBT plant will forward the waste according to the hierarchy defined in Waste Brazilian Law.
Meeting this goal for involvement collectors	1	2	With lower level of mechanization, the separation of recyclable items originated selective collection requires the participation of a larger number of collectors.
Return to profitability of collectors	3	1	The larger volume of recyclables to market generates higher revenues. TM has greater productivity in obtaining recyclable materials.
TOTAL	**36**	**22**	

Thus, it is concluded that the use of a UMBT for the city will bring short-term results and meet the objectives of NSWP. To better understand the cost and consequent economic viability, it is necessary a more detailed analysis of costs and revenues in the process.

3 Literature

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Capacity Building and Fundamental Research to Develop and Implement a Mechanical Biological Treatment Facility with an Integrated Fermentation Stage in Jundiaí-SP, Brazil

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Abstract

Waste management has changed significantly in the last years, becoming an icon of sustainable development, contributing to environmental protection and guaranteeing the climate protection and the preservation of natural resources. In this context, Brazil passed a National Solid Waste Policy, which provides for selective collection and treatment of waste before final disposal in the whole country by 2014. The development of technology, technical consulting and state-of-the-art machinery are necessary to implement the Policy. In addition to implementing the new policy, sustainable waste management systems must be developed to mitigate the environmental impact generated over the last few decades in the country. This poses a considerable challenge due the limited expertise available to develop the necessary technology and to streamline them into the Brazilian market, which, in its turn, results in faltering decision-making at all public levels (federal, state and municipalities) as well as other relevant stakeholders, such as funding and environmental licensing agencies.

Keywords

Capacity building. Research. Cooperation. Residues. Mechanical and Biological Treatment.

1 Introduction

Waste management has changed brutally in recent years, becoming the icon of sustainable development, greatly contributing to environmental protection and, through recycling of waste also ensures better environmental conditions.

The differential impacts generated by urban solid waste justify the necessity of concrete interventions, possible only from the design of appropriate management programs. In this sense the use of technology, machinery and technical assistance is essential, both specialized and compatible with proper management, covering issues such as waste management, economic viability, environmental preservation, quality of maintenance of the public health, urban landscape and even generate employment and income.

It is in this context that the research project implemented in Jundiaí has the objective to generate results aimed at fostering multidisciplinary discussion integrating various market segments to enable the design of tools for the implementation of sustainable management of municipal solid waste.

The completion of the project also provided comprehensive global knowledge of this new market and also the construction of an interrelationship with the waste sector in Brazil - Germany framework , establishing an exchange with German institutions icons in practice ensuring climate protection and the preservation of natural resources, oportunizing this way a permanent exchange of experiences , through vocational and technological education .

2 Project

The proposed project establishes cooperation between the Municipality of Jundiaí , TU Braunschweig , PUC -RIO , CREED , GIZ , DAAD , CAPES and DBFZ for the development of an eco-efficient management of municipal solid waste , in order to generate the following results: training of technical staff from the Municipality, qualitative and quantitative analysis of large generators , planning and implementation of a scientific laboratory for analysis of substrates and products, characterization of household waste , definition of technological routes and promotion of pilot plants from the techniques of drying and composting, market mapping of consumer products, events promotion to disseminate the information produced and intensify international cooperation .

2.1 General Information

Located 60 km from the city of São Paulo , the city of Jundiaí has 431,969 square kilometers and 397,965 inhabitants (IBGE 2014) , and was ranked first place by the Exame magazine and the UN as the best city to live in , according to the quality of life and quality of the public services , a condition demonstrated by the following data :

- Water supply: 100 % urban area
- Sewage treatment : 100 % in urban and in rural areas;
- Waste: 95% of waste collection;
- Total annual budget for 2014: 500 million euro.
- Annual budget of the Secretary for Public Services: approximately 42 million euro, about 8.2 % of the total municipal budget. The department has 319 employees, of which: 251 with high school, 56 with higher education and 12 post- graduates. Outsourced public services are provided by 12 companies.
- 140,000 tons per year RSD , or 384 tons per day, or 0.96 kg / person / day

2.2 Challengers

During the implementation of the project we were faced with a number of challenges, namely:

- Lack of legal prerogatives
- Lack of community awareness and the private sector
- Need for protection of industrial property
- Bureaucratic Procedures tied to government practices
- None database
- Lack of interaction between actors
- Communication difficulties
- Individualization of practices

2.3 Developed Products

Products developed from the implementation of the project corroborated to generate an intelligent information network, facilitating access to the database for all involved, even identifying the demands of training and producing results that bolstered the city's decision-making as refers to the development of the environmental education program and definition of the technological route.

2.3.1 Information Multiplication

The actions and decisions taken under the project did not end in the municipality border and also served as a reference for other segments, being them public or private from the economy of solid waste.

In the events held various sectors of society participated, being it researchers and entrepreneurs or public managers, having been transferred functional knowledge to establish sustainable waste management systems, also integrating the fermentation and other waste recovery models. The technical events also served to build bilateral cooperation of knowledge for the successful implementation of projects. This also includes the development and adaptation of technologies for Brazilian conditions.

Table 1 Qualification Summary. Source: TU Braunschweig 2015

Events and professional qualification	Local	Date	Participants
1st. Technical Meeting Brazil Germany	UVA park-PMJ	dec /13	780
Workshop PUC-RJ	PUC-RJ	mar/14	18
Training planning	Situation room- PMI	mar/14	30
Workshop CIESP	CIESP Jundiai	apr/14	145
2nd. Technical Meeting Brazil Germany	Florianópolis	may/14	330
7th high-level technical meeting composting	CETESB-SP	aug/14	85
Capacity for characterization for Large Generators	Boardroom SMSP-PMJ	jun/14	30
RWM FAIR	São Paulo	sept/14	30
1st Connective dialogue cities of Latin America	Cuenca-Ecuador	nov/14	40
Gravimetric study of urban solid residue	Geresol-PMJ	april and oct/14	30
Environmental Cooperlínea visit Brazil	Paulínea	Nov/14	10
Technical leveling course in sustainable management MSW	DAE Jundiaí	nov/14	230
Technical visit logs	São Paulo	nov/14	15
TOTAL			1173

2.3.2 Technical cooperation

The Brazilian market is lacking in theoretical and practical information on a differentiated waste management. This fact is not due to lower market interest in the subject, but by our pioneering condition, with no examples of large- scale that give opportunity to the sharing of experiences. Based on this need, the proposed project aroused a lot of attention in the market resulting in the formation of strategic partnerships for the purpose not only of democratization of data but mainly for the development of joint projects that minimized the errors , optimizing the arrangements in favor of consistent projects. The partners found during the course of the project were: Municipality of Florianópolis, Municipality of Votuporanga, Municipality of Paulista, Municipality of Lueneburg, CIESP, KFW, FINEP and Senac - Jundiaí.

2.3.3 Waste generation evaluation at the industry and commerce sector

Through the questionnaires it was possible to characterize the scenario where the municipality of Jundiai fits, from the generation of municipal solid waste, but also related to large generators understanding on the allocation of various materials and the difficulties of managing systems, both public and private. The prepared questionnaire addressed the following aspects: project identification and general information, Legal Analysis, System of waste management in the company, external solid waste management, evaluation of services, and composition of waste.

Table 2

Large generators characterization	**Campaign 1**	
Realization period	5 months	May to September
Involved personnel	23	
Number of contacted institutions	232	
Number of effected institutions	224	1% of the sampled universe
Number of existing institutions	22726	Secretary of Economical Development, Science and Technology – basis 2013

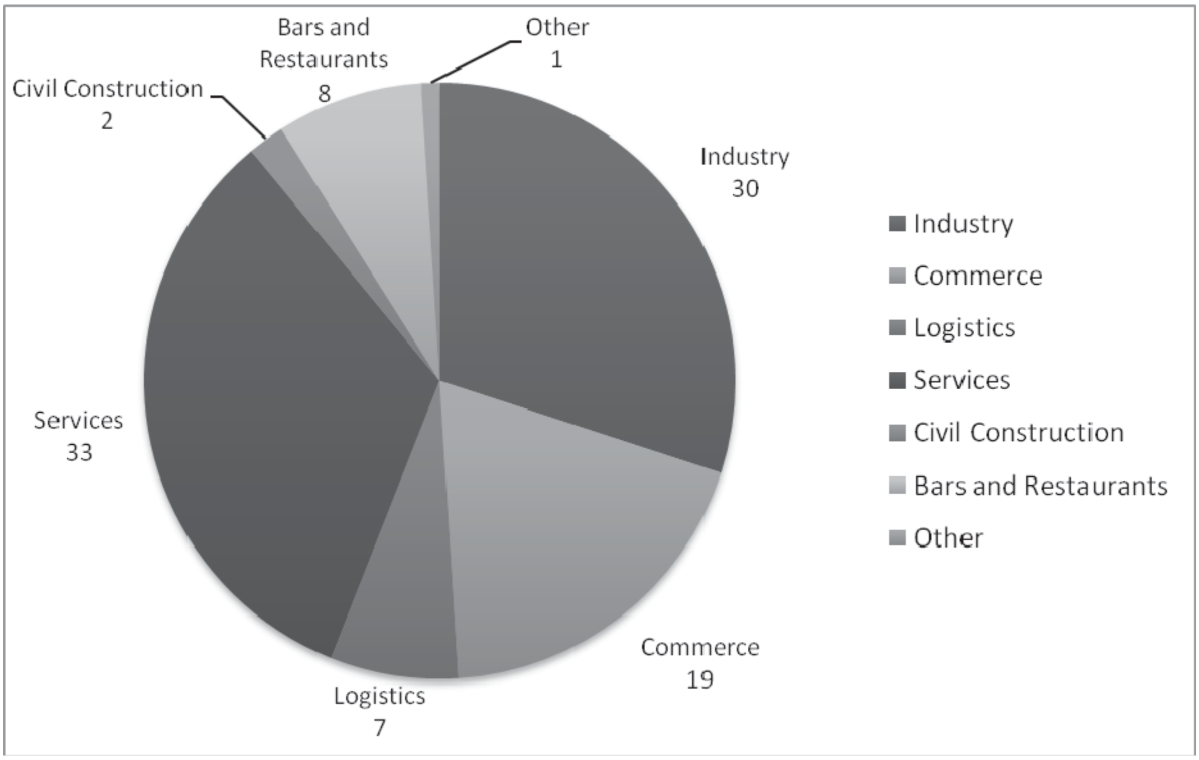

Figure 1

The completion of the environmental assessment in large generators brought up management issues where it was realized that in most shops, schools and service providers there was no control of the data regarding the disposal of waste, such as quantities , input and output values of materials, recycling and disposal .

Even in more instrumentalized corporate environment such as the industrial, it was found that the quantitative and qualitative control was not performed. Incidentally some employees showed to be insecure in answering the questionnaire because they are not well targeted and informed of data and activities of the own company, regarding to residues management, thereby undermining the questionnaire by interviewers.

Taking into account that industrial enterprise environments have greater rigidity management and thus a greater concern with the control of raw materials and waste, costs and images related to their brands, inexperience and ignorance of this information was appointed as a surprise factor during the questionnaire.

Therefore , in both cases , being it in the business environment and services or being it the industrial environment, the questionnaire proved to be a promoter of educational activities , increasing the perception on waste management and by-products both for the domestic public (respondent) and to external stakeholders (interviewer) , still disseminating updated information on municipal waste management, legal assumptions , suggestions for improvements of the management and integration between the public and private sectors.

Regarding reverse logistics, we have that the greatest difficulties encountered by the companies are related to electronics disposal, batteries and fluorescent lamps, those residues elected by National Solid Waste Policy (PNRS) as instruments of reverse logistics. Many companies showed to be unaware of how such waste is disposed of after allocation at the point of voluntary collection and collection by the contractors as well as on their responsibilities on their management in the form of shared responsibility. Some even said that they would adopt a qualified control through the certificate issued by the company responsible for the collection and disposal of waste.

In short , this adversity due to lack of knowledge and therefore of control mechanisms , was due to the lack of qualified service providers to collect and properly destination the material according to the guidelines imposed by the National Solid Waste Policy .

2.3.4 MSW characterization

The characterization of municipal solid waste is an important tool for the development of technological concepts of treatment plants, allowing to select the best technologies and adapt them to the existing material flow from the gravimetric, granulometric and analytics analysis, allowing not only sizing the equipment but also choosing the best techniques according to their employability potential in the operational flow and responsiveness of the consumer market of secondary resources.

Table 3

Waste characterization	campaign 01	campaign 02
Realization period	10 working days	30 working days
Persons involved	approx. 16	approx. 26
Sample routes	5 routes	15 routes
Total routes	25 routes	
Percentage of routes attended	80%	
Total quantity of sampled waste	818.3 kg	2653.05 kg
Quantity sampled daily	180 kg	
Percentage sampled from the truck	2%	
Population attended	54524	111200
Total population in 2014 (IBGE)	397965	
Percentage of attended population	42%	
Quantity of neighborhoods attended	63	141
Total quantity of neighborhoods of the Municipality	420	
Percentage of attended neighborhoods	49%	

Classes <80 mm contain lots of organic , representing 45% in the 40-80 mm class and up to 85% in the 20-40 mm class. In contrast, the upper sieved focus greater presence of plastic fractions. Thus, the class > 80mm contains more than 50% recycled material and in addition significant quantities of fractions textiles and other materials suitable for use as a RDF.

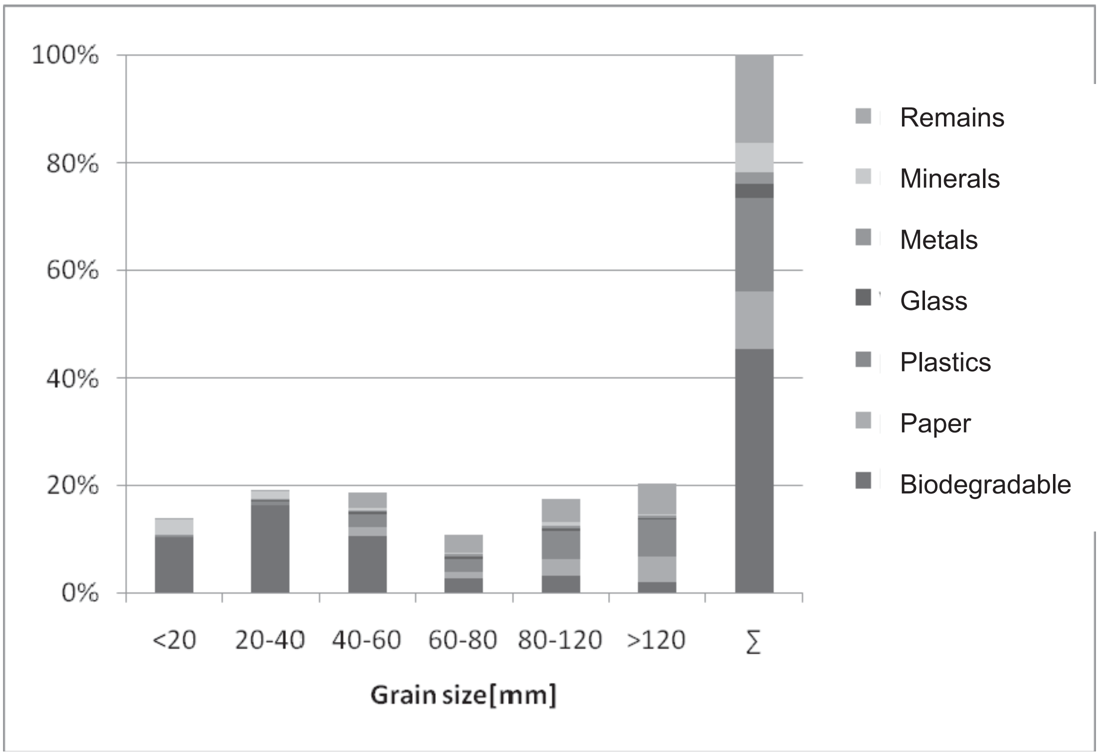

Figure 2

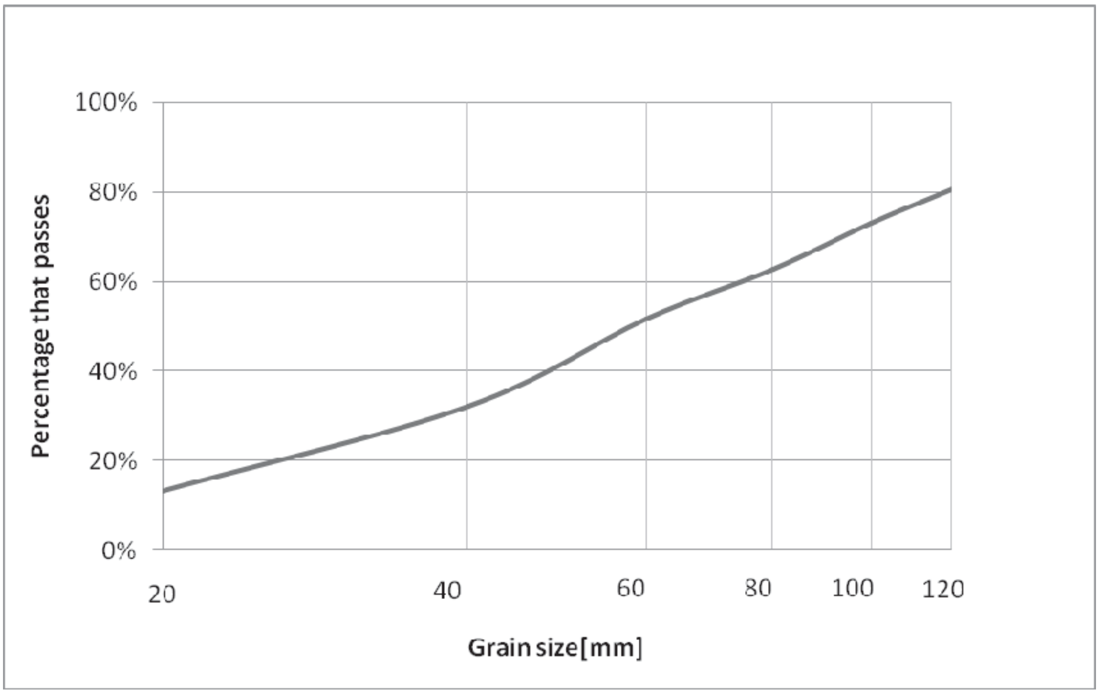

Figure 3

Biodegradable (composed by organic, toilet paper and green wood), represent only 45%. Even with the selective collection implemented in all districts of Jundiaí, MSW still contain high levels of recycled materials, with respectively 11% paper, 18% plastic, 3 % glass and 2% metals. Fractions identified as "residues" consist of textile, leather, diapers, among others, and represent 16% of the mass.

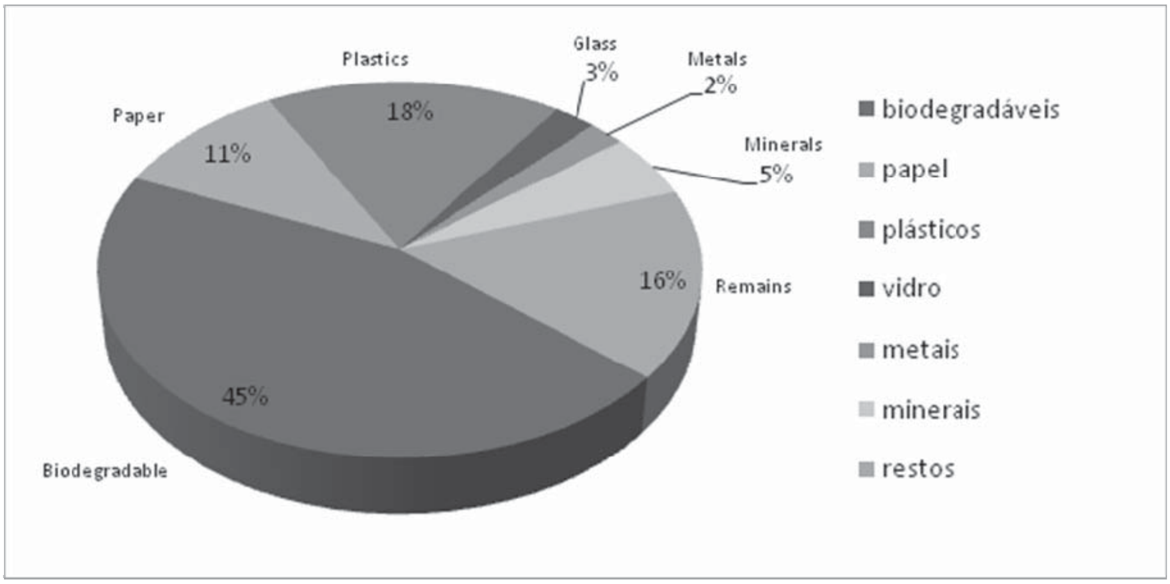

Figure 4

2.3.5 Laboratory

During the project a 210 m² excellence laboratory was implemented that will perform physical -chemical and biological analysis in order to evaluate the potential of waste to recycling, composting, digestion and RDF. This lab was outfitted with the latest equipment becoming a reference for the Brazilian market in the search for qualified analytical interventions. Products purchased were:

Figure 5

Table 4

Eudiometer (GB21)	Muffle	Scales
Centrifugal	Water Pump	Screens
Spectrophotometer	Heater	Shaker with heating
PH Meter	Gas Chromatograph	Conductivity meter
Filters	Refrigerator	Greenhouse
Freezer	Containers	Reagents
Filters	PPE	Other materials

2.3.6 CREED do Brasil

Creed is an NGO that emerged in 2009 and has more than 70 members, with an international center for research & development and both basic and advanced training on waste and natural resource management with an international focus. At the same time, the center functions as a demonstration site for environmental technology of the management of waste and resources sector of Germany. The main areas of activity are:

- Research and development, mainly through the use of technological resources present in Pohlsche -Heide and nearby waste management infrastructure ;
- Basic, continued and advanced training in the waste management area and resources and adjacent disciplines such as urban water management and energy management as well as agriculture , establishing a close relationship between theory and practice;
- Presentation and demonstration of technologies in scale of waste management and resources for those interested in Germany and abroad with emphasis on waste management and natural resources.

The Creed of Brazil will have as purpose to cross boundaries and introduce in Latin America a holistic perspective of sustainable management of MSW, ensuring a multidisciplinary and transterritorial intervention, joining what is most developed in Europe with the new demands of Latin America.

Thus, the Creed of Brazil will be a physical space dedicated to the development of alternative energy sources and improvement of social reality and also a showcase of exhibitions and dialogues between consumers, researchers, entrepreneurs, opinion leaders and all the general public. Our goal is to contribute to building sustainable tools for the benefit of the whole society.

Area destinated to CREED

Total area of the GERESOL

Figure 6

2.3.7 Campus of Eco-efficiency in Waste Management - CER

From the provided legal requirement that establishes the recovery of waste and considerations that concern the protection of natural resources and climate, we propose the implementation of a technology park called CER- Campus of Eco-efficiency in waste, which aims not only to promote productive activities, but mainly ensuring educational components for these activities, thus enabling the multiplication of instruments designed for the citizenship and sustainable development.

The multidisciplinary concept incorporates to the area of CER diverse environments such as an auditorium , offices , environmental education room, laboratory , center for training and research , and technological drivers to ensure the highest landfill diversion rate as well as the incorporation of by-products in the economic chain , by means of the following technologies : sorting of recyclable , fermentation , composting , drying to generate biomass and aggregates from the construction . The renewable energy that will be produced by the treatment plant through the biogas processing, the principle will be used for the own consumption and can be expanded according to market demand.

There is a plant in planning with capacity to meet municipal domestic generation with starting capacity of around 200,000 t per year, considering a lapse of generation of 10 years, but, through the studies to be undertaken, the proposed plant may have its capacity increased, thus meeting the demand identified in large generators and domestic generation in the region, offering an appropriate destination of choice for both the government and private entities.

3 Desired Impact

The research project aimed to develop an eco-efficient solid waste management system. For this, there were instructors trained to provide training on-site of the technical staff; develop and adapt technologies to meet the Brazilian demand.

The project also provided the requirements for a substantial waste management system in Jundiaí and, more specifically, to plan and present Mechanical- Biological Treatment (MBT) proposals with an integrated fermentation step in the city.

The Creed of Brazil (Research Center on Education and Demonstration in Waste Management) will also be implemented as a result of the project, with the goal of providing training, information and advice to decision-makers, public administration, waste management industry, power industry and regulators within and outside the Jundiai region.

Finally, the project will increase the capacity of two local universities (PUC -Rio and Anchieta Jundiai) in research and education in the area of waste management.

4 Recommendations

The challenges of promoting sustainable management of municipal solid waste can be mitigated through the exchange of experiences and technical, scientific and technological knowledge. In addition, trainings, seminars, discussion forums, technical visits and database training can reverse the external vulnerability in high-technology sectors; encourage continued implementation of research & development; increase the competitiveness of Brazilian industry; support the inclusion of innovative global markets; encourage the participation of private capital in innovation and minimize the impact mainly due to insufficient technical capacity.

Considering the great demand of projects and its technical sophistication, more knowledge should be developed. It is therefore essential to interact with experts with international experience and professional training centers with current technologies to design, implement and monitor effective waste management systems.

We also have the following proposals to ensure the continuity of the Project:

- Availability of project data for community access on the website of City Hall and print booklets
- Public consultation realization for presentation of results
- Details of technological alternatives and economic analysis of selected processes

- Formation of technical agreements with other municipalities to multiplication of results and technical training promotion
- Formation of technical cooperation agreements with research and academic institutions to promote basic and applied research
- Promotion of partnerships with the private sector to share information
- Formation of internal and external training courses and promoting broad participation events
- Promotion of CREED of Brazil competences to promote sustainable waste management in Brazil and Latin America
- Regional approach with the public and private sectors

5 Externalities

The project also includes a number of externalities that impact not only the teams involved but society as a whole, namely:

- Multiplication of the results through the implementation of the first training and research center in the management of municipal solid waste;
- Market development for secondary resources;
- Consolidation of foreign partnerships;
- Promotion of environmental education;
- Protection of primary resources and climate;
- Brazilian Industrial Park Development to supply technologies for recovery of waste;
- Training of technical professionals, graduates and post- graduates;
- Democratization access to the plant and its information;
- Database consolidation;

6 Conclusion

Germany has been a pioneer in waste management for three decades and the university is a world reference formed by a highly competent staff, The partnership with the TU Braunschweig and the PUC -Rio was extremely important to increase awareness of the Municipal technical staff and academic entities involved in the i-NOPA project.

The support and the dissemination of practical knowledge of German management brought to Jundiaí an innovative vision and inspiration to transform the current system in an efficient and continuous reality that meets the premises of the National Solid Waste Policy and the global trends

With regard to large generators, we think the questionnaires allowed us to conclude that despite all the challenges to be faced, the minds of those involved are congruent with respect to the prioritization of recovery of waste. Thus, federal law presents itself as a strong tool of support and promotion of new practices.

Industries are committed to meet the demand regulated in order to improve the internal management system and ensure the reverse logistics. The trade and services sector has not shown to have much knowledge of the subject, since their waste management is simple and requires no more than an overview of the actions, which are often inefficient.

The city has a very homogeneous generation of waste materials not being identified significant variation according to social status. This result is directly related to the economic condition of the population predominantly of the middle class, the low rate of unemployment and the increase in the consumption pattern coming from the economic development in recent years.

As for waste characterization we conclude that there is a high potential for use due to a significant portion of recoverable fractions both organic and recyclable.

The conditions identified in the region regarding the flow of by-products point to the establishment of a mechanical - biological plant as focus on energy recovery, the use of recyclable and RDF production of both Class 1 and 2. Composting is indicated for those organic fractions collected selectively mainly through agreements with the food industry.

The project allowed accumulating differentiated and pioneering knowledge, given that the National Solid Waste Policy is recent and the first actions in Jundiaí began to be taken less than two years ago. Through this experience it was possible for the involved actors to understand the problem of solid waste generation in the city, the instruments of National Solid Waste Policy, learn the ways of generation, treatment and disposal of adequate residues to their natures, meet treatment and minimization of environmental impacts technologies, thus broadening the discussion with society on sustainable management of solid waste.

Still, the experience lived by both internal and external audiences makes them able to establish relationships with other areas of knowledge, present a systemic view regarding the organization of work capacity and alignment with the trends related to the area.

Thus, the experience of sharing is not limited to the executing team, it spreads through society that had its horizons expanded when it had access to information which outlines new practices of waste management and mainly enters into a common commitment for environmental preservation and climate protection for the benefit of future generations.

7 Literature

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Municipal Solid Waste Management in Turkey: Status, Challenges and Future Strategies

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Abstract

Solid waste management, a globally challenging issue due to its adverse environmental effects and higher costs, constitutes one of the most crucial problems faced by Turkish cities and local governments today. The rise in both total and per capita waste generation and environmental impacts associated with inappropriate waste disposal practices together with the absence of an effective management mechanism has created severe problems in waste management in Turkey. Today, with the help of EU adaptation, waste generation and management have been recognized as a priority for Turkey and policies are being developed to overcome existing obstacles. Institutional capacity have been developed in both central government and many municipalities in Turkey to overcome the waste problem. Furthermore, waste management has been a pressure point for Turkey while being a candidate country for EU accession.

This study examines the current status of waste management in Turkey and underlines problematic areas in waste management sector. It also gives

Keywords: municipal solid waste, disposal, management, problems, Turkey.

1 Introduction

As in many developing countries, municipal solid waste (MSW) is one of the major environmental problems in Turkey. Problems associated with MSW are difficult to address, but efforts towards more efficient and environmentally acceptable waste disposal continue in Turkey. Although strict regulations on the management of solid waste are in place, undesirable disposal methods such as open dumping still have been widely applied in Turkey.

In İzmir, for an example, MSW was dumped in a swamp area between Bornova and Bayraklı districts at the end of 1960s, Valuable materials were separated from waste by people buying these materials. This waste mass were stabilized by anaerobic decomposition by years. There were many workplaces for glass waste processing (recycling) in İzmir. There were operated two compost plants (DANO Biostabilization) in Çiğli and Halkapınar (ERDIN & AKINCI, 2010). For more information about solid waste management in Turkey over 40 years can be found in ERDIN & AKINCI, 2010.

The aim of this study is to present an overview of MSW management in Turkey. The legally established MSW responsibility and management structure in Turkey is also presented. Finally, based primarily on data from the Turkish State Statistical Institute (TURKSTAT), MSW characteristics and management trends are presented. Challenges of MSW management and future strategies for Turkey are also summarized.

2 Current Status of MSW Management in Turkey

2.1 Legislative Framework in MSW Management

Environmental Law 2872, published by the Ministry of Environment in 1983, is the first stage in order to improve the environmental situation in Turkey. However, this law have not dealt with the best option for MSW management. In the 20-year period up to 2003, (1983–2003), only three regulations concerning waste were established. In 1991, the Solid Waste Control Regulation came into force and described key strategies, methods, operations and obligations related to MSW management. The regulation played a fundamental role in solid waste collection, storage, transport, and disposal. And it has been continuously updated in 1992, 1994, 1998, 1999, 2000, 2002 and 2005. The Medical Waste Control Regulation, issued in 1993 and updated in 2005, established a basic strategies for medical waste management based on the collection, storage, transport, and disposal or reuse of the waste by its owner. The Hazardous Waste Control Regulation, came into force in 1995 and updated in 2005, set the criteria for the collection, transport, and final disposal of hazardous waste, including options for landfilling or incineration, as well as the design criteria and the operational rules for sanitary landfills and incinerators. The regulation also focuses on the minimization of hazardous waste and encouragement of recycling (TURAN ET AL., 2009; GÖREN & ÖZDEMIR, 2010). After 2003, more specific regulations about waste management came into force (Table 1).

Waste management has been a pressure point for Turkey while being a candidate country for EU accession. After the start of EU integration studies in 2004, therefore, new legislations are issued, policies are being developed to overcome existing obstacles. Institutional capacity have been developed in both central government and many municipalities in Turkey to overcome the waste problem.

2.2 MSW Generation and Composition

As reported by METIN ET AL., 2003, until 1994, there were only estimates of MSW generation in Turkey because of the predominance of open dumping and the difficulty of recording MSW generation. The Turkish State Statistical Institute (TURKSTAT) has compiled statistics about MSW management since 1994. It was estimated that total amount of MSW has not exceeded 3 - 4 million ton/year in the 1960s, in Turkey. However, according to the TURKSTAT's 2014 database, approximately 26 million ton of MSW was generated annually (Fig. 1). Increasing population levels, rapid economic growth, and the rise in community living standards will accelerate the future solid waste generation rate in Turkey. The spatial distribution of amount of MSW per capita in 2012 (based on TURKSTAT statistics) is given in Fig. 2. The generation rate per capita varies considerably from the summer season to the winter season, especially in tourism areas. The rate of waste generation is highly influenced by the size of the community / city. The rate of MSW generation in the small sized cities / regions is 1.5 kg/ca·day, while this figure decreases up to 1.0 kg/ca·day in cities with high populations. TURKSTAT (2014) reported that the average per capita waste generation rate is 1.14 kg/ca·day for summer and 1.09 kg/ca·day for winter.

Table 1 Regulations on MSW in Turkey (Source: mevzuat.basbakanlik.gov.tr).

Year	**Regulation** (*with Official Gazette Issue No*)
2004	Reg. on the Control of Used Batteries and Accumulators (No: 25569)
	Reg. on Excavation Soil, Construction Waste and Debris (No: 25406)
2005	Reg. for Control of Medical Waste (No: 25883)
	Reg. on Control of Hazardous Waste(No: 25755)
2006	Regulation for Control of the Tire that Completed Their Life-Cycles (No: 26357)
2007	Reg. on Control of PCB and PCT (No: 26739)
2008	Reg. on Control of Waste Oils (No: 26952)
2010	Reg. on Sanitary Landfilling of Waste (No: 27533)
	Reg. on the Incineration of Waste (No: 27721)
2011	Reg. on the Control of Packaging and Packaging Waste (No: 28035)
2012	Reg. on Control of Waste Electrical and Electronic Equipment (WEEE) (No: 28300)
2013	Reg. on Radioactive Waste Management (No: 28582)
2014	Communique of RDF, Additional Fuel and Alternative Raw Material (No: 29036)
2015	Reg. on Waste Management (No: 29314)

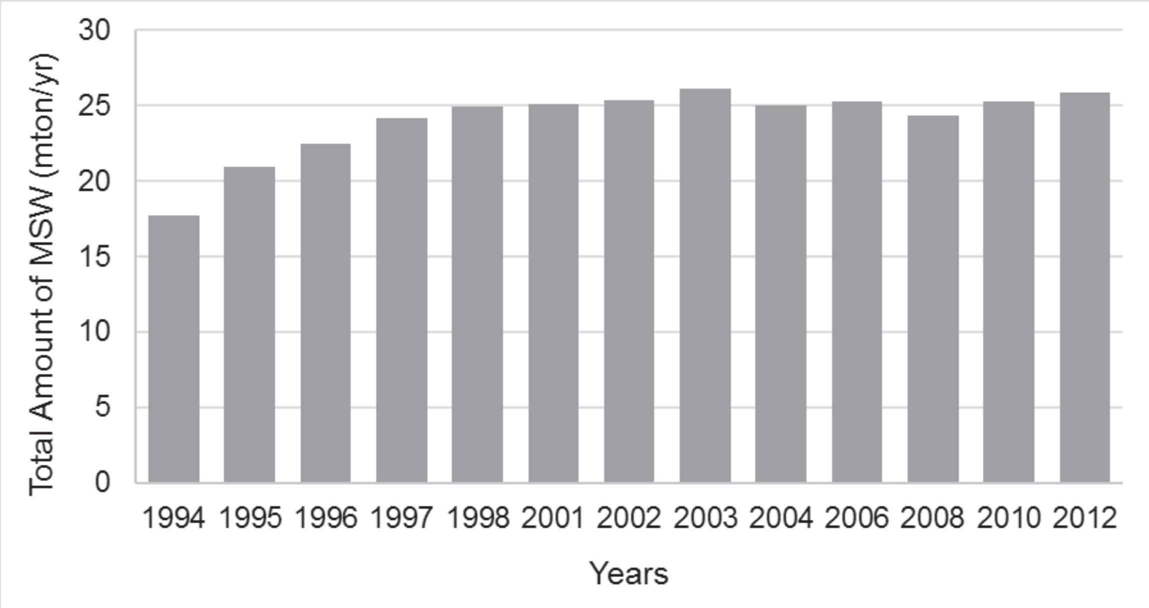

Figure 1 Total amount of MSW collected in Turkey

The typical composition of MSW in Turkey is shown in Table 2. Organic waste is the main component of MSW. Other materials except from organics and recyclables (i.e. paper/cardboard, plastics, metals and glass) are denoted as “others”. These materials, chancing between 7% and 24%, mainly include construction and demolition debris, coal ash and hazardous waste. The high concentration of biodegradable matter and inert material results in a high waste density (weight-to-volume ratio) and high moisture content. In the summer season, the MSW densities are relatively high in the high income regions because of the higher quantities of organic waste compared to the low income regions. MSW in Turkey generally consists of a high organic fraction because of high consumption of vegetables and fruits. In rural areas, the ash content is higher due to the use of stoves for heating purposes in the winter.

Table 2 MSW Composition in Turkey

Components	**Range (%)**
Organics	40 – 65
Paper / cardboard	7 – 18
Plastics	5 – 14
Metals	1 – 6
Glass	2 – 6
Others	7 – 24

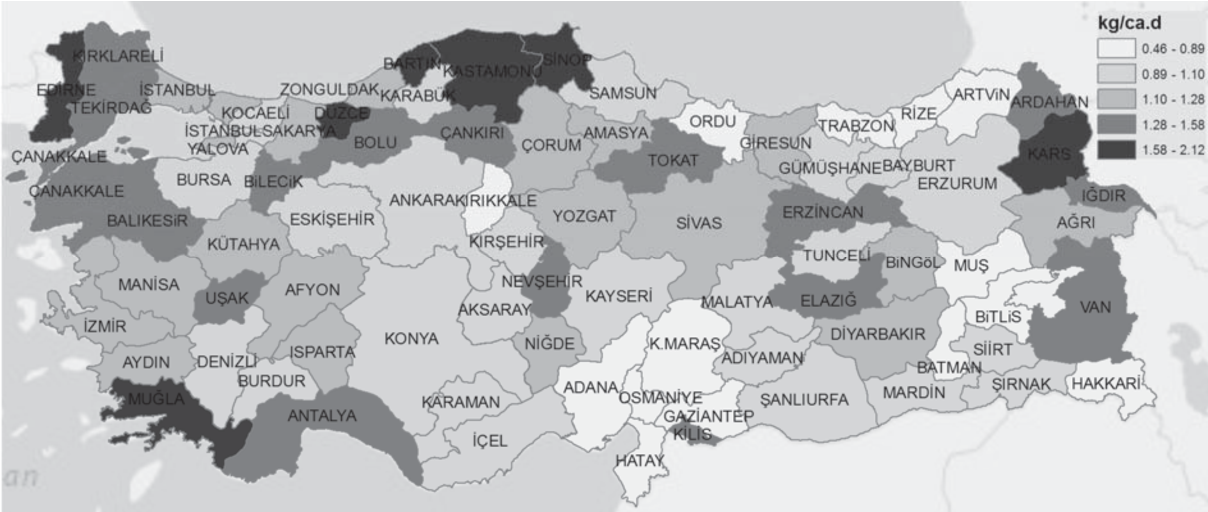

Figure 2 Specific (per capita) MSW generation in Turkey (2012)

There are typically a large number of scavengers at refuse bins in Turkey. The materials collected are subjected to some level of intermediate processing, such as separating, washing, and drying. The reclaimed materials are then sold to refuse dealers, who further separate the materials and sell them to appropriate processing/remolding mills and factories. It is estimated that approximately 10–15% of MSW is recycled by scavengers.

2.3 Administrative Structure of MSW Management

Waste generation and management have been recognized as a priority for Turkey and policies are being developed to overcome existing obstacles. Furthermore, MSW management has been a pressure point for Turkey while being a candidate country for EU accession.

In Turkey, municipalities are assigned as the main implementation authority. The tasks of policy making and directing the implementation at national level, which was initially within the mandate of the Ministry of Health, are today carried out by the Ministry of Environment and Urbanization (TCoA, 2007).

2.4 Collection and Transport of MSW

There are 2950 municipalities in Turkey, and 16 of them are metropolitan municipalities. A total of 2894 municipalities have solid waste management services. The population receiving solid waste services from 1994 to 2012 is shown in Fig. 3 (TURKSTAT, 2014).

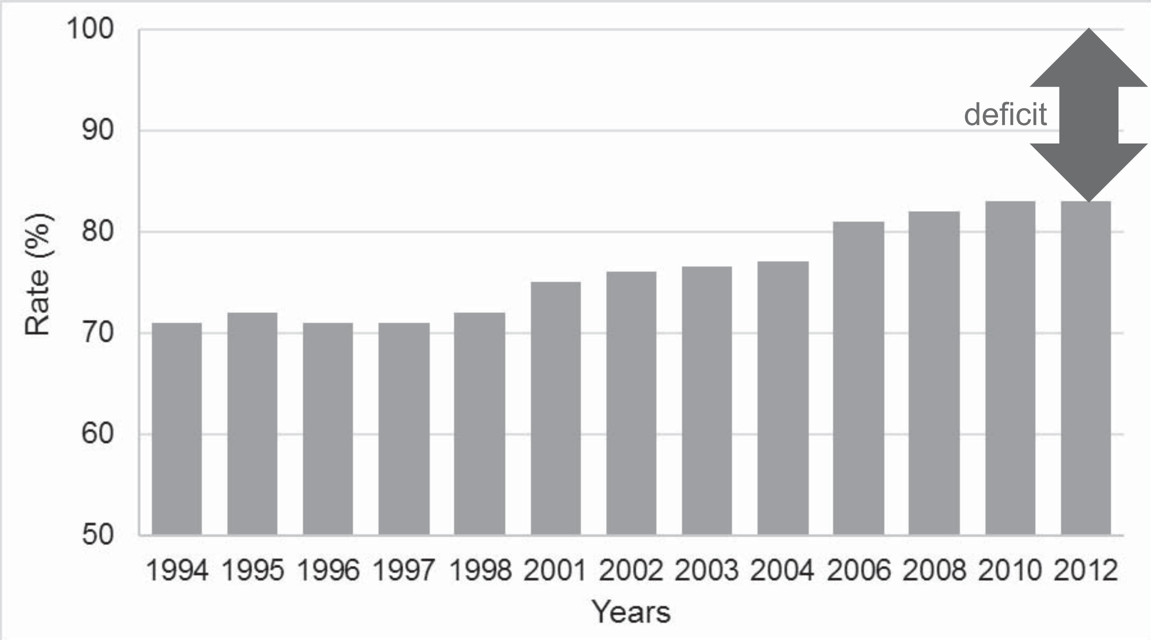

Figure 3 Rate of population receiving MSW services by years

The percentage of the population receiving solid waste services (i.e. collection of waste) increased from 71% in 1994 to 83% in 2012 (Fig. 3). Although the growth in MSW collection services, wastes, generated by 17% of the population (most living in rural areas), still cannot be collected in Turkey. The spatial differences (performance) in MSW services is also significant issue in Turkey. Rate of MSW collection service is somehow lower in east cities as seen in Fig. 4.

In most of the settlement units of Turkey, the collection and transportation components of MSW management are generally well organized. The municipalities spend a significant portion of their efforts and budgets for these services. There are two types of collection systems: Container - Curbside system: applied in the central parts of the cities and large towns and the waste is collected daily or twice a day. Community bin system: commonly practiced in small settlements and the poorly developed outer parts of urban areas. Depending on the population of an area, community bins with various non-standard sizes and models are placed on the streets, and waste from these bins is collected by various types of vehicles, ranging from tractors to compactors. Municipalities use their own vehicles for solid waste collection and transportation. In general, both the collection and transportation services are performed by the same vehicles. The collection and transportation vehicles are generally trucks with capacities of 3.5–7 ton (TURAN ET AL., 2009).

Figure 4 Rate of population receiving MSW services by cities in 2012

2.5 MSW Disposal

The common approach for MSW disposal system in Turkey was open dumping. However, the trend for disposal of MSW is towards implementing waste diversion and creating an integrated MSW management system. According to Waste Disposal and Recovery Facilities Survey results, it is determined that a total of 674 facilities, 83 of which were waste disposal facilities and 589 of which were recovery facilities were in operation in Turkey, in 2012. Currently 2095 open dumping sites are used in Turkey (TURKSTAT, 2014).

Amount of MSW disposed in controlled landfill sites was 15.5 million tons; i.e. 60% of total MSW stream. There are 80 controlled landfill sites, with a total capacity of 480 million m^3. Moreover, in 36 sterilization facilities having a total capacity of 116,000 tons/year, 46,000 tons of medical waste was sterilized. After sterilization 43% of medical waste was disposed in controlled landfill sites and 57% was disposed of in municipal dumping sites (TURKSTAT, 2014).

Incineration is not a general method for MSW disposal in Turkey. There exist 3 incineration plants having a total capacity of 61,000 tons/year; and 50,000 tons of waste, 47,000 tons of which was hazardous was disposed in these plants (TURKSTAT, 2014).

In 10 composting facilities 155,000 tons of waste was processed and 26,000 tons of compost was produced. Furthermore, in 32 co-incineration plants having waste recovery licenses, 539,000 tons of waste was incinerated with energy recovery. In other 551 licensed recovery facilities, a total amount of 9,5 million tons of waste metal, plastic, paper etc. was recovered (TURKSTAT, 2014).

Another significant issue in waste management in Turkey is hazardous waste handling and disposal. For the solution of the hazardous waste problem, extensive studies have been completed for industrial zones (TABASARAN, 2008). Tabasaran (2008) reported that amount of hazardous waste generated in İstanbul was 41,000 ton in 1992, 64,000 ton in 2005 and it was estimated as 109,000 ton for the year 2020 with the yearly increase rate of 3.5%.

With the financial support of EU Environmental Investment Fund and German Development Bank (KwF), sanitary landfill site projects have been planned and applied in Ankara, Diyarbakır, Gaziantep, Adana, Urfa, Van, Samsun, Bursa, Giresun and etc.

3 Challenges of MSW Management in Turkey

As a developing country, Turkey faced many difficulties / challenges in MSW management. These are summarized below.

In Turkey, many different departments and institutions deal with the management of solid waste and there is no integration or interaction between them. Sharing authorities and responsibilities by several bodies and institutions in this area causes overlapping powers and duties in the fields such as determining standards, principles and policies related to environment, monitoring illicit acts and punishing them. In practice, there is no sufficient cooperation and coordination among the institutions and organizations, especially the municipalities, which are responsible for providing technical and financial support, monitoring and follow-up, issuing permits and licenses and ensuring coordination in the field of waste management. Thus, effective and steady provision of such services in accordance with certain standards and in a way that is not to give harm to environment has not been possible (TCoA, 2007).

In the core of the problems related to MSW management, there exists the inadequate institutional and technical capacity of responsible institutions and organizations. The Ministry of Environment and Urbanization does not have adequate institutional structure and implementation capacity. As the main implementers in waste management, the municipalities do not have adequate institutional capacity in this field. Since the municipalities deal solely with waste collection and transfer and these services are outsourced to private companies, there exists no arrangement for waste management in their administrative structure. Therefore, a mechanism to ensure effective implementation of audit and monitoring, development and rehabilitation of existing infrastructure in accordance with contemporary standards cannot be established.

In many cities in Turkey, deficiencies in the provision of waste services are the result of inadequate financial resources, management, and technical skills of municipalities and government authorities to deal with the rapid growth in demand for services. In the financing of waste management, all costs should be covered by waste producers as required by the principle of “polluter pays” and the instruments to ensure this should be provided. However, effective implementation of this principle has not been possible since that the cost factor is not considered in pricing waste services, the infrastructure is inadequate and audit and monitoring activities are limited. This situation makes difficult the effective implementation of fundamental environmental principles such as waste minimization, recycling and sanitary disposal.

Despite the fact that separation at source and recycling activities form the basis of waste management policies, these activities are conducted at a very low level in Turkey. In fact, the legislation in force holds all production, distribution and sale units as well as final users including households responsible for separation at source and envisages criminal sanctions for illicit acts. Even the disposal of wastes other than organic wastes to regular storage areas is banned by this legislation, and in a sense, it obliges recycling. Despite this, recycling is realized mostly by street-collectors in a very unhealthy way; the production and distribution firms responsible for recycling generally fulfil their notification liabilities (quota) through financing street-collecting system instead of directly undertaking recycling responsibility (TCoA, 2007).

Open dumps can be detrimental to the urban environment. In spite of efforts to change open dumps into sanitary landflls and to build modern recycling and composting facilities, Turkey still has over 2000 open dumps.

With existing hazardous waste treatment plants and their capacities (İZAYDAŞ 35,000 tons/year, PETKIM 35,000 tons/year incineration, TUPRAS 17;500 ton/year incineration, ERDEMIR 6084 ton/year landfilling and ISKEN 11,000 ton/year landfilling) in Turkey, more than 80% of hazardous wastes left to nature with no control or disposed to municipal dumps together with household wastes. Infected wastes are directly disposed to municipal dumps generally without any treatment except from some examples of good practices at some provinces. Medical wastes are in generally dumped to municipal waste storage areas without due care and any treatment excluding certain good practices of big provinces.

The research and development activities directed towards strengthening social and cultural infrastructure required in the area of waste management and the training and studies aiming to create public awareness are at a very limited level. Hence, limited level of consciousness within the society and waste generators, and the restricted number of voluntary contributions are among the foregoing impediments in the implementation of an effective waste management.

4 Strategies for Better MSW Management in Turkey

"*For solution to the problems of waste management, initially organizational capacity should be developed. The institutional capacity of the Ministry, the control and reporting* *infrastructure should be strengthened and coordination among the concerned institutions and organizations should be maintained, research and training activities should be given more ground. Through strengthening the administrative and technical capacity of the provincial units of the Ministry, these units should be ensured to perform monitoring and preventive functions.*

As the fundamental implementing institutions, the financial, institutional and technical capacities of the municipalities should be strengthened. By taking the type and the population of the provinces into consideration, the Ministry should ensure establishment of model waste management units and determine the standards which shall be applied in the operation and structuring of these units.

Legislation on waste management should be improved particularly to strengthen implementation. Waste management plans at various levels required by legislation and by international commitments, which will constitute the main framework of an effective waste management should be prepared and put into effect. Similarly, priority should be given to the improvement of the manuals that will have a major role in strengthening the implementation capacity covering also good practices and international comparisons.

Measures should be taken that will ensure permanent and functional flow of information among organizations and entities having authority and responsibilities at different levels in the field of waste management. The Ministry should set up necessary related mechanisms and take measures to ensure institutionalization of cooperation and coordination. For a strong coordination and cooperation, distribution of powers and duties among fewer institutions, solving the problem of overlapping powers and excessive disorganization in the distribution of powers stemming from previous arrangements shall bring great benefit. The relevant legislation should be reviewed and summarized so as to eradicate unnecessary duplications and overlapping powers.

Monitoring and control activities should be expanded and carried out in a more effective manner. To this end, the central and local Ministry's audit capacities, which are currently very limited, should be promptly strengthened and obstacles before efficient functioning of sanctions should be removed in order to render the audit function effective. It should be ensured that authorized and responsible institutions, primarily the municipalities have a more effective role in audits and that an effective coordination and cooperation in the field of audit be set up among them.

Number of pilot projects encouraging recycling and collection of wastes separately at their source should be increased and this practice should be expanded immediately in all provinces. For this purpose, the Ministry should provide support to the development of necessary technical and socio-cultural infrastructure.

In terms of legal arrangements, good practices of developed countries should be benefited in the implementation of relevant actions in addition to EU regulations. Various experiences such as public awareness campaigns in modern countries and tools used for improving the efficiency of relevant practices should be benefited as well and interna-

tional comparison should be used as a method to develop the most effective management model" (TCoA, 2007).

Development of a modern and effective MSW management system cannot be achieved only by the support of public institutions and organizations or through the efforts of industrial and commercial establishments. All segments of society are responsible in this field. Thus, participatory policies should be developed so as to maximize the support and contribution of institutions and organizations such as non-governmental organizations, professional unions, educational establishments, academic institutions, media, etc.

5 Conclusion

For the solution of MSW problem in Turkey, another most significant issue is to identify and apply best available technology for MSW management. It's also important to develop special strategies and MSW disposal system for each project.

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Improving operations of a large MBT plant in Turkey

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Abstract: Larger difficulties at Kömürcüoda MBT near Istanbul, Turkey, led the management of HEREKO / RECYDIA AS not only to a technical improvement program for this plant. They also engaged RESSOURCE ABFALL GMBH for "Improving plant performance and operations at Kömürcüoda MBT", a large MBT with formerly three – after revamping – four plant units for 2.000 Mg/d mixed household waste and plastics recycling plus SRF production. The plant operation improvement project was prepared and executed in steps and with a clear methodology. Based on an inventory and analysis of previous plant operation an action plan was developed to establish clear structures, capacity building and training of staff and regular follow-up of plant operation. Everything was integrated into the overall task of developing "a leading culture for Kömürcüoda MBT", a clear and responsible way how each member of upper level staff (site manager and plant section managers) and also middle management staff will act in all situations.

Keywords: Mechanical-Biological-Treatment, plant operation, realistic concepts, raising plant availability

1 Introduction – Background and Kömürcüoda MBT

Mechanical-Biological-Treatment (MBT) of municicpal solid waste has attracted some attention during the recent years. Three main drivers can be recognized (SCHNEIDER, BEYWINKLER 2014):

1. Climate Protection
2. Fulfilling EU aims and directives related to waste management and
3. Recycling and Ressources Recovery from waste streams with higher contents of humidity

As climate protection is a priority for nearly all governments over the world, MBT-plants (especially – but not only – such with an AD-stage) are regarded as a suitable solution to reduce methane-emissions from landfills, if such plants are constructed and operated well and using state-of-the-art emission reduction equipment. Some projects on MBT-plants in different countries have shown that it is not sufficient just to have a promising technology by itself. The demands on process technology and subsequent operation of a MBT-plant however are quite high concerning operation organisation, preventive maintenance and care for machinery as well as quality of recycling products and solid recovered fuel (SRF).

Larger difficulties at Kömürcüoda MBT near Istanbul, Turkey, led the management of HEREKO / RECYDIA AS not only to a technical improvement program for this plant. They also engaged Ressource Abfall GmbH for “Improving plant performance and operation at Kömürcüoda MBT” (in the following shortly mentioned as PLANT OPERATION IMPROVEMENT). Main aspects and results of this PLANT OPERATION IMPROVEMENT project will be described within this paper. The described engagement with regular presence on-site lasted from May 2013 until May 2014.

Kömürcüoda MBT is a large MBT with formerly three – after revamping – four plant units for household waste and plastics recycling plus SRF production, situated about 50 km away from Istanbul city center on the Asian side ISTAC-landfill, owned and operated by HEREKO / RECYDIA. It consists of:

1) Pre-MT plant for 2.000 Mg/d mixed household waste in two shift plant operation,
2) Bio-Drying for 1.700 Mg/d Organics and wet SRF from Pre-MT,
3) Post-MT plant for 640 Mg/d dried material with SRF-production in two shift plant operation – and after revamping
4) Plastics-Recycling plant for 36 Mg/d of separated films from Pre-MT in three shift plant operation

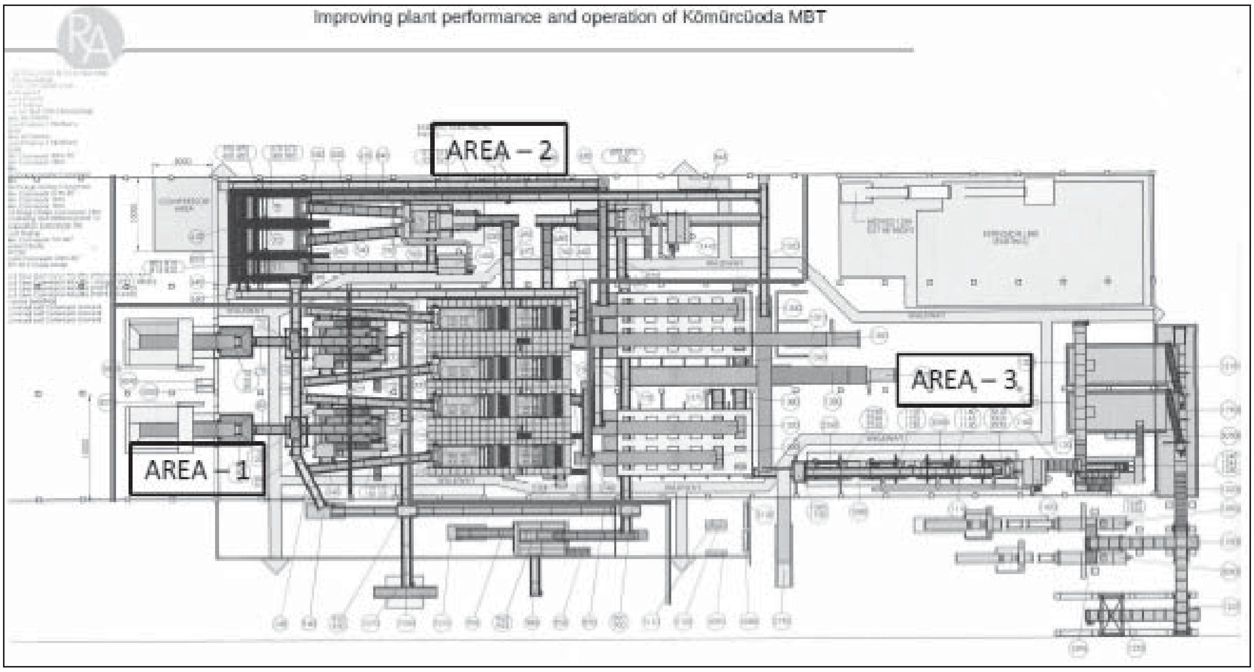

Figure 1: Former Plant Layout of Kömürcüoda MBT – Pre-MT plant

2 Proceeding

This chapter introduces steps and methodology of approach during the PLANT OPERATION IMPROVEMENT:

1) Inventory of previous plant operation
2) Analysis and Action Plan
3) Organisational advice and development of clear structures
4) Capacity building and training with plant operation staff
5) Regular follow-up of plant operation and staff' way-of-working

For each step aims and way of approach are shortly explained in the following subchapters. Everything was integrated into the overall task of developing "a leading culture for Kömürcüoda MBT", a clear and responsible way how each member of upper level staff (site manager and plant section managers) and also middle management staff will act in all situations (DR. OBLADEN & PARTNER 2012).

2.1 Proceeding of Inventory of Previous Plant Operation

Observation of plant operation, machinery and staff, dealing with operation, maintenance and cleaning as long as possible before existing plant sections were shut down for modification had the aim to supply facts concerning:

a) Existing organisation
b) Existing way of working
c) Existing capacity of staff
d) Existing responsibilities
e) Existing machinery
f) Existing communication within operation staff
g) Existing maintenance
h) Existing throughput and quality of products

The on-site inventory was planned to be based on a systematic approach, documentation and regular exchange with the upper level (site manager and plant section managers) and middle level (shift leaders, area leaders) of plant operation staff. It should be elaborated by

1) Two weeks of presence on site during most of the daily operation time as well as some hours before and after production period.
2) Observation and evaluation of regular daily operation reports.
3) Observation and evaluation of tasks the members of HEREKO plant staff had worked out between visits.
4) Observation and evaluation of QM-System documents.
5) Observation and evaluation of HEREKO-internal reports.
6) Systematic exchange with plant staff.

2.2 Proceeding of Analysis and Action Plan

Bottlenecks in daily operation practice and areas with deficits in maintenance, significant for plant operation, should be identified. Existing and additional downtime analyses and results from last month with two shift production period should be evaluated. Objectives and goals as framework for the oncoming next steps of PLANT OPERATION IMPROVEMENT should be defined. An action plan with individual measures to be achieved during future plant operation was intended as top management information instrument.

In several internal workshops with HEREKO plant staff facts and impressions from the inventory should be presented and discussed. Plant staff's own experience and approach to improve as well as intended objectives concerning short term and long term perspectives should be discussed and identified. Resulting actions from this analysis and discussions should be grouped into three categories of an action plan:

a) Immediate actions – those that have high operation efficiency and cost efficiency,
b) Important actions – those that have high operation efficiency but intend higher invest-ments,
c) Other actions with effects on plant operation improvement.

2.3 Proceeding of organisational advice and development of clear structures

Tasks, roles and structures of staff members should be documented and analysed. Organisational transparency about roles, tasks and ways of good and fruitful cooperation will be supported, instruments to clarify will be used in cases where necessary. Advice on necessary staff – numbers and capacities – for the oncoming new plant situation should be supplied.

2.4 Proceeding of capacity building and training with plant operation staff

Concerning future plant operation and cleaning works a training plan for HEREKO staff should be developed as far as this would not belong to the machinery-supplier. It was expected that especially the relation of operation and cleaning of machines should be revised. Follow-up of plant operation on site by the responsible persons should be also an issue of training. All trainings should be divided into a smaller part of “theory” and a larger one with “some repeated practice sections” during warm start-up and trial operation.

Where necessary deepening of consciousness about the individual role of certain staff members should be trained and supported.

2.5 Proceeding of regular follow-up of plant operation and staff way-of-working

As soon as plant operation will restart the new way of plant operation should also start. During real plant operation implementing of the action plan and the related maintenance and operation works should be focused with special attention to:

a) Structures and clear responsibility taking by every staff member;
b) Awareness and competence of staff (including H & S – issues);
c) Emergency preparedness;
d) Communication.

The daily way of following steps “to live” 5 s – system in plant reality should be checked and necessary improvement measures focused with responsible persons within plant operation.

Systematic breakdown-analysis of plant should be executed concerning **reasons, initial signals indicating the breakdown and lessons for maintenance plan and future plant operation.**

Regular weekly meetings on “quality of plant operation” should be organized as instrument of exchange and self-control for relevant members of plant staff.

3 Realisation of PLANT OPERATİON IMPROVEMENT

The execution of all measures was integrated into the framework of ten so-called priority-projects defined by the CEO of HEREKO / RECYDIA AS.

There are several key activities to be performed at Kömürcüoda during the shut-down period for the re-engineering in the following areas in order to maximise the effectiveness and successfulness of the project:

1. **Organisation**
2. **Maintenance**
3. Internal Logistics
4. Process Management
5. Quality Control
6. **Production**
7. Procurement
8. Sales
9. Finance
10. **EH&S**

The Leaders of each of these functional areas are responsible for defining detailed work programmes, define priorities and intermediate milestones,

Figure 2: HEREKO / RECYDIA AS CEO priority-projects – Main subjects within PLANT OPERATİON IMPROVEMENT project are highlighted

3.1 Inventory of Previous Plant Operation

The operation situation of Kömürcüoda MBT before technical revamping and PLANT OPERATION IMPROVEMENT is described in general by **Figure 3** showing downtimes.

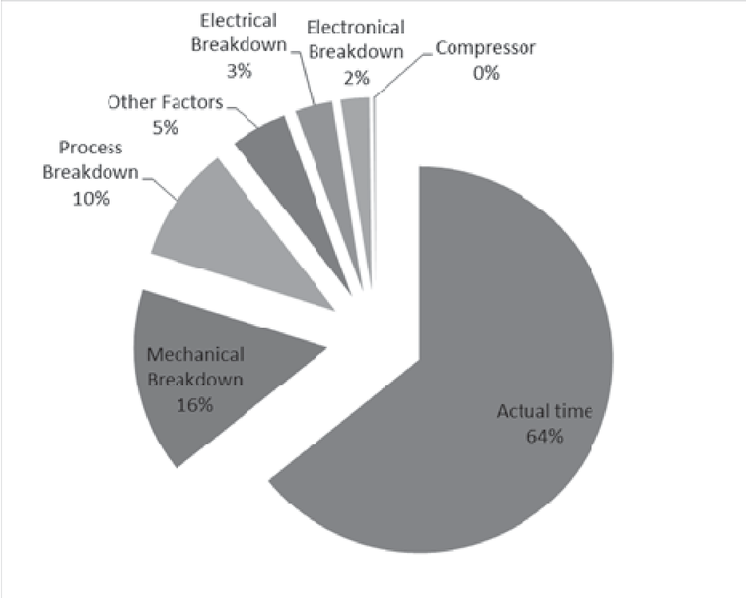

Figure 3: Downtimes and causes during winter 2012/2013 (about four months)

The inventory of the previous plant operation including cleaning of machinery as well as maintenance planning and execution was executed within about 1,5 months period and showed the following main root-causes:

Table 1: Main results/root-causes of downtimes from Inventory of previous plant operation

1) Technical situation needs improvement	A few conveyors, operation of pre-shredders, air-system for TiTECH etc., dust in Post-MT caused troubles regularly during operation.
2) Attitude of plant operation	Although the troubles at the above mentioned conveyor as well as with the windshifters were known to all operation staff, these "*neuralgic areas*" were not "observed"/checked constantly during operation.
3) Attitude of plant operation + Attitude to lead staff	In general HEREKO staff was not around in the pre-treatment hall, when the plant was running. No responsibility for the execution of work by subcontractor's staff.
4) Attitude to lead staff	Too less presence of leading personal in the plant.
5) Attitude of plant operation + Understanding of role as "plant operators"	There was too much dirt on a lot of machinery. This dirt was not removed regularly. The understanding of "cleaning" is too much related to the ground floor and too less with machinery.

6) Lack of consequence in working	Ex. windshifter Breakdown: It was caused by windings around the axes, hindering turning around of the axle. Normally these should be removed during lunch breaks and shift change, but nobody had down – at least at that day.
7) Lack of "handing-over" of tasks in case of shift-change, days-off etc.	Ex. windshifter Breakdown: Area leader said, they would tell the late shift to remove the remaining things. Checking at next morning showed that nothing was removed. That caused two hours preparation work by two persons with whole plant down.
	The information board was not used during my presence.

3.2 Analysis and Action Plan

The analysis of problems and the discussion with responsible staff resulted in plans like the one shown in **Figure 4** for Pre-MT plant.

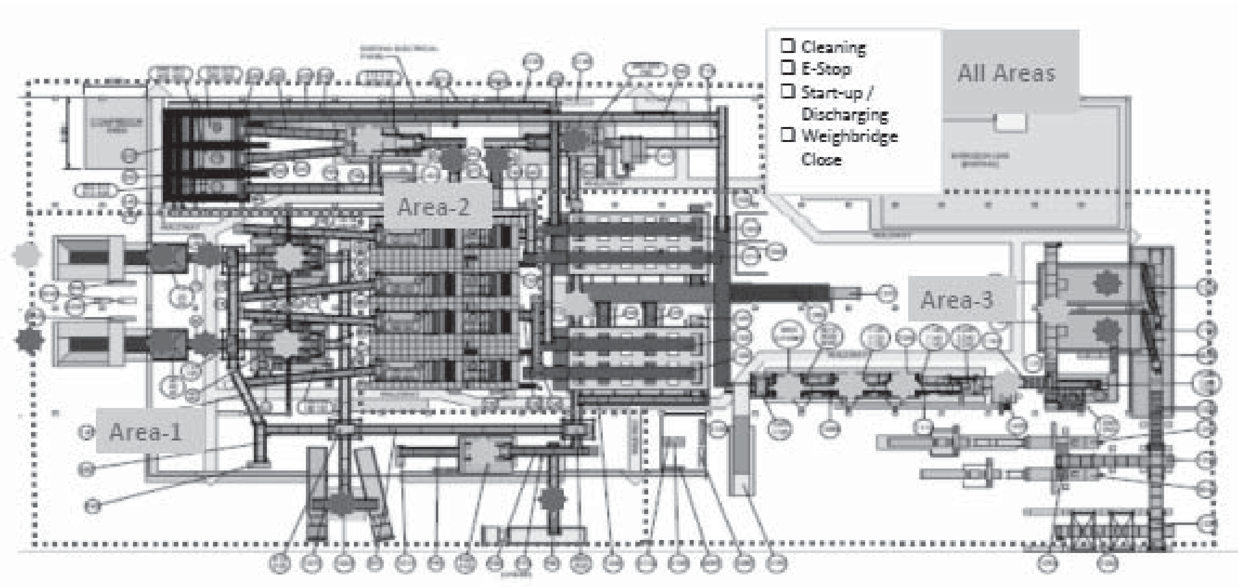

Figure 4: Marked main problem areas in Pre-MT

Further result of the discussions in workshops with upper and middle management staff of each plant section were priority-tables for Pre-MT plant and Post-MT plant. For each plant items mentioned by everybody during discussion were sorted and classified according to their expected effects on operation efficiency and cost efficiency into three priority categories.

3.3 Organisational Advice and development of clear structures

Within the key activity no. 1 all levels of upper plant management staff and the CEO were supported during revamping period and start-up in the development of a clear work-force organisation and the necessary staff capacity for each task in the plant sections. During plant operation slight modification of organisation and capacity of night shift cleaning in Post-MT plant section became necessary.

3.4 Capacity building with plant operation staff

Capacity building with plant operation staff took place by

a) Weekly meetings with the complete upper plant management
b) Daily meetings with individual plant section manager according to start-up program defined by the plant (= Pre-MT and Post-MT) revamping company as well as the plastics line constructing company.
c) Meetings with individual plant section manager and section middle management (=shift-leaders and/or area-leaders) depending on observations and challenges occurring during preparation and execution of start-up, trial-operations and regular operation of the related plant section.
d) Individual exchange with the related plant section manager and related staff in case of any observed severe indication.
e) Trouble-shooting meetings on whatever important problem which occurred, including budget responsibility and decision taking of middle management, differences with the revamping company – in cooperation with the British contract manager for the revamping – internal cooperation of plant sections and other branches of HEREKO / RECYDIA AS.

During all meetings “follow-up culture” and “longer term planning” (= more than the actual working day) were tried to be anchored within the persons trained.

3.5 Regular follow-up of plant operation and staff way-of-working

Since start of cold commissioning of revamped Pre-MT plant in October 2013 and furthermore after start of warm commissioning of Pre-MT in November 2013 during every day of presence on site regular inspection tours - e. g. every morning before start of plant operation to check night shift care for machinery - and irregular inspection tours were executed.

As mentioned before in all internal regular meetings and some additionally initiated internal trouble-shooting meetings observed operation deficits causing downtimes were adressed to the related plant manager and his team. Discussions always aimed and achieved a better understanding of processes and way of leading staff in the related area. Vice - versa to improvement of operation behaviour some pending technical issue regarding machinery were transfered to the revamping company and the CEO of HEREKO / RECYDIA AS. Special consideration was taken concerning evaluation of cleaning of machinery and night shift care for preventive maintenance. In some cases also way of working of daytime maintenance crew-members was addressed.

3.6 Results achieved

Figure 5 and **Figure 6** show the development of availability during warm start-up and takeover-tests (ToT) for Pre-MT and Post-MT plant sections plus Pre-MT after ToT. It is easy to recognise from **Figure 5** that at Pre-MT availability has been the main area to take care and fulfill the contractual requirements.

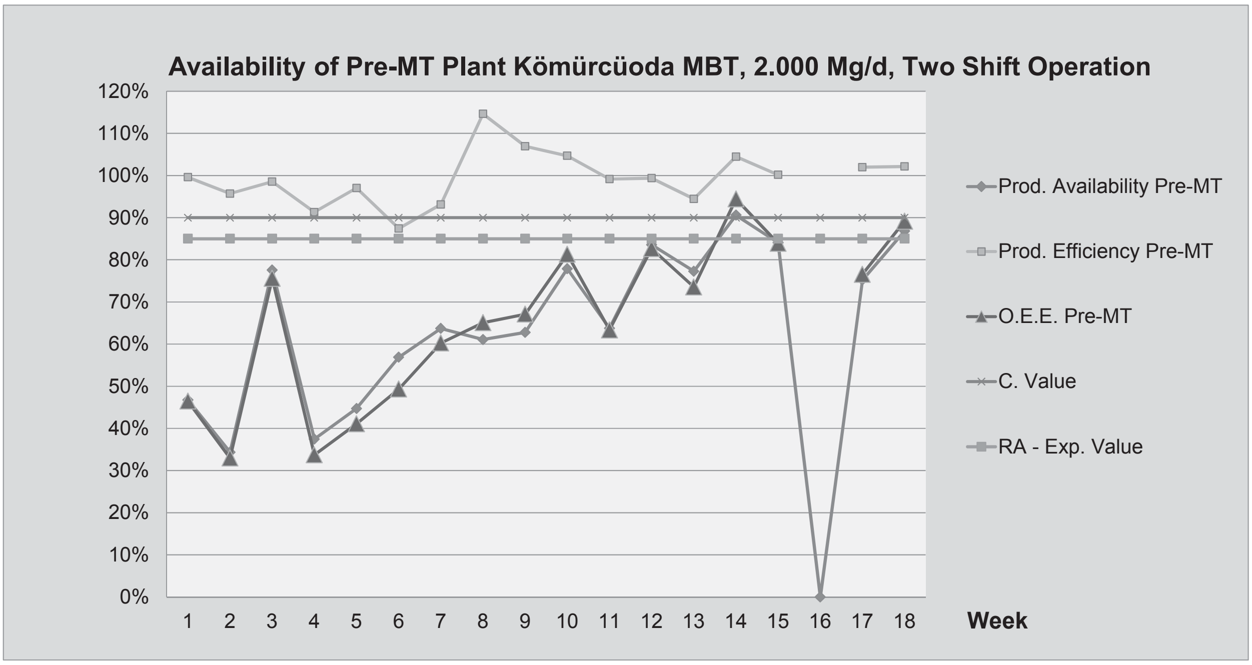

Figure 5: Development of Pre-MT Availability during weeks in 2014

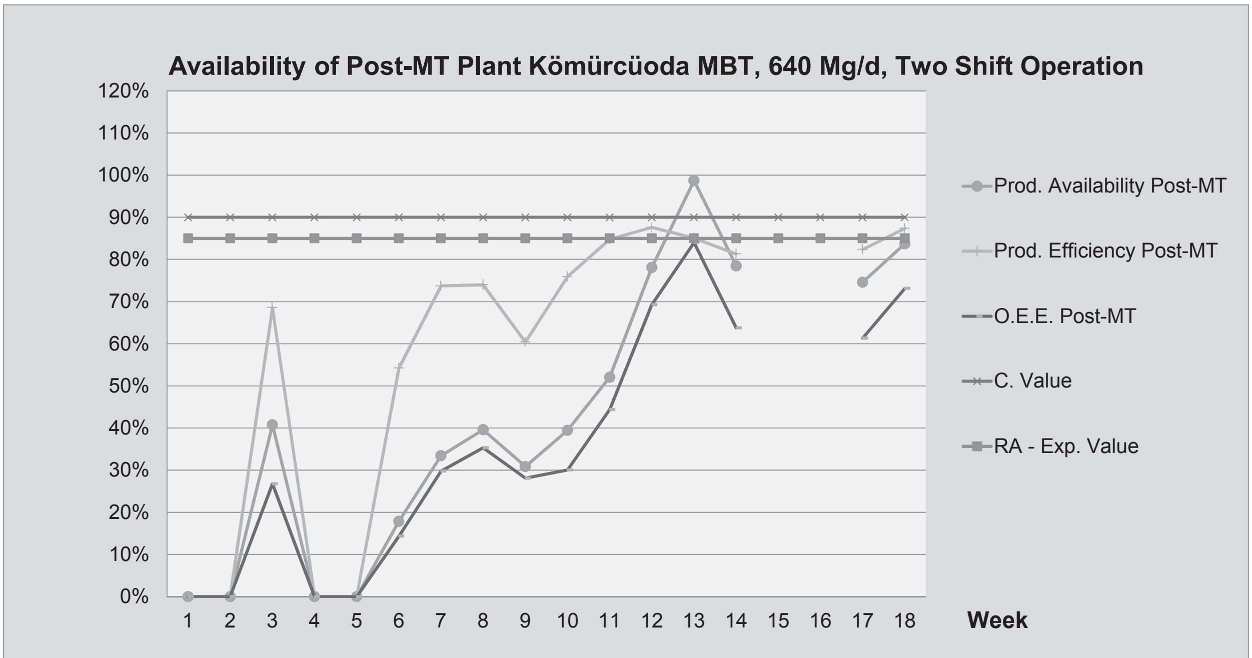

Figure 6: Development of Post-MT Availability during weeks in 2014

Additional to the machinery-based downtimes there have been operationally caused downtimes at Pre-MT plant, see **Figure 7**, which were not subject of the responsibility of the plant revamping company.

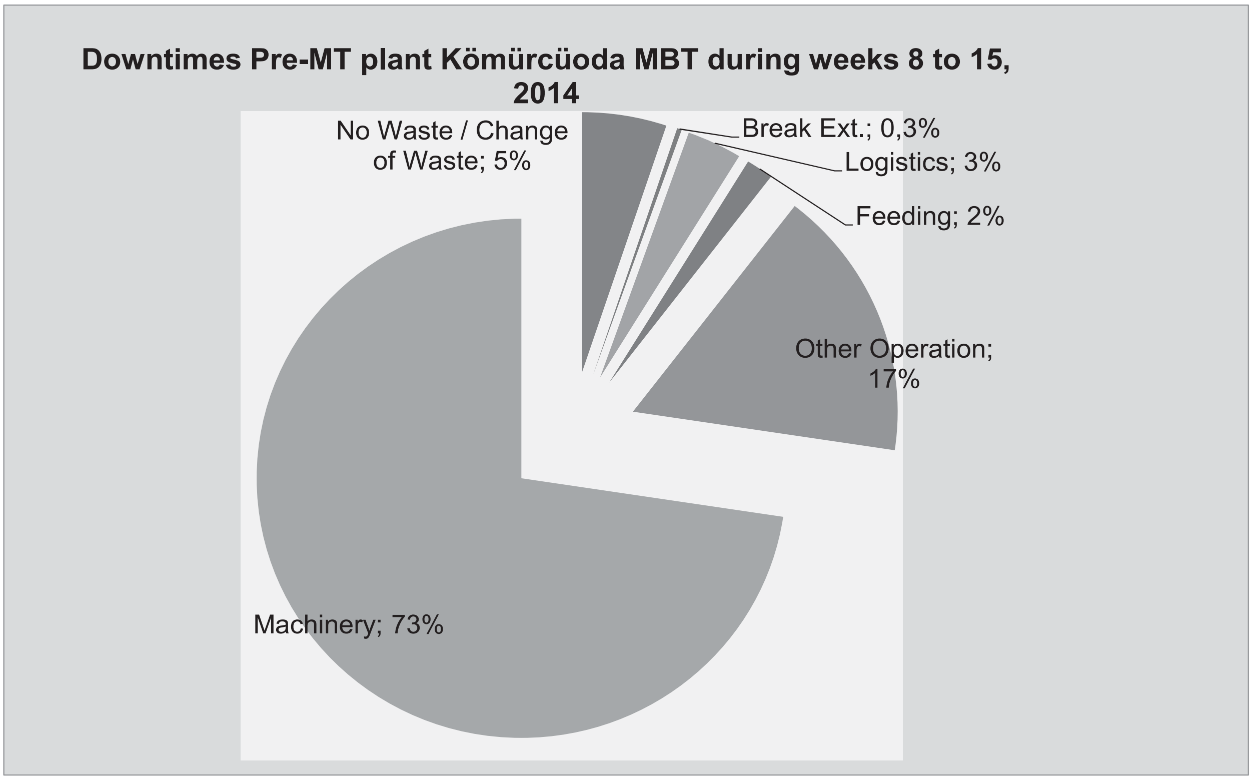

Figure 7: Downtime causes during weeks 8 to 15, 2014 (about two months)

During the PLANT OPERATION IMPROVEMENT project takeover-test at Post-MT could not be finished successfully.

3.7 Remaining important topics

Despite all improvements achieved and the engagement of the plant section managers and most of their middle management staff there remained some important issues when the PLANT OPERATION IMPROVEMENT project was finished by Ressource Abfall GmbH. As main topics remain:

- Discipline of staff including:
  - improving follow-up of tasks,
  - Taking care of your next level staff and
  - Stop "laissez faire" in all operation issues and on all levels of staff.
- Preparation and execution of regular preventive maintenance including regular cleaning / care for machinery.
- Having in mind next weeks and months of plant operations.

4 Conclusion

Respecting the general baselines described in other papers a MBT-plant could be an interesting option for many countries with some development in the waste management sector during the last decade or years.

The Kömürcüoda MBT case study with its PLANT OPERATION IMPROVEMENT project shows that technical equipment of a MBT-plant as well as the requirements of producing "products" – recyclables and SRF – set out a huge, very significant difference to the operation of a dumpsite or simple landfill and high demands on upper and middle plant management and operation staff. To maintain safety devices demands much higher requests than used at most dumpsites. Regular maintenance procedures require higher accuracy and the availibilty of spare and wear parts must be introduced as another change from former landfill operation.

Especially the tasks of

- "take care and cleaning of machinery"
- "take care of your next level staff" and
- "think on next week and next month, months of plant operation including (preventive) maintenance"

were most relevant issues to be trained, learned and followed-up in the Kömürcüoda MBT case study.

PLANT OPERATION IMPROVEMENT has meant in this case:

"It's a big ship you want to take a turn!"

The turn was started and – not only due to the engagement of Ressource Abfall GmbH – quite successfully done during the project period. The long-term stability of this turn HEREKO / RECYDIA AS have taken into their own hands.
Very good success with operation in the future!

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Experiences during the elaboration of Waste management concepts for eight waste management unions in Turkey

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Abstract

The content, experiences and outcome of the project „Technical Assistance to prepare Integrated Solid Waste Management Projects - Lot 2", co-funded by the EU and the Republic of Turkey is presented under the main questions: "Is waste currently seen as a resource in Turkey or can it in the future be seen as a resource"? and "What are the prospects for MBT in waste management in Turkey seen in the light of the project"? The general purpose of the project is to prepare integrated solid waste management projects ready for financing and implementation under the IPA II instrument (EU's Instrument for Pre-accession Assistance). To that end, analysis of the current waste situation has been conducted in 8 regions in mainly the Eastern part of Turkey, covering approx. 2.7 million inhabitants, and investment projects elaborated. The status is that the current waste management is poor, the regions lack adequate WM facilities, the affordability is low, and no proper tariff/user payment systems are in place. These are the main obstacles for implementing MBT facilities on a larger scale and for perceiving waste as a resource in Turkey.

Keywords

Turkey, Waste Management, IPA II, Tariff scheme, Barriers for waste-to-resources, MBT, Sanitary landfill, Closure of dumpsites.

1 Background

1.1 The Project assignment

The general purpose for the project is to prepare integrated solid waste management projects approved by EU and ready for financing and implementation under IPA (Instrument for Pre-Accession Assistance) funds in accordance with the Turkish Legislation and the EU acquis for 8 Waste management Unions in the eastern and central Turkey, as seen in the below figure (Figure 1). The waste management Unions were established according to the Turkish law and are situated in eight different Provinces, namely Artvin, Erzurum, Mersin, Şanliurfa, Diyarbakir, Hakkari, Kahramanmaraş, and Ordu.

Figure 1 The location of the project areas in Turkey (map base Google Earth)

The project assignment includes the following tasks:

A. Preparation of IPA Application Forms with annexes including

- Solid waste characterization studies
- Master Plans for a time horizon of 30 years including asset inventory, gap analysis for compliance with the EU acquis and national legislation in the environment sector, and prioritized list of investments together with a financing plan
- Feasibility studies with a strong emphasis on option analysis (technical, land etc.), affordability analysis, risk analysis, and cost benefit analysis,
- Environmental impact assessment reports, public hearings twice and non technical summary of EIA studies
- Soil and hydrological surveys, geotechnical Studies, topographical (1:500 and 1:1000) and cadastral maps for each project component,
- Design reports and detailed drawings
- Operation manuals
- Detailed cost estimation in comparison with a cost catalogue
- IPA Application Forms

B. Tender Dossiers and supporting documents, including

- Tender dossiers for each works contract, technical specifications, drawings, detailed bill of quantities/ breakdown of prices, and procurement notice

- Tender dossiers for each supply contract, technical specifications, drawings, detailed cost estimation, market survey, and procurement notice
- Tender dossiers for each service contract, terms of reference (technical assistance, supervision of construction etc.), detailed budget breakdown and time table of activities against resources, and procurement notice

1.2 Turkish waste management

Following the recognition of Turkey as a candidate country at the Helsinki European Council of December 1999, some progress has been achieved in the waste management sector. However, in Turkey, uncontrolled and unsafe dumping of solid waste tends to be common practice, and the level of recycling is low. According to the Turkish Statistical Institute (TUIK), 63.7 million out of a total of 75.6 million inhabitants received municipal waste services in 2012 (83%), producing waste of which 15.5 million tons were sent to a controlled landfills. whereas 9.3 million tons were dumped in uncontrolled dumpsites, burned or dumped in lakes, rivers, or the sea. In addition, more than 5 million tons of waste from the non-served population is disposed of similarly. A total number of 52 controlled landfills with a total capacity of 423 million tons exist in Turkey (2012), 2 waste incinerators (2010) for chemical/medical waste (with a total capacity of 44,000 tons/year), and 5 composting plants are (probably) in operation. Also, according to the TUIK, most municipalities reported non-compliance with the solid waste regulation, packaging regulation, and other regulations. The amount of generated waste is estimated at 1.13 kg/cap and day.

2 Current waste management practices in the project areas

The numbers given by the TUIK do not entirely tally with the experience of the Consultants when examining the solid waste situation in the project areas in the period 2012-14. I nearly all cases, waste is not collected from rural areas even if the towns and other urban areas are served. This means that in average only 63% of the waste was collected in 2012, according to the Consultant's estimations. This figure varies between 49% and 76%, and it reflects by and large the ratio of urban population. In provinces hosting a sanitary landfill, organisational structures, road distances and geographical features prevent large parts of the population from using the landfill for their waste. Instead, waste is dumped in uncontrolled dumpsites, in rivers, in the sea or similar. In general, the problems in relation to the waste storage, collection, transport, and disposal of the waste encountered in the project areas can be summarised as follows:

- Waste is in many cases not containerized. This leads to unsanitary storage of the waste on the streets and it gives rise to odour and vermin problems, scavenging by animals, leachate problems and hence pollution of the environment and human health hazards
- Collection service of MSW is in urban areas acceptable with daily collection from communal containers/collection points. However, in rural areas is the collection service in some places non-existent, in other places covering only a limited part of the population
- In general, no services are offered for collection of recyclables
- No services are offered for collection of special types of waste such as bulky waste, household hazardous waste, and construction and demolition waste
- In general, the municipalities have no designated a places for the disposal of construction and demolition waste. This waste is therefore in many cases collected with the MSW, dumped haphazardly, or sometimes used for filling of roads
- Waste is sometimes fly-dumped and waste is seen accumulating on roadsides, in vacant areas, in river beds, and other places causing unsanitary, un-aesthetical and environmentally damaging conditions
- The capacity (number, size, and standard) of the current collection trucks and containers are insufficient to fulfil the needs of the entire population (urban and rural)
- Dumpsites are poorly managed and in many cases their location is very poor with respect to environmental protection, that is: close to rivers and other water bodies, or adjacent to major roads
- Dumpsites are used not only for MSW, but also for various other types of waste such as industrial and commercial waste, and hazardous waste
- The level of recycling is relatively low and does not meet the current legal demands. Moreover, the working conditions are poor for those waste workers that actually contribute to the recycling of the waste by street and dumpsite scavenging.

The problems in relation to the institutional and organizational aspects of waste management in the municipalities are in summary:

- Low public understanding of the need for environmentally sound waste management and only little or non-existing public education in terms of proper waste management

- Low collection rates on payments for municipal services. To date, charges for solid waste management through the environmental cleaning tax (ECT) have been negligible. The introduction of tariffs for solid waste collection and disposal will require customers to begin paying the full costs of the services, which may strain the willingness to pay for services

- The municipalities need to improve their capacities to determine and monitor the costs of providing solid waste disposal and collection services, respectively. Currently, many municipalities are not able to present the actual costs of providing solid waste collection services; instead, these costs are embedded in the general costs of the cleaning services or civil works departments. Cost recovery cannot be achieved if the costs of service provision are not known.

- According to the law , the Metropolitan Municipalities have the right to receive and collect contributions from municipal budgets to cover costs of disposal which is under their responsibility (where such Metropolitan Municipalities exist). There is a strong mechanism to compel payment of this share, as it can be taken from the budget transfers the municipal governments receive. On the other hand, at present there is no legal and administrative solution to effect payments from municipalities to the Metropolitan Municipality for the provision of solid waste disposal services. A legal basis needs to be established for the transfer of waste disposal fees from the municipalities to the Metropolitan Municipality, or directly to the Metropolitan Municipality from customers.

- Operation of solid waste collection and disposal services in most cases is not performed in accordance with commercial principles. No performance indicators are used in measuring the effectiveness of providing these services.

- A new tariff regulation is in force, but it is poorly understood by municipalities and implementation has not begun in most cases.

- Lack of local by-laws for the handling, storage, and disposal of waste; low capacity for implementing such local regulation.

- Low capacity of municipalities to co-finance investments and currently no capacity of the Metropolitan Municipality to co-finance investments.

Based on this, and with reference to the description of the current EU, national, regional, and local requirements and standards, the Consortium has identified the following development needs for the project areas:

- Provision of regular and reliable services for the entire population, including commercial and institutional entities and other producers of MSW, including extension of the service to urban and rural areas currently not serviced
- Provision of adequate equipment (collection trucks and storage containers) in order to provide sound storage of the waste prior to collection and efficient collection and transport
- Provision of systems and structures for encouragement of enhanced recycling and services for separate collection of various waste types for recycling or special treatment, e.g. segregated collection systems, recycling centres and facilities for processing recyclables
- Provision of systems and facilities for efficient and economical transfer of waste to centralized places of disposal
- Provision of adequate treatment and disposal facilities in accordance with the legal requirements, e.g. sanitary landfill and recycling facilities
- Adoption of the required management plans and programmes for waste prevention, recovery, and disposal.

3 Proposed IPA investments

To meet the needs of the municipalities of the project areas, the project has proposed a number of measures to be implemented in the short term (up to 2020) for the Unions. These measures include:

- Provision of collection equipment: Nearly 25,000 4-wheel, 770 litre standard containers are planned to be purchased in addition to smaller containers for ash collection from individual coal-fired stoves/furnaces
- Provision of collection trucks: 144 rear-end compacting collection trucks and 55 side-loaders with 22 m³ demountable truck bodies in addition to trucks for household hazardous waste and ash collection
- Provision of transfer stations and equipment: 8 transfer stations with 13 tractors for transport of large compacting containers and provision of 34 such containers in addition to 31 truck/trailers and fitting 117 demountable containers also for use of waste transfer
- Establishment of 8 engineered, sanitary landfills with a total designed volume of approx. 21 million m³ of which approx. 7 million m³ are planned to be established as part of the short term investment plan

- Establishment of 7 MRF plants and compost facilities with a design capacity of 46,000 tons/year and 87,000 tons/year respectively and one medical waste sterilization plant
- Procurement of moving equipment at the landfills (dozers, loaders, compactors, etc.)
- Closure and rehabilitation of a total of 91 small to medium/large sized dumpsites, of which 33 will be closed in-situ and 58 small dumpsites will be reinstated by total removal of the waste and contaminated soil
- Total investments are estimated at around EUR 236 million over four years (2017-2020)

4 Waste flow effects

For all eight project areas, an analyses of the effects on the waste stream of the anticipated investments (short and long term) have been conducted. Some of the results are:

- A much larger percentage of the waste will be collected: up to 95% of the generated waste implemented up to 2025 and onwards (see figure 2)
- Service provision will be extended to nearly all households, in urban as well as rural areas gradually, starting from 2018
- Dumping of waste is planned to cease, and waste will be taken to sanitary landfills and proper recovery installations (see figure 3)
- The waste management unions will be able to comply with the requirements in the Turkish regulation regarding recycling of packaging waste
- However, only one region will be able to comply with the requirement regarding landfilling of biodegradable waste whereas seven Unions will achieve significant improvements (see figure 4)
- None of the Unions will comply with a requirement for recycling of 50% of the waste

Only if full-scale MBT plants (or other plants with similar effect) are set up can the project areas expect to comply with the European/Turkish landfill regulation regarding BMW and the (future) requirements for recycling. However, for affordability reasons (see below) MBTs are not suggested for the project areas. In one case, however, will the requirements be complied with, namely in the area of Ordu on the Black Sea coast. Here, a system of MRF plants with RDF production and bio-drying of wet organic waste for SRF production is proposed to be implemented[1]. The system is unique because a local cement industry has a demand for the produced RDF/SDF and has made an agreement with the City to take the waste for free.

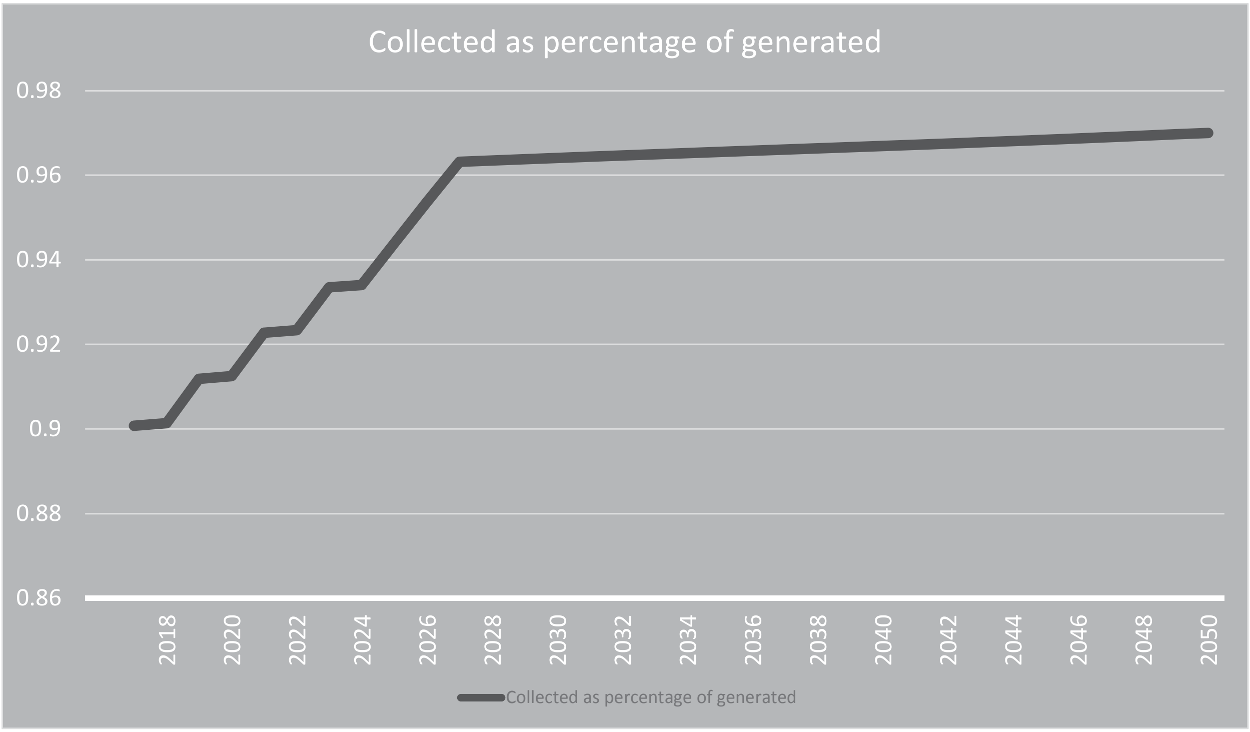

Figure 2 Collection of MSW, Akdeniz Union 2018-50. As can be seen, increasing amounts of MSW will be collected

[1] RDF=refuse derived fuel, SRF=Solid recovered fuel.

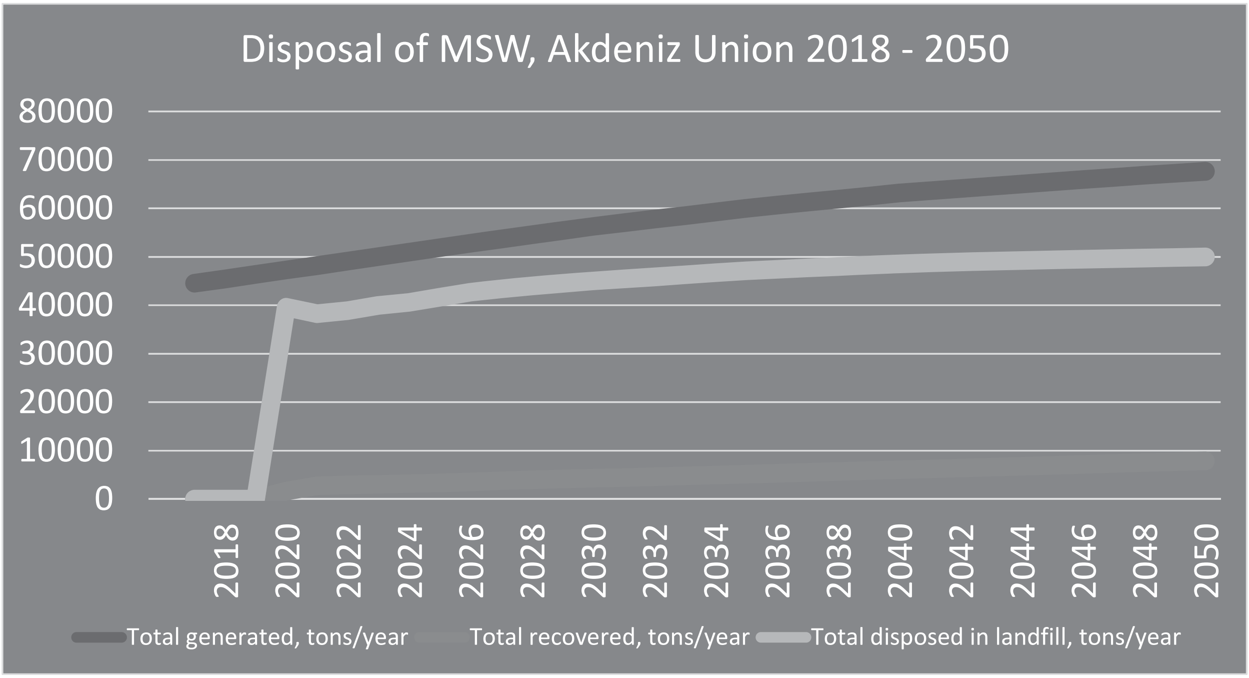

Figure 3 Disposal of MSW, Akdeniz Union 2018-2050

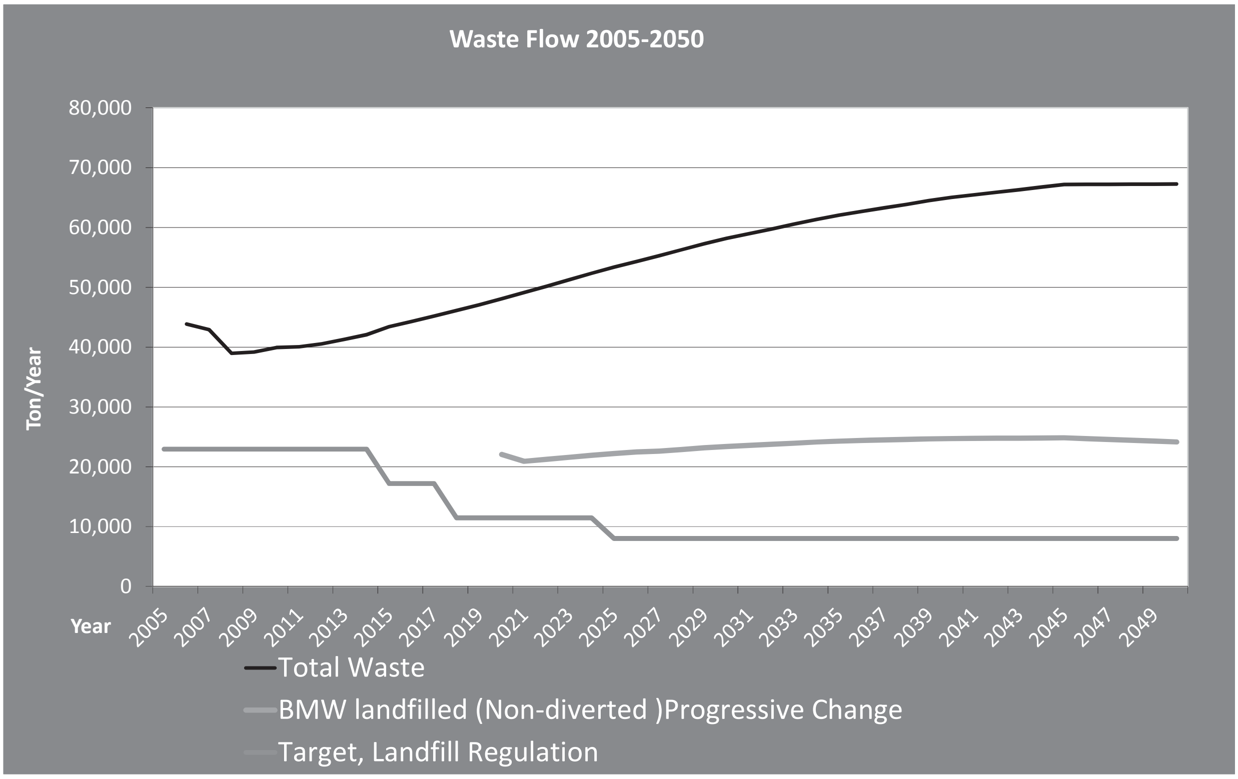

Figure 4 Typical waste flow diagram for BMW, Akdeniz Union. As can be seen, the target is not achieved completely

5 Affordability

Three scenarios have been set up for each of the eight projects areas, indicating

- a "do-nothing" situation,
- "gradual change" and a
- full-scale MBT scenario.

In the "do-nothing" scenario, investments are restricted to new landfills and additional collection equipment. In the "gradual change" scenarios, additional investments are made in MRF/composting and other recycling measures, whereas the MBT scenarios have been designed with full scale MBT plants to process a major part of the waste stream. The "do-nothing" as well as the "Gradual change" scenarios are in all instances affordable to the population with affordability ratios below or about 1% of the household income (which is the commonly used threshold). In none of the project areas are the MBT scenarios affordable, with affordability ratios well above 1%.

For the "Gradual change" scenario, full cost recovery tariffs have been indicated in the range of EUR 38 – EUR 58 per tons with the average around EUR 47 per tons. The proposed tariff for the population is in average for all project areas EUR 37 per tons of waste. The current payment – which is linked to the water bill and called ECT (Environmental Cleaning Tax) is around or below 50% of the indicated full cost recovery tariff. In this connection it must be mentioned that not all Environmental Cleaning Taxes can be collected from the population in the current situation. In any case, the future system will impose larger user payments if the principle of polluter's pay is to be adhered to and tariff collection is to cover the costs of the entire waste management system.

6 Risks and barriers for future sound waste management - Conclusion

The transition from the current waste management system in the project areas in Turkey to a system based on modern principles both in terms of technology (sanitary landfills not dumpsites, segregated collection systems not mixed waste collection, MRFs and composting), organization and financing (full cost or nearly full cost recovery tariffs) will be demanding.

A number of risks exist that the future system will be malfunctioning despite investments and implementation of the proposed projects:

If the public entities cannot acquire the required capacity and capability for management of the more advanced technological systems and thus leave the management to private operators based on ambiguous contracts and at the same time do not implement a proper tariff collection scheme the risk is that waste will still be dumped in an uncontrolled manner because the problem of gate fees cannot be solved: The municipalities cannot cover the gate fees because tariffs cannot be collated, the operator denies the waste access to the landfill and municipalities (or operators of the collection system) have no alternative but to dump the waste in former dumpsites or in new.

If economic incentives are not removed and regulation enforced, street scavenging may not discontinue which will render the planned MRFs in part needless, however maintain very poor working conditions for waste workers and leave a considerable part of the waste unprocessed for recyclables.

Consumers will reject the idea of source segregation and separate collection systems for different types of waste. This may be based on a kind of arrogance towards waste issues (historically taken care of by the lowest in society), low levels of public education and environmental consciousness, and the common phenomenon "out of sight, out of mind".

In the project areas in eastern and central Turkey waste is still not regarded as a resource but something that needs to get out of sight as quickly as possible. For reasons of affordability it is not possible in the short term to implement technical systems by which recycling and recovery can significantly be boosted, and from an environmental point of view sound disposal in engineered landfills should also have top priority – for a long time to come. Only when the population actually learns what the real cost of the waste management amounts to it may be possible to convey a better understanding of the need for perceiving waste as a resource (only if paid for has the waste value). This takes – on the other hand – a targeted effort from the Government in terms of concrete enforcement/implementation on the local levels of the tariff regulation and other waste management regulation. Without this, the current situation will by and large continue.

7 Project details

The project was awarded the Consortium comprising:

COWI AS, Denmark (lead), Poyry Evironment GmbH (later Lahmeyer, later GKW Consult GmbH), Germany, C&E Consulting und Engineering GmbH, Germany, COWI SNS Consulting and Engineering Ltd., Turkey, and MiMKO AS, Turkey.

Sub-consultants and partners are:

TUJA, Jeoloji İnşaat Mühendislik Harita Enerji Proje Turizm Sanayi ve Ticaret Ltd. Şti., Turkey (Surveyor and geotechnical services), Enviroplan S.A, Greece (Design of landfills and plants), G.E.O.S. Ingenieurgesellschaft mbH, and a number of independent Turkish consultants.

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MBT demonstration project in Tunisia

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Abstract

To test MBT for Tunisian a windrow composting system with forced aeration was installed. Composting trials have been conducted over the course of one year to determine seasonal impacts. To protect the windrows from sun and rain membranes were used to cover the windrows. In a first step the total waste was biologically dried, then RDF was separated by a simple screening steps. The fines were then further matured with the composting system to achieve a stable product. The windrows were turned once a week and irrigated as required. The composting process was computer-controlled and samples were taken and analysed during the whole process to monitor the drying and stabilization process. The results from these trials encouraged the Tunisian National Agency for Waste Management (ANGed) to establish MBT as part of their waste treatment strategy.

Keywords

Mechanical biological treatment (MBT); Refuse derived fuel (RDF); composting, biological decomposition of waste , semipermeable membrane, biological drying, stabilisation, forced aeration

1 Introduction and scope of the project

Tunisian waste is rich in organic and hence fairly wet. This causes technical problems and adverse environmental effects when landfilled. But next to the formation of leachate and landfill gas also operation problems were observed especially at pit landfills because of unsufficient drainage of the leachate which resulted in situations that the whole waste is soaked with leachate and hence the mechanical stability is reduced.

The main objective of the pilot test was to prove that the PMB is a feasible solution for the conditions in Tunisia and an adequate option to overcome some of the problems mentioned above.

The specific objectives of the treatment to be tested were:

- Minimize
  - the emissions of odours, landfill gas and leachate
  - the need for water and energy
  - the remaining waste to be landfilled (quantity and emission)
  - system costs
- Optimize the biological decomposition
- Evaluation of the opportunity to use the stabilized organic matter as low quality compost
- Determine the potential to produce secondary fuels (RDF)
- Identification of the optimal method for mechanical and biological processing steps under the conditions in Tunisia
- Determine the need for adaptation of the system of MBT to Tunisian conditions
- Definition of treatment targets for MBT in Tunisia

2 Installation of the Demonstration plant

The demonstration plant was established at an existing small, windrow composting facility in Béja located in the north-western part of Tunisia in the Medjerda valley. For the trials some modifications were installed:

- An aeration system for 2 windrows (40 m length)
- Semipermeable windrow cover sheets were used to protect the windrows from sun and rain (in the winter) and to reduce the odour
- A windrow turner was rented to enable mixing of the waste and turning of the composting windrows
- The existing machines (shredder, screen, tractor) were repaired
- Some new equipment for the lab was brought to Béja to enable accurate monitoring of the trials

The operation of the trials was mainly done by the staff of the site with supervision from the project team.

The monitoring of the trials, sampling and lab analysis was done by students from Tunisian university and Rostock University (Germany). For these tasks the students were trained by the international MBT expert (Innsbruck University) and the supplier of the composting technology (Compost Systems, Austria).

Figure 1 : Compost plant for the demonstration trials

It was planned to conduct trials during the summer and during the winter season to determine the impact of summer and winter climate both on the waste composition and the decomposing conditions.

For the trials household waste from Beja was used. The waste was delivered to the MBT site and samples were taken from the fresh waste to determine the composition of the waste and conduct lab analyses. The analyses of the samples were started but due to organisational issues a lot of results are still pending. For this report the data so far available were used and amended with experiences and data from other investigations in MBT facilities and scientific projects. More results will be presented in the final report.

3 Results

3.1 Waste characterisation

From all trials representative samples were taken from the fresh waste after delivery and sorted by hand into different fractions.

The results are summarized in Figure 2. The waste consists to more than 60 % of organic material, which is mainly food waste. The next largest fractions are textiles (8.5 %), followed by nappies (6.3%) and plastic film (5.1%). Paper and Cardboard combined contribute with 7.2 % to the waste composition. All these materials have a high calorific value and can be utilised to produce Refuse Derived Fuel (RDF), which can be used e.g. in cement factories.

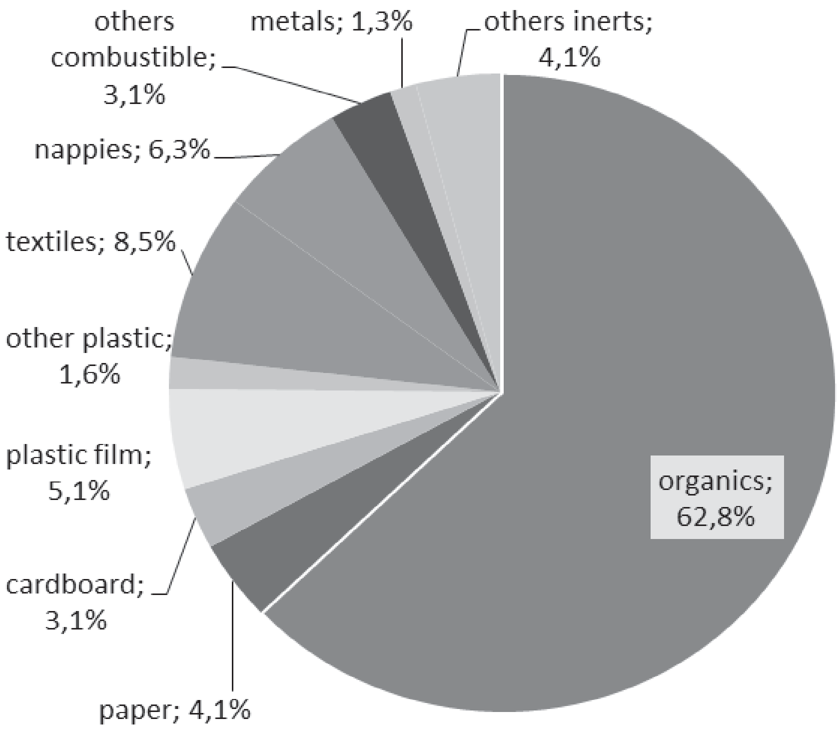

Figure 2 : Composition of household waste from Beja, average of three analyses (June, July, August 2014)

3.2 MBT concept and mass balance

Due to the leachate problems with the Tunisian waste the first aim of the mechanical-biological treatment is to reduce the moisture content of the waste.

To facilitate an efficient composting process the delivered waste bags were opened and the waste was mixed. Furthermore a forced aeration system was installed to ensure that sufficient air is blown into the waste which is necessary to provide optimum conditions for composting. During the composting of the waste a lot of heat is produced with temperatures rising up to 70 °C and above. Due to this heat the water in the waste is starting to evaporate. Only during the first days of the decomposing process small amounts of leachate (less than 1 % of the waste mass) were observed. The aeration also drives out the moisture.

In addition to the evaporation of water the forced aerations helps to establish optimum composting conditions and to reduce the production of odorous substances. To further reduce the emission of odour to the environment the windrows were covered with a membrane. The other purpose of the membrane is the protection of the composting windrows against sun and rain.

To maintain optimum composting conditions the piles were turned and mixed once a week using a composting turner. As the aim was to dry the waste no water was added in this stage of the process before screening the waste after 3 weeks.

After three weeks of composting the waste was fairly dry with a moisture content between 20 and 30 %.

The mass was reduced by approx. 40 %. In other words: If this material would be landfilled 40 % less volume would be needed. Furthermore no leachate would be produced if the landfill was carefully covered to protect from rainfall.

After three weeks of composting and drying the waste can be screened efficiently into a coarse fraction with high calorific value which can be used as a basis for the production of substitute fuel, e.g. in cement kiln or combustion facilities. The coarse fraction may have to be further mechanically processed (e.g. air separation, shredding, etc.) to produce a product which is suitable for the utilisation process.

3.3 Characterisation of the coarse fraction

A 80 mm drum screen was used to separate the coarse fraction > 80 mm from the fines fraction < 80 mm. Approx. 20 % of the waste input was found to be > 80 mm. From this material samples were taken both for lab analysis and waste characterisation (by means of hand sorting). Figure 3 shows the composition of the coarse fraction.

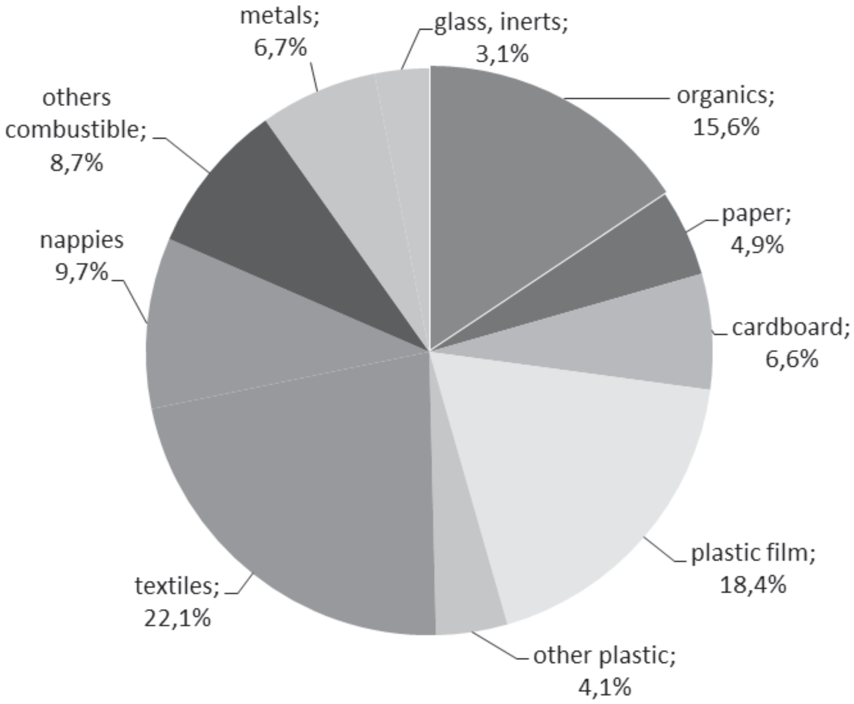

Figure 3 : Composition of screen overflow > 80 mm after 3 weeks composting of household waste from Beja, average of three analyses (July, August, September 2014)

The proportion of plastics, textiles, nappies and paper/cardboard are increased compared to the fresh waste composition. There is still some organics in the coarse fraction but this can be further reduced by optimisation measures.

The heating value of this material was determined with 13 MJ/kg.

3.4 Composting of the organic fines

The fines smaller 80 mm (40 % of the waste input) were then further composted. A prerequisite for efficient composting and further mass reduction an optimum moisture content of 40 – 50 % in the composting pile has to be maintained. As the material had a lower moisture content of 25 - 30 % after the screening water had to be added. After adding water the material was mixed again and further composted. During this process also water is lost and has to be added if needed. Therefore samples were taken once a week and water was added.

Over a period of 6 weeks approx. 1,500 l of water was added to 1 ton of fines materials after screening. This means approx. 600 l moisture is required in relation to 1 ton of fresh waste that this processed. It has to be stated that these figures was derived from the trials in summer where the ambient temperature is high which also causes some water loss. In the winter with colder temperatures the water required for irrigation might be lower. These figures are going to be evaluated during the trials presently (February - April 2015) carried out.

3.5 Separation of low grade compost

After the composting of the fines fraction further approx. 15% of mass reduction was achieved. The material after composting mainly consists of stabilized organic material similar to the organic material of compost but it is mixed with impurities like plastics and glass particles. To produce a product with lower concentration of impurities the stabilized organic fraction was screened with lab screens at 10 mm. From the stabilized waste after 10 weeks of composting the compost was fairly dry and therefore well suited for screening. The proportion < 10 mm was approx. 50-70% of the stabilized waste. Since the amount of stabilized waste was 25 % of the input waste to the trials (fresh household waste) this means that 10-15 % of compost related to the input material can be expected. Further screening tests were done with 5 mm and 2 mm. The compost derived from this screening was lower in quantity but also the compost was lower in impurities. It has to be stressed that screening at 5 mm and even more 2 mm is only possible with dry material. The dry matter content of the compost was 78 %.

3.6 Stabilisation

Alongside with the mass reduction during the composting process the waste gains an increasing stability against further degradation in the landfill. The better stabilized the waste the less landfill gas will be produced in the landfill.

The stabilisation can be measured with the biological test parameter «respiration activity» AT4. The AT4 analysis was not known in Tunisia so far and therefore it first had to be implemented and tested. This process is still ongoing. Based on preliminary results the stabilisation was quite good and in a same range as with similar composting installations in Europe.

3.7 Mass balance

Figure 4 shows the mass balance of the summer trials in Beja. The RDF preparation from the screen overflow was not tested in large scale but was calculated based on the composition analysis of the screen overflow > 80 mm.

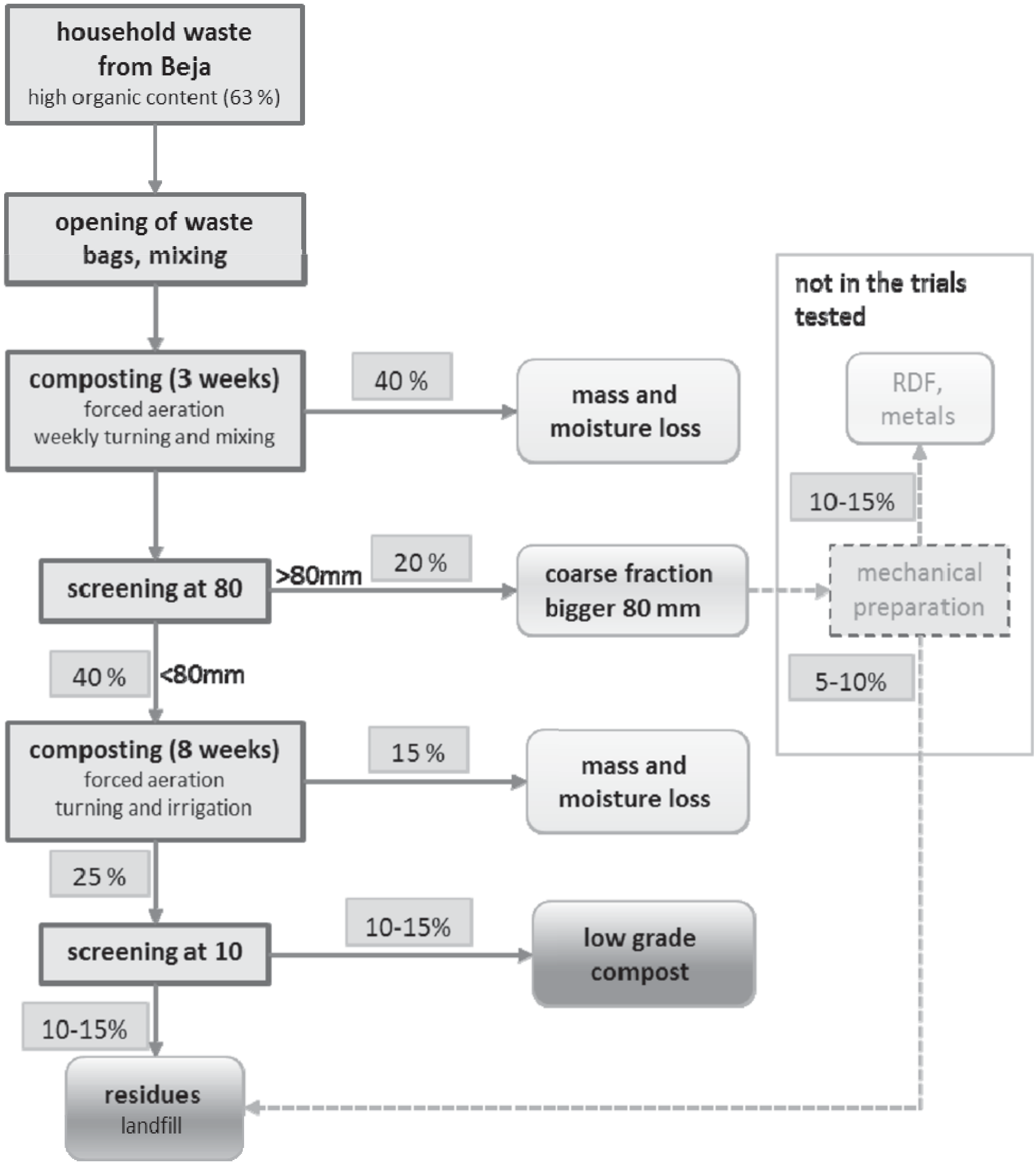

Figure 4 : Process steps and mass balance of the summer trials Beja

4 Conclusions

The MBT trials conducted in summer 2014 at the composting facility in Beja showed that Tunisian household waste can very successfully be treated with mechanical-biological waste treatment.

The waste of Beja was rich in organic and fairly wet. To ensure an appropriate treatment a forced aeration system was installed to supply the waste piles with the required oxygen and to drive out of the moisture. Furthermore the waste was mixed once a week and irrigated with water later in the process.

This treatment process allowed drying of the waste within 3 weeks. This enabled an efficient screening of the waste to separate the recyclables and high calorific components from the organic fines fraction. The organic fines fraction was then further composted to further reduce the waste quantity. Furthermore the waste was stabilized and hence the formation of greenhouse gases was substantially reduced. The stabilized organics could then be refined to separate a low grade compost which can be used for various purposes: landfill cover, land reclamation, road construction, etc.

The trials could demonstrate that an efficient waste treatment can be achieved with a fairly basic and low-cost MBT concept and appropriate technical and operational measures:

- Reduction of the landfill volume required by 60 – 80 % depending on the overall concept
- Substantial reduction of air emissions from the landfill, in particular greenhouse gases
- Minimisation of leachate emissions from landfill due to the dry waste which is landfilled
- Utilisation of landfill leachate water for the stabilisation process
- Production of a substitute fuel for industrial processes / cement kilns

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Material-specific waste treatment as an integrated component of RETech export

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Abstract

The German Recycling Technologies and Waste Management Partnership e.V. was established at the end of 2011 as a result of the Recycling and Efficiency Technology Initiative of the Federal Ministry of the Environment. RETech activities are focused on the promotion of applying sustainable environmental technology of German recycling abroad. RETech supports all areas of waste management. German knowhow and German technology can help to improve the situation of waste management worldwide. By the example of Arab states and the PRC, this paper briefly outlines the status of waste management and points out the potential for German manufacturers and consultants.

Keywords

RETech; China; Arab states; Waste management; Mechanical-biological treatment (MBT); Refuse-derived fuel (RDF)

1 Introduction

The waste management industry must increasingly align itself to the provisions of sustainable resource and climate protection goals. One of the central global tasks of the future in this field is the ensuring of a sustainable – in other words economically, ecologically and socially sound – supply of raw materials and energy. The waste industry can make an important contribution in both fields. In Germany a positive interim balance can be drawn here. Especially the positive ecological effects of the avoidance, utilisation and disposal of waste have been confirmed by numerous scientific studies. In Germany the recycling industry now makes a significant contribution to climate protection, whereas in many developing and emerging countries around 10 to 15 per cent of the climate-relevant emissions come from waste-industry processes. The construction of modern waste and recycling management therefore makes a significant contribution to the solving of these global future tasks.

Germany and its waste and recycling industry can be seen as an international model. The already highly developed recycling management is characterised by the following values:

- Around 15,000 waste management plants form an extensive infrastructure
- More than 60 per cent of household waste is directed to recycling
- Nearly 80 per cent of all waste is directed to reprocessing
- More than 15 per cent of the raw materials required by industry are recovered from waste
- Since 2005 only pretreated waste can be disposed of

Waste management technology from Germany has a world market share of around 25 per cent

Against this backdrop there is significant interest in German technology and in corresponding knowledge transfer. German companies from the waste management and recycling industries offer thanks to their technology leadership relevant, tested and competitive solutions. This development offers German companies – especially SMEs – as well as scientific institutions good prospects in international markets that should be taken advantage of even more in the future.

A modern waste management industry belongs alongside water and energy supply, education and health-care provision, and mobility to the basic infrastructures of a society. Examples in many countries show that organised waste management is a central foundation of the prosperity of a society: healthy living conditions, civilised cohabitation and sustainable economic development demand an appropriate approach to the waste materials of our economic activity and consumption. Waste management not only makes important contributions here in the protection of the environment, resources and health, but also offers extensive employment opportunities.

Germany has made it its task to support countries in completing the presented development steps as quickly as possible in the construction of their waste management industries. Instead of conventional solutions (depositing), the country supports the construction of recycling management systems that have the goal of recovering as much energy and as many secondary raw materials as possible from waste and of minimising the amount of waste that is dumped.

For this a unique alliance has been formed that is financed by German RETech Partnership e.V. (RETech). Well-known German companies and institutions of the waste management and recycling industries have come together under this umbrella. They span research, planning, machinery, logistics, operations and the marketing of secondary raw materials. RETech is supported by the German Federal Government, especially the Federal Environment Ministry, the Federal Ministry for Economic Affairs and Energy, and the Federal Ministry for Economic Cooperation and Development, which contributes knowledge and support. The organisations UBA, SRU, GTAI, GIZ and KfW are also involved, which support the work in an advisory committee along with the organisations of the waste industry branch BDE, bvse, VKU, VAK and VDMA.

2 RETech – formation, aims and example markets

2.1 Formation

The German Recycling Technologies and Waste Management Partnership e.V. emerged at the end of 2011 from the 2007-founded Recycling and Efficiency Technology Initiative of the Federal Ministry of the Environment. The German RETech partnership is the network of companies and institutions of the waste disposal and recycling industries in Germany for the export of innovative technologies and knowledge transfer with the aim of establishing suitable waste management around the world. The focus of the activities of RETech is the promotion of the use of the sustainable environmental technology of the German recycling industry abroad.

RETech is the contact for all public and private organisations and institutions in Germany and abroad with an interest in German resource and efficiency technology. Through the support of public bodies, RETech achieves the preconditions for the successful export of German technologies and services already at the conception and planning stages of waste management infrastructures and measures.

RETech offers a neutral platform for companies interested in innovative technologies for recycling and waste management issues and their export. Within this platform members may exchange information on technical issues such as the financing or the hedging of foreign business. To establish a network of actors supporting the export of German recycling and waste management technology as well as the transfer of knowledge, RETech cooperates with ministries, subordinated authorities, institutes and associations both in Germany and abroad.

Membership of RETech is open to all natural and legal entities with the exception of organisations, provided they are active in the field of recycling or their activities are affected by it. Members correspondingly come from all fields of the waste management sector along the value chain of a resource-efficient waste industry. The number of members has increased from 12 at the founding of RETech at the end of 2011 to over 40. Thirteen new members joined in 2014 alone.

2.2 Aims

An efficient waste disposal industry makes an invaluable contribution to climate and resource protection, is a precondition for the health and hygiene of the population in interaction with waste, creates jobs and thus promotes economic development. German knowhow and German technology can make an essential contribution to the construction of efficient waste disposal structures. This field also represents an important export market for the German economy.

However the opening up of new markets in the field of waste and recycling management differs quite considerably from the fields of investment and consumer goods as a result of contracting authorities at the local level. Contracting authorities do not immediately behave as purchasers, but generally implement competitive tendering procedures to build infrastructure and to ensure the services related to collection, transport, sorting, reprocessing and disposal. Before a decision can be made on the drafting of this tendering procedure extensive conceptual spadework is required related for example to questions of the type and quantity of the waste to be collected, the configuration of collection structures, the use of sorting technology and different handling processes, the possibilities for recycling and any other reprocessing as well as finally the environmentally friendly disposal of waste. In these processes the demand for German technologies and services as a precondition for successful export is clear.

The demand for support from Germany and for contacts from ministries, public authorities, industry-relevant institutions, universities, manufacturers and service providers in the development of disposal structures is very high as a result of the responsible public authorities in developing countries (ministries and regional and local governments). RETech unites under one umbrella the above-mentioned contacts and members from all fields of the disposal chain.

For the work of the RETech export initiative, above all the following aims emerge from the highlighted situation:

- Improvement of the export preconditions for companies in the recycling and disposal industries
- Strengthening of the competitiveness of German SMEs and promotion of the marketing of sustainable and innovative recycling and efficiency technologies
- Promoting knowledge transfer

- Construction of a network of ministries, lower-ranking authorities, scientific institutions and organisations that supports the export of German recycling and disposal technology as well as knowledge transfer
- Development and strengthening of the international waste management standards in particular in developing and emerging countries
- Supporting politics in Germany and abroad in the establishment of a regulatory framework for waste management
- Supporting foreign partners in the application of sustainable environmental technology and sustainable environmental management

The successful implementation of these goals creates the preconditions for a successful export business in the German waste management and recycling industries.

2.3 Importance of a material-specific consideration in the development of resource- and environmentally friendly waste management structures

Across the globe, the waste management industry finds itself in the construction phase in many countries – still in an early phase in developing and emerging countries and in very different configurations in the industrial regions. At first glance the concepts differ from one another strongly, but upon closer inspection the provided technology available around the world forms the leitmotif of the concepts. The handling of large quantities of municipal solid waste is only possible through the use of modern technology, which is why the waste management concepts are to be adjusted to the standards of the technology and develop under this pressure in a joint direction. The technology permits many variations and the political organisation is set few boundaries. The RETech working group “domestic waste” deals with these fundamental considerations concerning the approach to the establishing of resource-friendly and environmentally friendly waste management adapted to the respective local circumstances. The concepts adapted to the local circumstances (societal, financial, cultural and technical) are fundamental preconditions for the successful export of German technology. In a first step, the following five-stage model of waste management as a basis for capacity building is developed.

STAGE 1:

Waste dumped freely, no organised waste collection, recyclables (steel scrap, metals, plastic bottles, paper, etc.) occasionally collected by the informal sector and find their way over many stages back in the reusable material cycle. People live on the edge under inhumane conditions. Town hygiene and plague prevention, environment and climate protection only rudimentarily considered. Domestic fires for heating and cooking are widespread.

STAGE 2:

Introduction of container collections and the first organised landfills; transfer stations at good transport connection points simplify the economic transport. The sorting plants comprise mechanical separation steps and sieve and sifter plants, and prepare the material for hand sorting. The first trade structures for recyclables that meet an industrial need and generate returns are created (RDF, PET, paper, etc.). The composting of green waste in simple plants with the aid of mobile units represents the first step of biological treatment.

STAGE 3:

Waste collection with the aid of modern waste collection vehicles, separate collection in multiple containers as a basis for high-quality sorting. The first optical separators allow the generation of high-value monofractions. A downstream recycling economy is formed because the input quantities are ensured. Very different industry processes are adapted to these materials. Significant numbers of jobs are created and waste management becomes part of industrial policy.

STAGE 4:

Modern sorting plants generate high-quality separated fractions. Colour sorting and separation of plastic monomers is introduced. In mechanical-biological treatment (MBT) centres composting and fermentation plants ensure the breakdown of the organics.

STAGE 5:

In this stage high recycling rates are achieved. The "self-supporting waste management" leads to a functioning closed loop recycling management. Only small residual quantities are deposited or burnt without risk to the environment. Waste avoidance and life cycle considerations are the basis for all production processes.

Mechanical waste separation gains particular importance at the latest by stage 3. Alongside the technology however further fields in the target regions and countries must be developed in parallel so that the higher stages of waste management can be reached. This affects the fields of politics, society, market and financing. Also in these fields the objective analysis and the definition of measures are essential preconditions for the further development towards resource-friendly and environmentally friendly waste management and the successful export of German technology.

2.4 Marketing of M(B)T technology abroad

Alongside the many changes that the waste management industry in developing and emerging countries should go through, technologies for the pretreatment of municipal solid waste (MSW) should also be established. China in particular has opted for thermal treatment in recent years (Nelles et al., 2015). Different technologies for mechanical-biological waste treatment offer sensible solutions for waste pretreatment. This allows the recovery of secondary raw materials as well as significant reductions in the proportion of waste that needs to be deposited or fed to an incinerator. In some countries above all the high-calorific fractions that can be separated from the municipal waste has awoken interest. Especially the cement industry has shown interest in the exploitation of the high-calorific fraction as a refuse-derived fuel. A biological step is not essential for every pretreatment. The mechanical preparation is only applied for the separation of material flows.

Mechanical treatment plants can be constructed from a wide range of components. The mechanical process engineering encompasses shredding, grading (i.e. separation according to particle size) and sorting (i.e. separation according to other physical and chemical characteristics). Material handling technology and possibilities for the storage of different waste flows complement the treatment plant. A range of machines are combined and adjusted to the waste to be treated. The machines must also be adjusted to the plant input. Alongside the municipal solid waste primarily described in this paper, there is also a wide range of industrial waste. The mechanical processing of mineral building waste, especially construction waste, generally requires completely different shredding plants than for the shredding of plastic waste.

Refuse-derived fuel can be isolated from municipal solid waste in a mechanical step. Sometimes filtering is all that is required. The mechanical processing of municipal solid waste also separates other exploitable material flows from residual waste. Metals – both ferromagnetic and nonferrous metals – are the best known recyclable materials. Modern optical separation methods allow the recovery of other recyclable materials, such as the plastic polyethylene terephthalate (PET). Optical separation methods are also used in refuse-derived fuel processing; polyvinyl chloride (PVC) can be separated in order to improve fuel quality.

The biological steps of the MBT process serve the stabilisation (inertisation) of the organic components in waste. If the waste separated from the high-calorific fraction is to be deposited in a landfill site, it must be stabilised (i.e. rendered inert) so that no further biological decomposition of the organic substances can occur. The MBT process, which also converts the organic waste in the refuse-derived fuel fraction, dries and stabilises all waste delivered to the MBT (the two right-hand drying processes in Figure 1). The refuse-derived fuel yield is greater in this process than in the process that deposits the stabilised (i.e. rendered inert) organic waste. In the drying processes the water content reduction in the waste can occur biologically or physically. The processes that reduce the water content biologically use the heat generated in the aerobic treatment to evaporate water (MBS – mechanical-biological stabilisation). The waste can however also be dried using heat or waste heat generated in the combustion process. A rotating, heated drum is loaded with waste to be dried (MPS – mechanical-physical stabilisation).

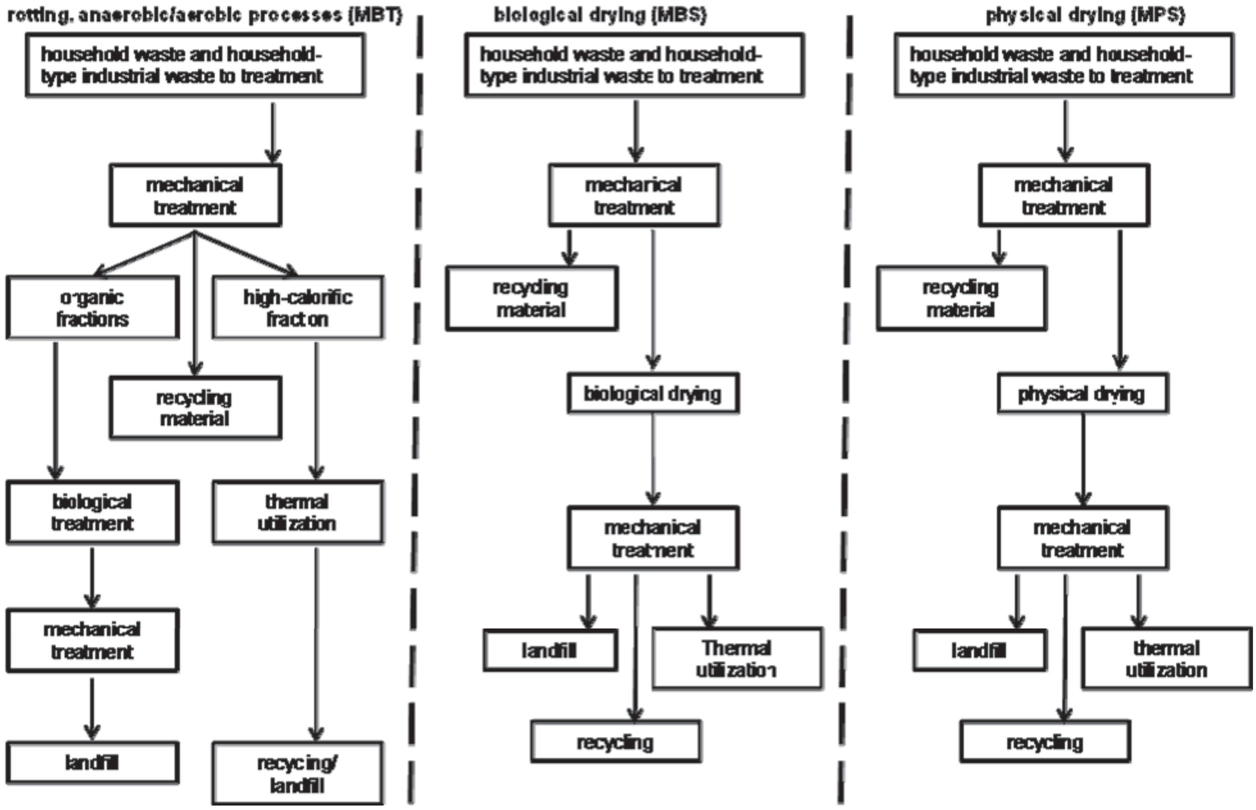

Figure 1: Process engineering of the mechanical-biological waste pretreatment

The waste industry must increasingly orient itself to the standards of sustainable resource and climate protection goals. The recovery of refuse-derived fuel can make a small contribution. Material-specific waste treatment with mechanical-biological waste treatment as the switching point of material flow separation with energy-efficient treatment and recycling of the individual flows offers a good starting position not only in Europe. The technical execution of MBT can be flexibly adjusted to the respective requirements and frameworks. Germany is seen in many countries (for example the Arab states, China and India) as a model country for waste management and its waste management concepts and the realised plant technology enjoy a good reputation. This needs to be capitalised on and the global development of waste management as a future task to be understood.

MBT is constructed from different components and machines. Many of these components are already constructed in the target countries. In some cases German companies have established subsidiaries. Structural and civil engineering components can be built by local firms in developing and emerging countries. The establishing of MBT technology proves equally difficult, as is the case for other changes in waste management that are connected to changes in the organisation and investments.

3 Examples of German activity in waste management

Around 300 million people live in the Arab states, and most of the countries can be described as developing countries. Exceptions are Saudi Arabia, the United Arab Emirates, Qatar and Kuwait. The Department of Waste Management and Material Flow of the University of Rostock has been active in the Arab states for more than 15 years and has been able to gain pertinent experience and develop appropriate solution approaches, and in some cases implement them. The Arab Spring and its repercussions have however also negatively affected projects. Some countries currently simply have “bigger problems” than waste management. The situation will however make increased efforts in the environmental field necessary and possible again in the future.

The growing environmental consciousness in the region has meant that environmental protection is nonetheless on the political agenda. In nearly all Arab states however, waste management developments are still in their infancy. Most governments in the Arab states have recognised the waste management problems and want to implement suitable solutions. The situation is however characterised by a lack of clear legal standards, norms and functioning organisational structures. The need for coherent and concrete legal environmental frameworks is great, but so far mostly foreign regulations have been and are being adopted without adjustment to the local circumstances. The monitoring and supervision of waste management practices is not possible due to the frequently unclear and too generally observed legal standards. The determination of responsibilities in implementation is inadequate. Controls are not undertaken and the existing laws are not adhered to. As a result of the instable political situation in the Arabic region delays will occur in the further development of the waste management structures, although the extent of these delays cannot currently be accurately determined.

In **Egypt** local production centres exist for basic sorting plants and composters. There are a handful of autonomously built waste treatment plants, but most of them have not proved reliable in practice. Targeted technical and organisational concepts are urgently required. Most waste and sorting residue is deposited. The large cities have modern landfills, whose operation however has much optimisation potential. Only a few recyclable materials are separated; these are sold nationally and internationally. There are no thermal recycling or treatment plants for waste. There is interest in M(B)T plants, although international firms only have a chance with technically highly developed solutions as the market for simple technologies is controlled by domestic companies. Financing must however be ensured, which so far has only been achieved in a small number of cases. The current concrete project developments are based primarily on mechanical processing plants for recyclable materials that can be exploited domestically and internationally. This also impacts the processing of high-calorific fractions for thermal utilisation in cement works, where demanding procedural solutions are required. The German government (GIZ) supports Egypt in the establishment of sustainable waste management. The following measures are currently being supported:

- Establishing of a waste authority
- Introduction of separated collection
- Implementation of product stewardship using the example of tyre recycling
- Utilisation of refuse-derived fuel from waste for the cement industry

In **Saudi Arabia** there are different waste treatment plants that have been built in the past two decades but in some cases have only been in operation for a short length of time. Depositing is the most common form of disposal, with several modern landfills available for this purpose. Incineration plants are used only for hospital waste. In Jeddah, Riyadh and other cities, negative experiences have been had with MBT plants due to poor constructional and procedural planning as well as flawed operation of the plants, which were then mothballed after a short time. The local firms are in the current perspective not in a position to conceive, construct and operate useful MBT plants. The legal framework does not oblige waste treatment, which makes it difficult to implement ecologically sensible MBT concepts. Improvements are planned in the environmental-legal field, but it is not assessable when these will become effective. Advanced MBT technology currently only has a realistic opportunity when large projects are awarded to foreign general contractors. Corresponding concepts should however in these cases be discussed in advance with the responsible ministries and city authorities. GIZ International Services advises Saudi Arabia on waste management and is a good address for the consultation and initiation of projects.

In **Lebanon** there are a few smaller waste treatment plants (sorting and composting). Local engineering offices have made plans but are frequently overwhelmed. Most projects are poorly planned and implemented from a constructional and procedural perspective. Lebanon has limited space for landfills or other solutions that require large amounts of land, so that a trend towards incineration options (for example in cement works) can be identified. In the city of Saïda a modern MBT plant with integrated wet-digestion stage was constructed in 2005 already. The plant has been in operation since 2013. Here it should be critically noted that it does not make sense to establish technologies in the framework of developmental aid projects that even in highly developed Germany have been associated with considerable operational problems in the past and to a certain extent still to this day.

In 2015 calls for tender will be made in the fields of waste collection, street cleaning and waste disposal. Calls for tender are also planned in the field of waste treatment. A recycling rate of 75 per cent from around 2020 is targeted. Waste management in Lebanon is also demanded as a result of the flow of refugees from Syria.

In **Jordan** there are still no plants for residual waste treatment. Waste management is however a central theme in the framework of the cooperation with the World Bank. Landfills and transfer stations will be financed in this way. The recovery of recyclables, the production and recycling of refuse-derived fuel in the cement industry and the biological treatment of waste are current topics. European engineering offices are being contracted to develop initial concepts and feasibility studies. The pilot project “Simple MBT” in the city of Amman is in the preparation stage. Building on this, further MBT projects could be developed in the coming years, with procedurally simple mechanical processing and aerobic treatment especially in demand. Up to now the German government has above all supported schemes for water supply and disposal; since 2015 waste management projects are also being promoted.

> In the framework of the German financial cooperation with Jordan a scheme in the field of municipal solid waste disposal is to be promoted. The goal is the construction of resource-efficient as well as environmentally and climate-friendly waste management through the introduction of a labour-intensive collection and recycling system in selected cities in Jordan. The main elements of the planned project, which also comprises a back-up measure, are consultancy services, delivery as well as internationally tendered construction works.
>
> The establishment of labour-intensive waste management is envisaged with separated gathering of recyclables and waste as applicable. This connects a simple primary collection process with an efficient, modern secondary collection system to a closed logistics concept and includes treatment and recycling plants. It is expected that at least 50 per cent of the generated municipal solid waste can be recycled. (Germany Trade & Invest, 2015).

For Amman a mechanical-biological waste treatment plant for the generation of refuse-derived fuel is in planning; the German government-owned development bank KfW is supporting the project. The introduction of separated collection aims to make recyclable material available. A waste disposal centre in Amman will serve as both transfer station and training centre. A project on aerobic or anaerobic treatment is planned for organic waste.

Jordan has also absorbed an enormous number of refugees from Syria. GIZ and the European Union (represented through GIZ) are supporting programmes in the north of Jordan that aim to manage the supply and disposal problems relating to refugee camps.

In **Tunisia** programmes exist that are supported by Germany (KfW) and other countries. No plant exists yet for residual waste treatment. The opportunities for MBT are good. The waste authority ANGed has with the support of KfW established the first MBT pilot plant in cooperation with the local and international private sector. The universities of Innsbruck, Tunis and Rostock are actively involved (Müller et al., 2015).

Kuwait has also had negative experiences with MBT. There is one MBT plant in the country, but it rarely runs and the decision-makers are critical of the MBT technology. Kuwait is very interested in German waste technology and would like closer cooperation in this field, which can be promoted via the RETech export initiative for example. Corresponding activities are currently underway at the Department of Waste Management and Material Flow of the University of Rostock in order to improve the chances of German MBT technology in Kuwait. The Fraunhofer Institute for Environmental, Safety and Energy Technology (UMSICHT) and the environment ministry in Kuwait City will develop a waste management master plan. The invitation to tender for a waste incineration plant has been issued, but the tender is currently on hold as the parameters are unclear. High levels of organic waste in residual waste reduce the calorific value; how waste incineration plants can circumvent this is a question asked around the world. Questions about the ecological tenability of burning organic waste also need to be considered.

Oman has tendered the management of its hazardous waste. The state authority for waste management, “be’ah”, is striving for improvements. A mechanical-biological waste treatment plant for 300,000 Mg/a is envisaged. The concept “waste to energy to water” is to be implemented here. Transfer stations and landfills are also to be established.

The **United Arab Emirates** has had many negative experiences in the field of waste management. The recycling rate of the collected municipal solid waste lies below 10 per cent; more than 90 per cent is deposited. Invitations for tenders for waste incineration plants have been issued, but no treatment plants have been constructed yet. The UAE lacks the experience with corresponding projects and technologies, and the financing by means of waste charges cannot be arranged. In Abu Dhabi a waste management centre will promote and coordinate waste management. A project for the capture and gathering of hazardous waste is already in place.

The Arab states still have much to do to reach an advanced stage of waste management. This is independent of the political or financial circumstances in the very different countries. Interest can still best be awoken by means of energy recovery from waste. Not all Arab lands have fossil fuels at their disposal.

The **People's Republic of China** has increased its efforts to establish waste processing technologies. Twenty per cent of municipal solid waste in metropolitan areas is pretreated and 35 per cent of waste is intended to be able to be burnt by 2015. In the developed regions in the east of China this should be possible for up to 48 per cent of waste (Tian et al., 2013). In 2012 at least 36 million tons of waste was thermally treated; in other treatment plants (different forms of MBT) up to four million tons was treated. The incinerator and MBT waste treatment technologies have to cope with the high proportion of native organic material and water – a challenge for both technologies. Mechanical-biological waste pretreatment has with different technologies the goal of final disposal of a majority of the waste or the conversion of as much of the supplied waste as possible to refuse-derived fuel. The improvements to the fuel characteristics can be large. Chen et al. (2007) reported that refuse-derived fuel through drying and fuel enrichment can achieve a calorific value of up to 17 MJ/kg and water content of under 15 per cent. The ALBA group has confirmed in multiple attempts in China that Chinese municipal solid waste can be processed into high-value refuse-derived fuel (green coal) through biologically supported drying. MBT fits into the attempts of the Chinese government (the 12th five-year programme) to increase the proportion of renewable energy to 11.4 per cent of total energy use by 2015 (Xinhua, 2011).

MBT is currently working with very different characteristics and a range of problems. These plants are frequently labelled compost plants. Frequently there is a lack of competent plant operation and a lack of possible uses for the separated waste flows. Some plants have been closed as the environmental regulations were not observed. MBT plants in Shanghai and Beijing have been affected by such problems. The opportunities presented by MBT for improved utilisation of the high-calorific fractions of municipal solid waste have not been sufficiently used.

3.1 Conclusion

Disposal contractors, mechanical engineers, engineering offices and universities have been engaged for many years in the establishing of MBT technology in developing and emerging countries. Despite financial support from the German Federal Ministry for Economic Cooperation and Development, GIZ and KfW and the application of private resources, the successes have been minimal.

The political goals of CO_2 reduction for climate protection offer an opportunity for the waste management industry. The reduction of waste depositing, the recovery of secondary raw material and the production of refuse-derived fuel can make an essential contribution. It can be seen that the recovery of refuse-derived fuel, which can then be thermally recycled, is currently the most interesting aspect of MBT for many countries. The cement industry around the world is interested in this fuel.

Waste sorting, mechanical treatment as well as biological treatment are internationally growing business fields for mechanical engineers, engineering offices, consultants and universities. RETech as an export network supports the industry in the capturing of these markets and has become the point of call for many international parties interested in German technologies and German knowhow.

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Experimental check of digestate processing via vermicomposting

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Abstract

The article examines potential processing of digestate via vermicomposting. The experiments focused on the assessment of the properties of vermicomposts produced from conventional biowastes and biowastes with added digestate. The properties of vermicomposts were examined by means of pot vegetation experiments, agrochemical analyses of the growth substrate and of the grown plant mass. The test confirmed that the application of vermicompost with added digestate had a positive effect on the nutrient intake by plants as well as on the quality of the growth substrate. Moreover, there were interesting differences in the contents of hazardous elements. For example, the content of lead analyzed in the substrate made from vermicompost and added digestate was 17.07 mg/kg, whereas in the substrate made from vermicompost only lead amounted to 24.49 mg/kg. In searching for various methods how to process digestate, vermicomposting appears as a feasible option.

Keywords

biowaste, vermicomposting, digestate, available nutrients, hazardous elements

1 Introduction

Biowastes make inseparable parts of life on the planet. As their quantities are growing, it becomes even more desirable to search for new methods how to utilise them as effectively as possible. Moreover, such efforts are also grounded in legislation, namely European Directive 1999/31/EC on the landfill of waste, which significantly reduces landfilling of biodegradable wastes.

Biodegradable waste may be used to generate power in biogas plants. Consequently, this technology produces waste in the form of digestate. Digestate is a stabilized material that contains undigested feedstock materials and necrotic microorganisms. Heviánková (2014) claims that, apart from hazardous or toxic elements, this residue of the fermentation process contains valuable substances which entered the technology in the feed biowaste (5). For more detailed analysis of digestate, see, for example, Botheju and Bakke 2010 (1), Kolář et al. 2010 (6).

In the Czech Republic digestate is applied as a fertilizer in agriculture. On one hand, a problem may be seen in the content of hazardous or even toxic substances, and on the other, that digestate is usually too liquid and the dry matter content is low. According to Heviánková (2014) research carried out by agricultural organizations often aims to increase the proportion of dry matter in the digestate, which is relevant in terms of the economy of fertilizing. As the maximisation of the benefits of the useful components may not be sustainable for the future, it is advisable to approach digestate in its complexity and also protect the environment (5).

A number of methods may be used to dispose of biowaste. Composting belongs among the most exploited processing methods for biowastes. Apart from environmental reasons, it is advisable to separate biowaste and compost it to acquire a high quality product to fertilise plants, to return nutrients back to soil, etc. Within this approach, vermicomposting, i.e. degradation of biowaste by means of earthworms, appears as a promising option. It has been verified that vermicompost fixes nutrients, helps their gradual release into the soil and improves the quality of the substrate (2, 4, 7).

For example, Krishnasamy et al (2014) tested possible preparation of vermicompost using digestate and wooden saw dust (7). Šupolíková et al. (2014) examined vermicomposting of waste paper fiber (9). Still, digestate is not a traditional feedstock in vermicomposting. The research herein aims to examine this option and find out the final effects, especially the exploitation of nutrients and other valuable components contained in the digestate. Via vermicomposting of digestate, we expected to increase the intake of nutrients by plants and their gradual release into the soil, and on the other hand, to decrease the intake of hazardous elements by plants.

2 Materials and methods

The article does not aim to provide as detailed analysis of the input and output materials as possible as we realize the input and thus the output materials will always differ. It focuses on the experimental testing of vermicomposting of digestate and its effect on the available nutrient contents.

The whole experiment started with the production of vermicompost and preparation of substrates. First, we prepared 2 types of vermicompost. The first included conventional biowastes and the second contained also conventional wastes with added digestate. As vermicompost is considered a fertiliser, it gets used mixed with soil. The obtained vermicomposts were mixed with soil to produce substrates in predetermined ratios of vermicompost to soil. To test the nutrient intake and for the purposes of the vegetation test itself, we carried out a pot vegetation experiment. Subsequently, we analysed the soil, biowastes, digestate, vermicomposts, and the grown green mass. Finally, all the values and results were evaluated.

The 2 types of vermicompost were made up from the following materials:

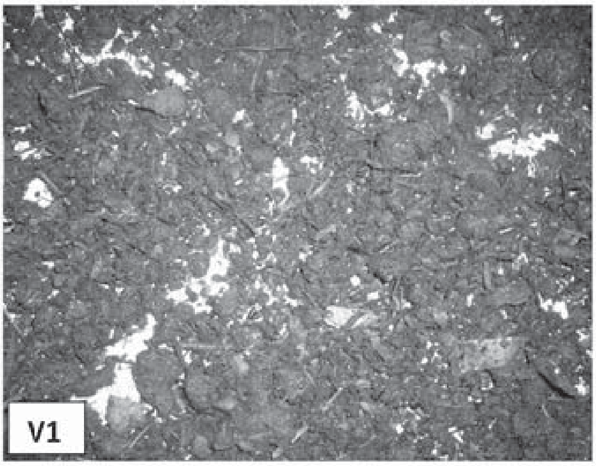
Vermicompost 1 (further referred to as V1): conventional biodegradable waste, i.e. horse manure, plant residues and waste (grass, leftovers from vegetable processing, gardening waste).

Vermicompost 2 (further referred to as V2): conventional biodegradable waste, i.e. horse manure, plant residues and waste (grass, leftovers from vegetable processing, gardening waste) with added digestate from a biogas plant in Stonava, Czech Republic.

For the experimental assays of vermicomposts, we set up a breeding patch for earthworms (Figures 1 and 2). Different earthworm species may be used in vermicomposting. Rajpal et al. (2014), for example, studied *Perionyx excavatus* and *Perionyx sansibaricus* (8). In this study we used *Eisenia andrei*. The breeding patch was divided into the check section containing the vermicomposted material (V1), and the other contained vermicomposted materials with added digestate (V2).

Fig. 1 Vermicomposted material 1 (V1) *Fig. 2 Vermicomposted material 2 (V2)*

In regular intervals, the earthworms were fed with the prepared mixture of biowaste and digestate resulting in V2, and biowaste without digestate resulting in V1. The overall process was monitored and lasted for 5 months. Gradually, the earthworms converted the wastes into vermicomposts (Figures 3 and 4).



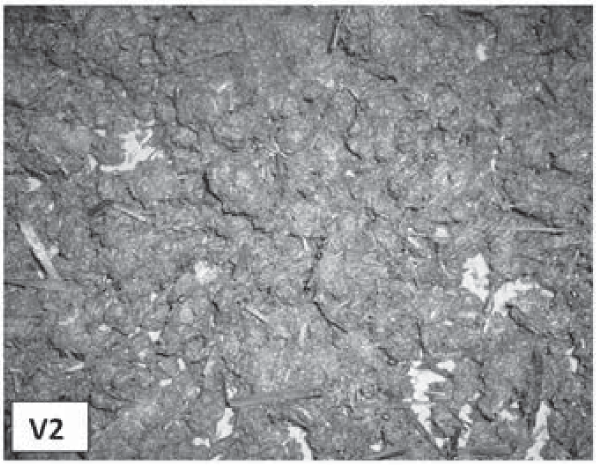


Fig. 3 Vermicompost V1 *Fig.4 Vermicompost V2*

To confirm the hypothesis of favourable properties of the vermicompost and of the substrates made from the vermicompost, we carried out a pot vegetation experiment. Hybrid rye grass was selected for the pot vegetation experiment and it was sown into prepared mixtures of vermicompost and soil in different proportions. The plant samples were grown under identical conditions, i.e. identical climatic conditions and watering.

The used soil was from the standard climatic region in the south of Moravia, namely the southern part of the Dyjskosvratecký úval (Dyje-Svratka Vale), Pavlovské vrchy (Pavlov Hills), Dolnomoravský úval (Lower Morava Vale). The soil is loamy to sand-loamy black soil of the so-called estimated pedologic-ecological unit 0.04.01 (referred to as BPEJ in the Czech Republic). As for the agricultural resource protection fund, it falls in Class 4 and its yield is roughly 50 % (3).

With respect to a high number of results, for the purposes of this article we chose such results that provided the information on the best grass mass yields under concurrent conservation of nutrients in the used substrate. The best results were obtained with the substrates below. For the purposes in this article the substrates are referred to as S1, S2, and S3.

Substrate 1 (S1) = blind sample, i.e. soil only

Substrate 2 (S2) = 1/3 of vermicompost with no added digestate (V1) mixed with 2/3 of soil

Substrate 3 (S3) = 1/3 of vermicompost with added digestate (V2) mixed with 2/3 of soil

Both the input values and the obtained values after the pot vegetation experiment underwent agrochemical analyses in an accredited laboratory of the Central Institute for Supervising and Testing in Agriculture in Opava (further referred to as UKZUZ) following the unified work procedures (10). The analyses concerned the vermicompost mixed with soil, and the soil itself (blind sample). We also analyzed the grown plant mass to identify macro and micro elements.

We analyzed all the input and output materials, i.e. manure, digestate, obtained vermicomposts, mixtures of vermicompost and soil and the grown plant mass. As mentioned above, the article focuses on the experimental testing of vermicomposting of digestate, and thus the results in the tables summarize the characteristics of the substrates. The following analyses were carried out: Mehlich III determination of available nutrients; determination of selected elements using aqua regia; determination of pH; determination of loss on ignition; determination of specific electric conductivity; determination of total nitrogen, nitrates and nitrites; determination of mercury, organic compounds and dry solids. In the plant mass the basic analysis concentrated on the identification of macro and micro elements.

3 Results

Figures 4, 5, and 6 show the final grown plant mass of hybrid rye grass. The hybrid rye grass is referred to as J in the tables and results.

Fig. 4 Grown grass mass S1/J

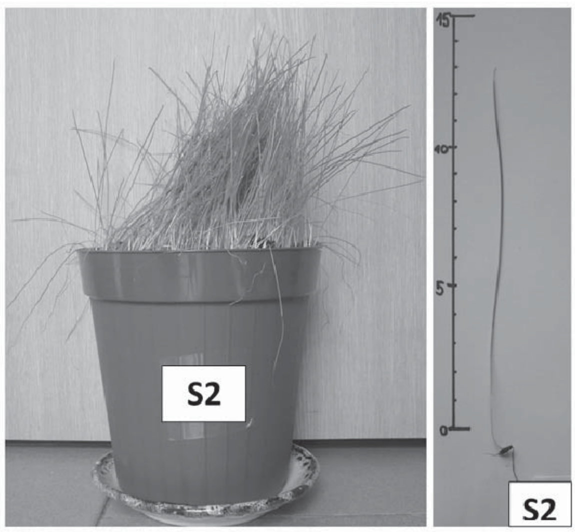


Fig. 5 Grown grass mass S2/J

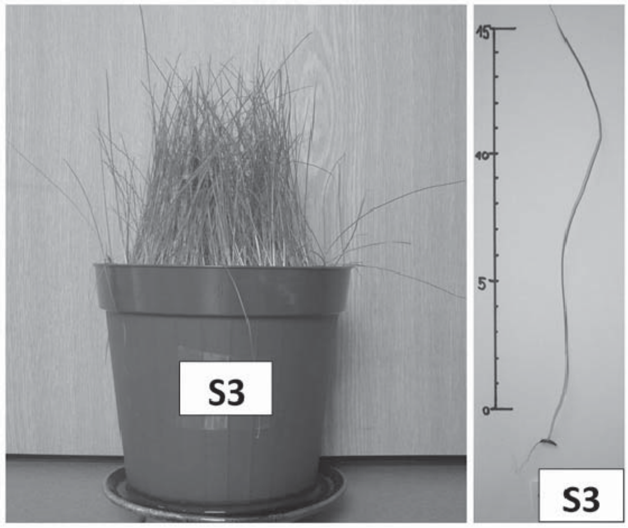


Fig. 6 Grown grass mass S3/J

The grown grass mass was analyzed for the Mehlich III content of available nutrients and the total content of hazardous elements in the plant mass using aqua regia. Tables 1 and 2 below summarize the plant mass analyses results after harvest.

Tab. 1 Content of available nutrients in Mehlich III.

Element	S3/J [%]	S2/J [%]	S1/J [%]
N	2.93	3.07	2.90
P	0.60	0.68	0.69
K	4.84	4.53	2.75
Mg	0.24	0.26	0.29
Ca	0.61	0.70	1.17

**S3/J – rye grass grown on S3 (vermicompost with added digestate + soil); S2/J – rye grass grown on S2 (check vermicompost + soil); S1/J – rye grass grown on S1 (blind sample, soil only)*

Tab. 2 Total contents of hazardous elements in the plant mass (using aqua regia)

Element	S3/J [mg/kg]	S2/J [mg/kg]	S1/J [mg/kg]
As	1.74	1.10	1.55
Cd	0.060	0.06	0.13
Cr	2.10	2.15	4.47
Cu	12.2	13.7	20.5
Hg	0.054	0.067	0.074
Mo	6.34	6.28	6.34
Ni	2.4	2.53	3.67
Pb	1.38	1.40	4.69
Zn	85.8	90.9	112

**S3/J – rye grass grown on S3 (vermicompost with added digestate + soil); S2/J – rye grass grown on S2 (check vermicompost + soil); S1/J – rye grass grown on S1 (blind sample, soil only)*

Next, we analyzed the substrate after the cultivation of the plant mass, namely for the total content of elements, available nutrients and the basic characteristics of the substrates.

Tables 3 and 4 below state the results of the analyses having grown the plant mass in the substrates.

Tab. 3 Total contents of elements in the tested substrates (using aqua regia)

Element	S3[mg/kg]	S2 [mg/kg]	S1 [mg/kg]
As	1.504	1.488	0.15
Ca	8455	8411	618.06
Cd	<0.3	<0.3	<0.3
Cr	11.59	10.93	12.63
Cu	20.12	18.83	20.51
K	3465	2570.85	1586.18
Mg	1596	1467.61	1454.84
Mo	<1.5	<1.5	<1.5
Ni	8.394	6.88	10.06
P	1494	1255.06	1171.95
Pb	17.07	24.49	18.79
Zn	109.8	99.9	102.04
Hg	0.042	0.040	0.037

**S3 – vermicompost with added digestate + soil (1/3 : 2/3); S2 – check vermicompost + soil (1/3 : 2/3); S1 – blind sample, soil only*

Tab.4 Overview of the basic characteristics of and available nutrients in the tested substrates

Parameter		S3	S2	S1
Ca in Mehlich III	[mg/kg]	4208	4322	4677.71
K in Mehlich III	[mg/kg]	2429	1488	294
Mg in Mehlich III	[mg/kg]	505.1	437.2	283.9
P in Mehlich III	[mg/kg]	605.7	502	331.38
Total N in dry solids	[%]Mehlich	0.24	0.17	0.14
$N\text{-}NH_4$ as received	[mg/kg]	6.370	6.130	1.850
$N\text{-}NO_3$ as received	[mg/kg]	18.16	30.66	11.25
pH in $CaCl_2$ extract	[-]	7.90	7.70	7.40
Conductivity	[uS/cm]	670	464	126.0
Organic matter in dry solids	[%]	6.0	4.60	3.30
Dry solids as received	[%]	98.4	98.80	99.0
C:N	[-]	12.5	13.53	11.79

**S3 – vermicompost with added digestate + soil (1/3 : 2/3); S2 – check vermicompost +soil (1/3 : 2/3); S1 – blind sample, soil only*

4 Discussion

The intake of available nutrients by rye grass (See Table 1) grown on different substrates S1,S2 and S3 shows no big variations. However, substrate S3 seems to render more favourable values as the rye grass grown on this substrate best accepted potassium. No doubt, the vermicomposts score positive on low intakes of hazardous elements by plants (See Table 2) and the sanitary effects appear as promising. Having introduced digestate into the mixture, none of the hazardous elements were significantly exceeded in the tested substrates. In S3, for example, arsenic scored higher, i.e. 1.504 mg/kg of dry solids. Nevertheless, it does not approach the limit set by legislation, which is 20 mg/kg of dry solids.

Moreover, vermicompost has soil amending properties. Analyzing the used substrates, again the mixture of vermicompost with added digestate, S3, provides best conditions for the cultivation of plants. It contains substantially more nitrogen, which is especially important for the growth of green mass. The other available macronutrients are also most abundant, except for calcium, which may be related to the organic matter contained in the vermicompost. The amount of hazardous elements is more or less comparable in all the three substrates. For example, the content of lead analyzed in the substrate made from vermicompost and added digestate was 17.07 mg/kg, whereas in the substrate made from vermicompost only lead amounted to 24.49 mg/kg. This may be attributed to the favourable properties of the vermicompost. Therefore, the mixture of vermicompost with added digestate, S3, appears to render best results in growing green mass.

The material analysis results were compared with Czech legislation and none of the observed parameters exceeded the limits set by valid regulations, i.e. Regulation 341/2008 Coll. on details on biodegradable waste disposal, and Regulation 474/2000 Coll. on the determination of requirements for fertilisers, as amended.

The results of the experiment are very interesting considering the non-traditional application of digestate, namely resulting in a soil amending product with positive effects on plants. The composition of the vermicompost mixture containing digestate positively reflected in the agrochemical and biological properties of the mixture and the enriched soil, on the yields of the plant mass and the production quality. This is documented by the implemented pot vegetation experiment as well as by the agrochemical analyses of the plant mass.

For future research, it would be interesting to compare the quality of vermicompost produced from other types of biowaste and the quality of vermicompost with added digestate.

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Post-treatment of Composting Leachate by Photocatalytic Process

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Abstract

In this study the capability of UV-ZnO photocatalytic process as a post treatment method for composting leachate was examined at laboratory scale and in batch mode. The effect of some factors such as initial pH, oxidant concentration, light intensity and reaction time on the removal of organic load and color of leachate were investigated. Biological pre-treated leachate samples were collected from the effluent of leachate treatment facility of a composting plant in north of Iran. A Plexiglas column with 110 mm inner diameter and 300 mm height were used to conduct experiments. UVC lamps with different power levels in the range of 8-40W at the centre of the column were used as the source of irradiation. Based on the results of experiments, after 180 minutes of radiation with 32W UV_C lamps in pH 11 and in the presence of $1 g.L^{-1}$ of slurry ZnO, maximum COD and color removal were achieved to be 57% and 67%, respectively.

Keywords

Composting, Leachate, Nanoparticles, Zinc oxide, Photocatalyst, UV

1 Introduction

Industrial and economic development over recent decades in most countries along with changes in lifestyle has resulted in considerable growth of industrial and household waste. In 1994, the amount of solid waste production was 1.3 billion tons/year, where it has amounted to 1.7 billion tons/year in 2004, indicating a 31% increase (FOO AND HAMEED 2009). The amount of waste production in Asia in 1998 was also 0.76 million ton per day. Since biodegradable organic materials constitute approximately 60% of the total urban solid waste in developing countries, leachate treatment is considered as a big concern for waste management in these areas.

leachate treatment methods are classified into three groups include: leachate transmission; biodegradation techniques and physiochemical treatment methods (WISZNIOWSKI ET AL., 2006).

Due to its reliability, simplicity and high cost-effectiveness, biological processes are among conventional methods used for immature leachate treatment. However, due to high organic load of leachate and also presence of refractory pollutants, biological process alone cannot remove all of the organic matters from leachate. In order to enhance the quality of leachate to the discharge standards, post treatment of biologically treated leachate is required (OLLER ET AL., 2011; SALEM ET AL., 2013).

One appropriate solution for complementary treatment of leachate and removal of refractory materials is application of photocatalytic processes. This process is mainly dependent on the in-situ generation of hydroxyl radicals under ambient conditions which are capable of converting a wide spectrum of organic compounds into relatively innocuous final products such as CO_2 and H_2O. Use of photocatalytic methods has attracted great deal of attention thanks to its unique features including full decomposition of contaminant to water and carbon dioxide, simple implementation, reusable materials, and quick removal of pollutants (PRIYA ET AL., 2008).

In photocatalytic treatment of leachate using slurry TiO_2 nanoparticles, maximum COD, BOD_5 and TOC removal of 59%, 75%, and 80% was achieved respectively (CHO ET AL., 2002). In another study, complementary treatment of landfill leachate (8 years old) was examined by photocatalytic UV-TiO_2 process. Based on the results, initial pH of the solution, nanoparticles concentration, and reaction time were reported as influential factors in the process. In this research, maximum COD removal of 60% and color removal of 97% were attained. The photocatalytic discoloration and degradation of C.I. Reactive Red 120 dye have been studied over ZnO nanoparticles under sunlight. It was observed that complete dye decolorization and 90% of dye degradation was obtained after 60 and 180 min, respectively (GHALY ET AL., 2014), Similarly 95% removal of phenol from wastewater during photocatalytic process via immobilized TiO_2 nanoparticles on the concrete was reported (DELNAVAZ ET AL., 2012). 88% removal of Hexavalent Chromium using ZnO nanoparticles stabilized on Kaolin was also reported by SHIRZAD ET AL., (2014).

Considering the specific characteristics of photocatalytic process, post treatment of composting leachate using ZnO nanoparticles through a photocatalytic process was selected as the main objective of this research. The effect of pH, concentration of nanoparticles, power of UV_C lamps, and irradiation time was examined and the optimal conditions for conducting this process have been determined.

2 Materials and methods

2.1 Experimental System

This study was conducted in laboratory scale and batch mode. Schematic sketch of the system is illustrated in Figure 1. The system consists of a Plexiglas column with 110 mm inner diameter and 300 mm height and total useful volume of 1000 mL. Philips UV_C

lamps with different power levels in the range of 8-40 W as the source of irradiation were placed inside a quartz tube mounted at the axial centre of the reactor. In order to provide necessary mixing, air was continuously injected into the column through a diffuser at the bottom of the reactor.

In each experiment, initially the leachate pH was adjusted by NaOH or H_2SO_4 solutions. After sonication of 20 gL^{-1} of ZnO suspension for 15 min in the ultrasonic bath, a desired amount of solution were added to the leachate, at ambient temperature and under a specified amount of UV_C radiation. Finally, samples were taken periodically from the reactor for analysis. Prior to analysis, the samples were centrifuged at 3000 rpm for 10 min and then passed through a 0.2µm filter paper to remove all suspended particles. In order to prevent reflection and scattering of UVC radiation in the environment, the reactor was covered with a thick layer of aluminum foil.

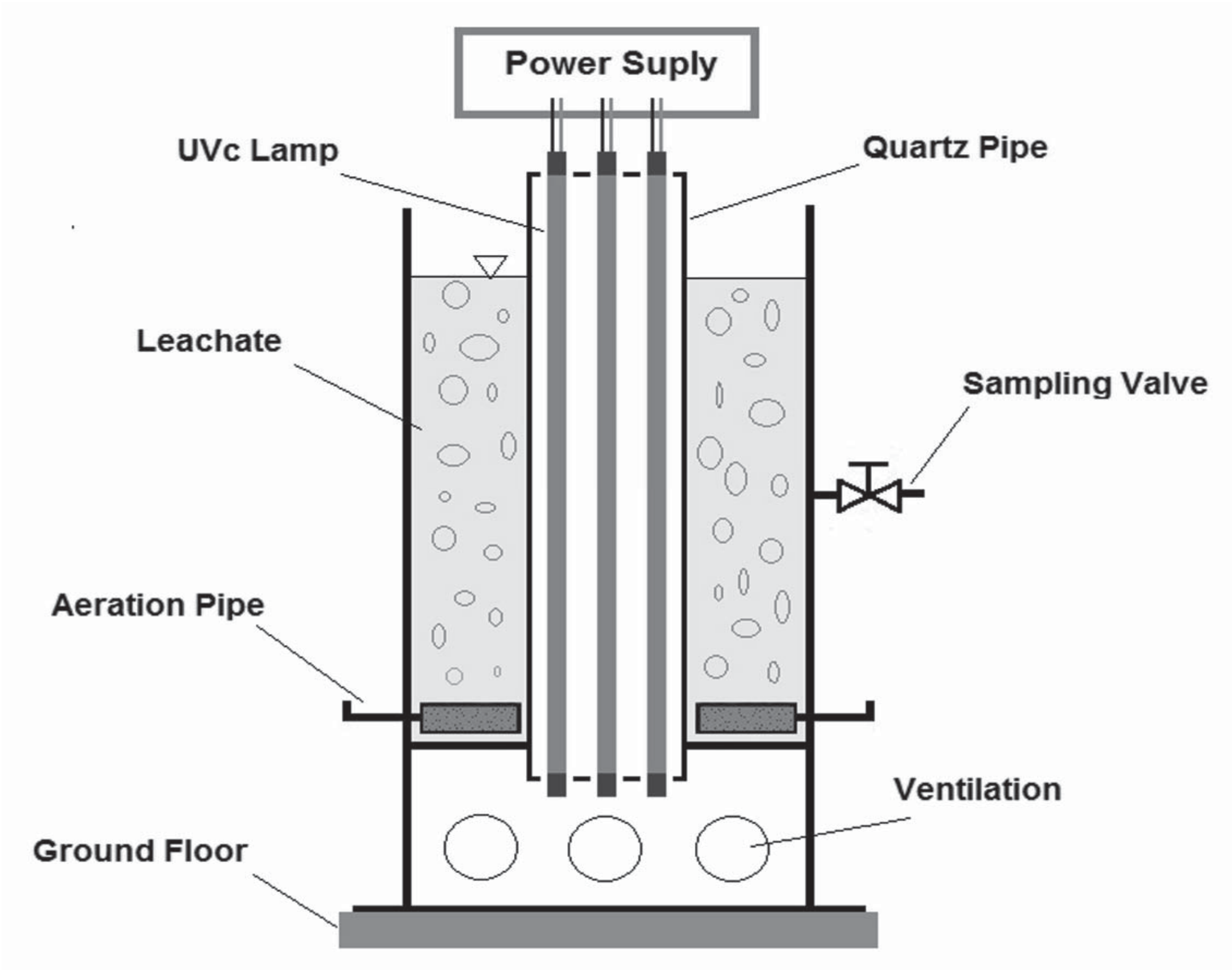

Figure 1 Schematic sketch of the used system

2.2 Materials

Biological pre-treated leachate samples were collected from the effluent of leachate treatment facility of a composting plant in north of Iran. The characteristics of the effluent of this plant are summarized in Table 1. In this plant, the organic load of leachate is significantly reduced through various biological and physical processes. But according to Iran Department of Environment (DOE), it is still above the level determined by standards to be discharged into the recipient environments (SHAERI AND RAHMATI 2012). This leads to the conclusion that a post treatment process for the effluent is mandatory. The leachate samples were collected in 20 L plastic containers, transported to the laboratory and immediately stored at 4˚C to minimize any changes that might occur in its properties until the experiments were carried out.

Table 1 Leachate Characteristics

Parameters	Concentration	Unit
COD	800	$mg.L^{-1}$
BOD_5	125	$mg.L^{-1}$
BOD_5/COD	0.15	-
TS	8000	$mg.L^{-1}$
TSS	200	$mg.L^{-1}$
EC	13	$\mu S.cm^{-1}$
pH	9	-
Color	7	Gardner
Turbidity	80	(NTU)
Alkalinity	605	$mg.L^{-}1$ as $CaCO_3$

Zinc oxide nano particle with an average particle size of 10-30 nm and purity over 99% was supplied by US Research Nanomaterials, Inc., USA. Commercially grade of sodium hydroxide and sulfuric acid were used for pH adjustment. All other chemicals employed for analysis were analytical grade and obtained from Merck Company.

2.3 Analytical procedures

Metrohm 691 pH meter with glass combination electrode was applied to measure pH. To ensure absence of nanoparticles in samples, Sigma 101 centrifuge, was used followed by Sartorius 0.2 micron, filter paper. Color and COD measurements were assayed at 780 nm and 640 nm, respectively, using DR 4000 Hach spectrophotometer (Method 10105 and 8000).

To measure the intensity of UV lamps radiation, Lutron RS-232 UV meter, was utilized. All other parameters were analyzed according to the standard methods for the examination of water and wastewater (APHA 2012).

3 Results and discussion

3.1 Reference experiments

Through a photocatalytic reaction, factors such as oxidant, photocatalyst, and energy source help the reaction proceed further. To prove effectiveness of all of the factors in a photocatalytic process, first the impact of each parameter on system was investigated independently and in combination without the concurrent presence of all factors.

As can be observed from Figure 2, presence of photocatalyst alone (lack of UV_C light) has no significant effect on the organic load removal of leachate on its own and after 120 min, only 2% of solution COD is removed. It can be attributed to lack of stimulation in nanoparticles due to absence of UV_C light and thus no generation of hydroxyl radicals.

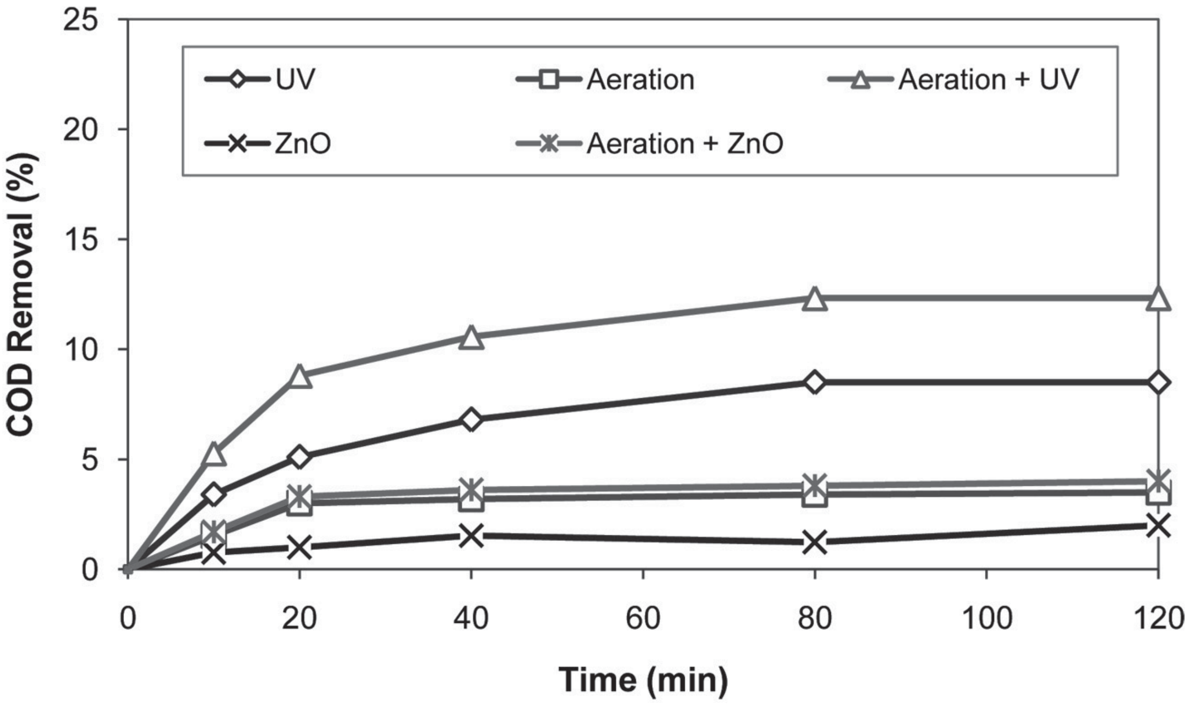

Figure 2 Reference experiments (UV=40 W, [ZnO] =1g.L^{-1}, Aeration= 2 L.min^{-1})

In aeration processes alone and concurrent application of aeration & photocatalyst, maximum COD removal efficiency of 3.5 and 4.5% was obtained respectively. As can be observed, UV_C light alone brought about an 8% removal, While the maximum COD removal efficiency of 12.5% was obtained when UV_C and aeration were utilized simultaneously.

3.2 The effect of pH

pH is one of effective parameter in photocatalytic process. The pH of solution influences the surface charge properties of the photocatalyst so it has significant effects on the electrostatic interaction between the catalyst surface and the pollutant molecules (SHAFAEI ET AL., 2010). In order to determine the effect of pH in the removal rate of COD, some experiments were carried out in the presence of $1g.L^{-1}$ of ZnO, 360 min irradiation with 32 W UV_C lamps and in different pH values (5 to 11). As can be seen in figure 3, by increasing pH, the COD removal efficiencies were also increased and reached its maximum value (60%) at pH 11. In a similar study, the removal efficiency of 2-phenylphenol, using UV-ZnO photocatalytic process was also found to increase with increasing the pH. (KHODJA ET AL, 2001).

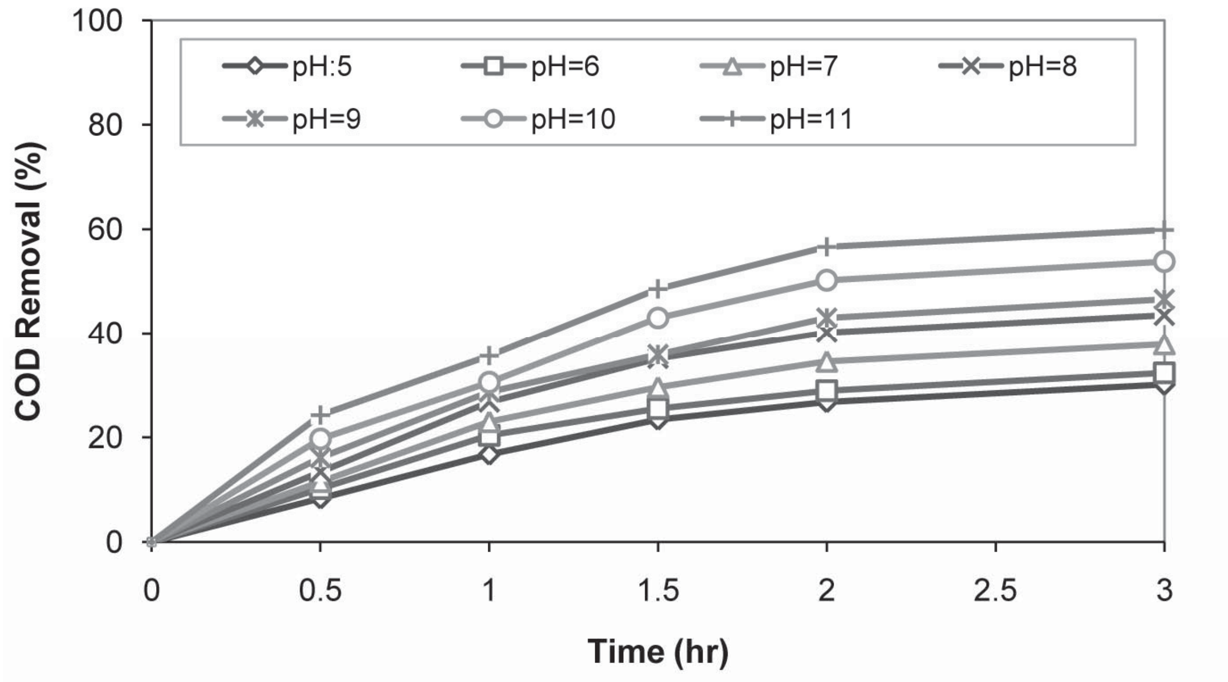

Figure 3 Effect of pH on COD removal ([ZnO]= $1g.L^{-1}$, UV=32 W, irradiation time= 3 hr)

The increase in removal efficiency at alkaline conditions can be related to the ability of photocatalytic process to initiate hydroxyl radical formation at high pH. Due to its high oxidation and reduction potential, hydroxyl radical plays an important role in the degradation of organic compounds.

Since higher pH levels are difficult to use in full-scale, pH value greater than 11 were not examined in this study. Due to photodecomposition of ZnO nanopowder in acidic solutions the effect of pH lower than 5 was also disregarded in this research (DANESHVAR ET AL., 2007).

3.3 Nanoparticles concentration

In order to examine the effect of nanoparticles concentration on the COD removal efficiency, experiments were repeated with 0.25, 0.5, 1.0, and 1.5 $g.L^{-1}$ of catalyst. As shown in Figure 4, when the concentration of photocatalyst increased from 0.25 to 1 $g.L^{-1}$, COD removal efficiency was also increased. However, when it was further increases up to 1.5 $g.L^{-1}$, COD removal efficiency decreased.

It is due to the fact that: increase in the concentration of photocatalyst raised the number of active sites on the photocatalyst surface, which in turn increased the number of hydroxyl, and superoxide radicals. Nevertheless, further addition of photocatalyst material would result an increase in the turbidity of suspension, which affects the penetration of UV light as a result of increased screening effect and scattering of light (ANANDAN ET AL., 2006).

In removal of dye (C.I. Acid Yellow 23) via ZnO photocatalytic process, similar results have also been reported (BEHNAJADY ET AL., 2006).

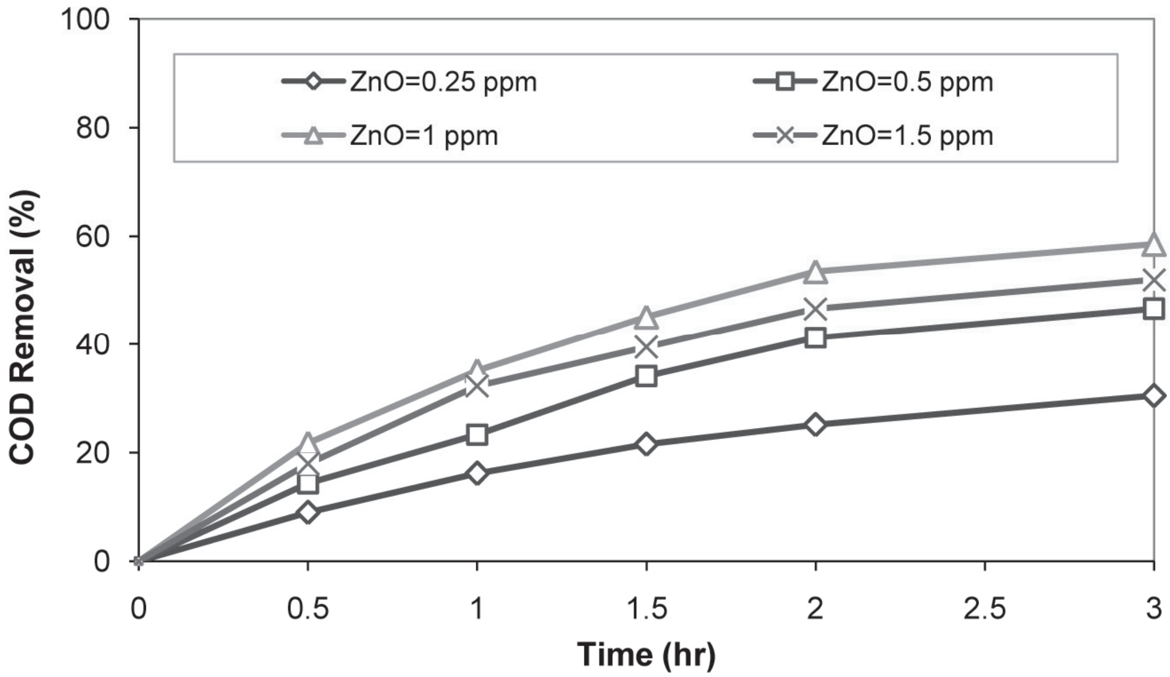

Figure 4 Effect of nanoparticles concentration on COD removal (pH=11, UV=32 W)

3.4 Light intensity

To investigate the effect of light intensity, experiments were repeated by several UV_C lamps the results of which are presented in Figure 5.

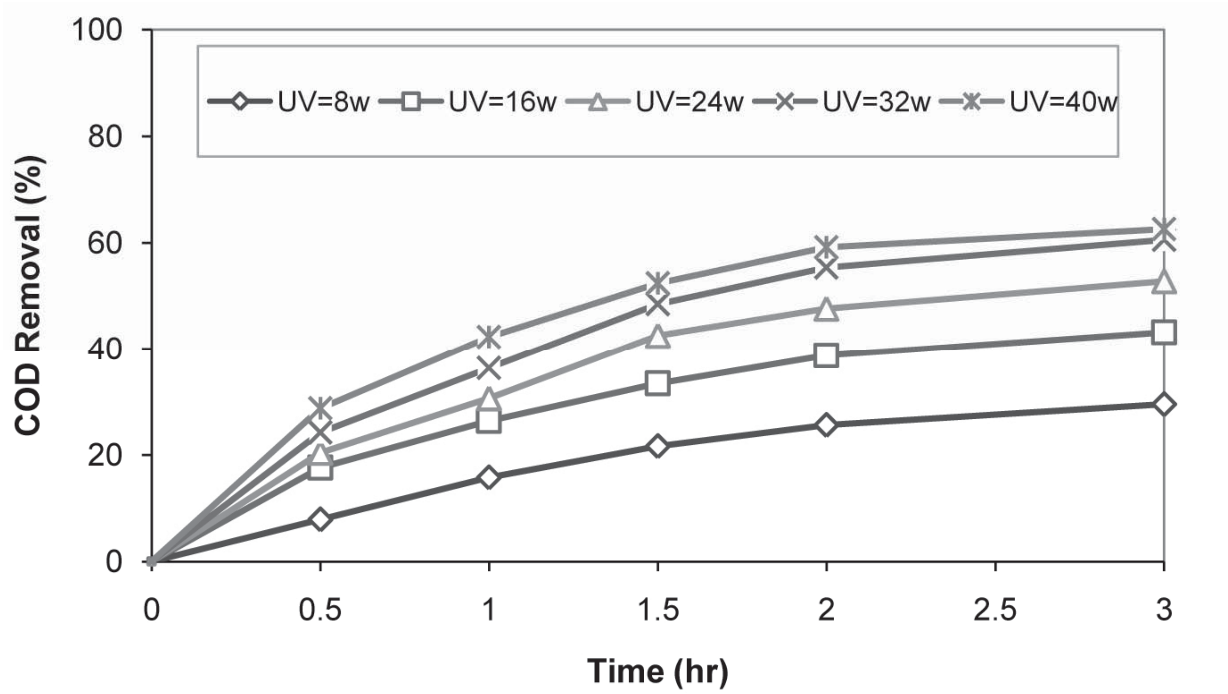

Figure 5 Effect of UVc lamps power on COD removal (pH= 11, [ZnO]= 1 g.L^{-1})

As can be seen, by increasing the lamps power, the removal rate was also increased. However, there is no linear relationship between these two parameters. Here by increasing the lamp power from 8 to 16 W, COD removal efficiency grew about 15%, but this development reached only 2% when the power was further increased from 32 to 40 W. In a similar study, COD removal efficiency of 70, 90, and 98% were obtained using 16, 32, and 64W UV_C lamps respectively, for the removal of terephthalic acid through a UV-ZnO photocatalytic process (FUJISHIMA ET AL., 2000).

As the power of lamp and thus intensity of radiation increases, the particulates of photocatalytic materials are further stimulated and thereby produce further hydroxyl radicals culminating in enhanced COD removal. However, due to the reactor shape and low distance between UV_C sources and nanoparticles, further increasing of UV_C lamp power would not lead to increased radiation intensity inside the reactor (LI ET AL., 2008). As a result, the intensity of radiation inside the reactor reached its maximum after some time according to Figure 6 and further increase of lamp powers cannot promote it significantly.

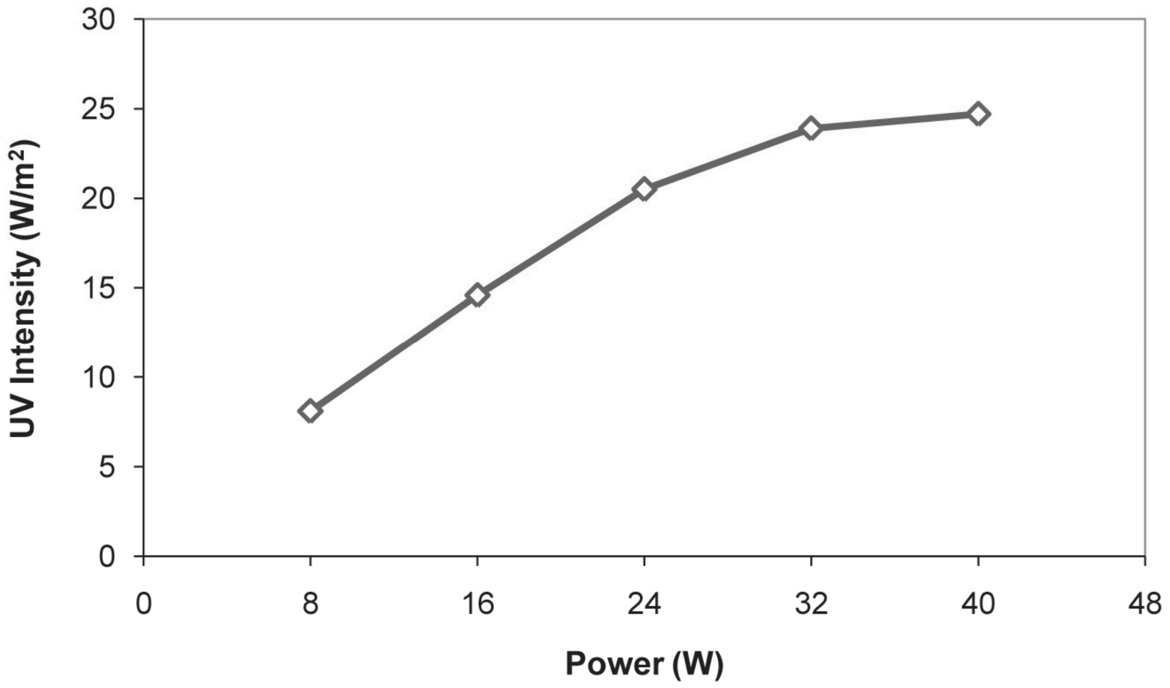

Figure 6 Relation between power and light intensity of UVc lamps inside the reactor

3.5 Irradiation time

In order to investigate the effect of irradiation time, some experiments were carried out with 32 W UV_C lamps (2.5 $mW.Cm^{-2}$ light intensity), pH=11 and ZnO concentration of 1 $g.L^{-1}$. As can be seen in figure 7, like COD removal, color removal has also been accomplished within the first 3 hours of reaction faster than the next 5 hours.

Regarding the considerably short lifespan of hydroxyl radicals (only a few nanoseconds), they only can cause oxidation at the formation site or somewhere very close to that (BARKA ET AL., 2008). Since in a photocatalytic process, the major factor of oxidation is hydroxyl radicals (FUJISHIMA ET AL., 2000) therefore, at the onset of reaction, due to presence of more pollutants at the site of hydroxyl radical formation, the rate of reaction progression is higher.

As shown in figure 7 after 360 minutes irradiation at optimum condition 57% removal of COD and 67% removal of color were obtained. Subsequently, by increasing the reaction time to 480 minutes only 5% and 7% increase in the removal of COD and color were obtained respectively. However, since there was no considerable increase in the removal efficiency and with considering energy costs, the reaction time for this process was considered to be 180 minutes.

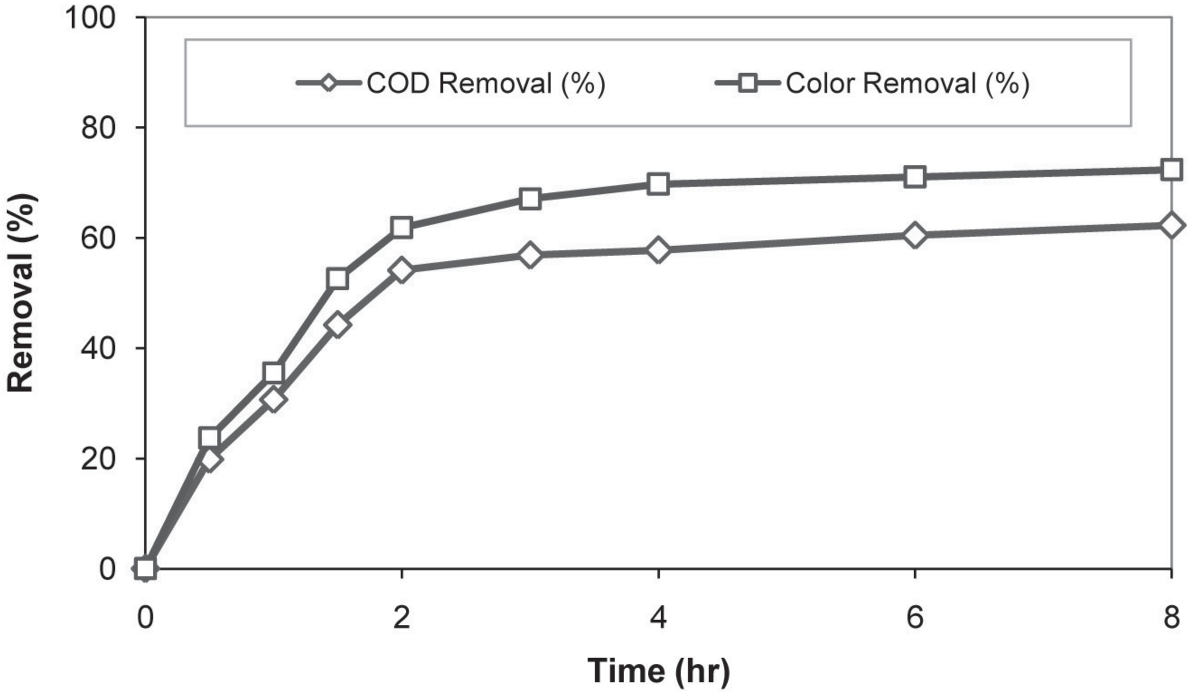

Figure 7 Effect of irradiation time on the COD and color removal efficiency (UV=32 W, pH=11, [ZnO]=1 g.L^{-1})

4 Conclusion

Photocatalytic process was investigated using ZnO nanoparticles in the post treatment of composting leachate at laboratory scale and in batch mode. The effect of pH, concentration of nanoparticles, power of UV_C lamps and irradiation time were investigated on the removal rate of organic load and color of leachate.In this study, the maximum COD and color removal efficiency were obtained, after 180 minutes irradiation with 32 W UV_C lamps, at pH 11 and via 1 g.L^{-1} ZnO nanoparticles. Under these conditions, the maximum simultaneous COD and color removal of 57% and 67% were achieved, respectively. By increasing the reaction time to 480 minutes (167% increasing in energy consumption), 5% and 7% increase in the removal of COD and color were obtained respectively. however, since there was no considerable increase in the removal efficiency and with considering energy costs, the reaction time for this process was considered to be 180 min.The results suggest that UV-ZnO photocatalytic process is an effective chemical oxidation process on the simultaneous reduction of COD and color from biologically treated composting leachates.

5 Acknowledgements

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Abfall zum Wertstoff – Die MBA im Wandel der Zeit

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From Waste to Resources – MBT Technology Through The Ages

1 Einleitung

1.1 Vorbemerkung

2012 wurden in Europa im Mittel 493 kg kommunaler Abfall[1] pro Person erzeugt.

Dänemark, mit 668 kg pro Person, hatte das höchste Abfallaufkommen. Zypern, Luxemburg und Deutschland folgen mit mehr als 600 kg pro Person.

Eine immense Anzahl an Waren, die wir im Alltag nutzen, wird aus Kunststoff, hergestellt – Flaschen, Einkaufstüten, Einweggeschirr, Rohre, Datenträger, Textilfasern, Einrichtungsgegenstände und vieles mehr.

1.2 Die historische Entwicklung

Bis in die 70er Jahre wurde Hausmüll überwiegend nicht verwertet, sondern weitgehend deponiert. In urbanen Ballungsräumen wurde jedoch das Deponieren zunehmend problematisch.

Seit dem Aufkommen der grünen Bewegung in den 1970/80ern findet jedoch ein Umdenken statt und die Problematik der Müllentsorgung wird heute als ein Hauptfaktor von Umweltbelastung erkannt.

Es wurden zunehmend Technologien entwickelt, die die Wiederaufbereitung vieler Arten von Altstoffen wirtschaftlich machen. Abfall, in der Form von Sekundärrohstoffen, wird so zu einem bedeutenden Wirtschaftsgut.

Zurzeit geschieht dies fast ausschließlich durch die getrennte Sammlung über das duale System und die angeschlossenen Recyclinganlagen.

Das deutsche Kreislaufwirtschaftsgesetz ist beispielhaft in Europa.

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[1] In 2012, 42% of treated municipal waste was recycled or composted, Eurostat press release 48/2014

1.3 Forschung, Entwicklung und Konstruktion

Doch nicht aller recycelbarer Müll wird sorgfältig getrennt und dem dualen System zugeführt. Im Hausmüll stecken deshalb wertvolle Ressourcen – und das nicht nur in Form von nutzbarer Energie. Es erweist sich zunehmend als unwirtschaftlich, hochwertige, recycelfähige Kunststoffe im Gemisch mit anderem heizwertreichen Abfall als Ersatzbrennstoff zu entsorgen.

Neu entwickelte Technologien und Absatzmärkte ermöglichen neue Ansätze, zumal der Export von Plastikabfall nicht mehr als angemessene Lösung für Deutschland angesehen werden kann.

Durch eine weitere Aufbereitungsstufe in bereits existierenden MBA-Anlagen und eine dadurch gesteigerte Rückführung von Kunststoffen in den Wirtschaftskreislauf kann die Abfallmenge zur Verbrennung oder Deponierung ökologisch und ökonomisch sinnvoll verringert werden.

Eines unserer erklärten Ziele ist deshalb eine deutliche Erhöhung der Recyclingquote durch Kunststoffe aus der Hausmüllaufbereitung.

HAASE Environmental Consulting (HEC) entwickelt Aufbereitungsverfahren und Prozesse für marktfähige Produkte, um wertvolle Sekundärrohstoffe aus dem Hausmüll zu nutzen und die Entsorgungskosten der Kommunen zu senken. Gleichzeitig wird dadurch auch ein Beitrag zum Klima- und Umweltschutz geleistet.

HEC plant komplette Neuanlagen „auf der grünen Wiese“ sowie Erweiterungen von bestehenden MBA-Anlagen zur Verbesserung des Kunststoffrecyclings.

Weg von der Verbrennung hin zur Kreislaufwirtschaft!

2 Integration einer Kunststoffaufbereitungsstufe in vorhandene MBA Technik

2.1 Thema und Zielsetzung des Vorhabens

In Deutschland, in Europa aber auch weltweit bestehen im Bereich Kunststoffrecycling sehr hohe Potentiale und der Bedarf an hochwertigen Kunststoffen für technische Produkte ist weltweit weiterhin stark steigend.

In dem Sortierprozess einer Mechanisch-Biologischen Abfallbehandlungsanlage (MBA) wird der Stoffstrom im Wesentlichen aufgeteilt in die Fraktionen:

- hochkalorische Komponenten (Papier, Kunststoffe)
- biologische Komponenten (Organik)

- mineralische Komponenten (Reststoffe zur weiteren Deponieeinlagerung)
- Metalle

Der angelieferte Hausmüll wird mechanisch aufbereitet und in die oben benannten Fraktionen sortiert. Die hochkalorische Komponente wird in der Regel als Ersatzbrennstoff (Refuse Derived Fuel, RDF) in Kraftwerken verbrannt oder in Zementfabriken verwendet.

Ziel der Integrierung einer zusätzlichen Kunststoffaufbereitungsstufe, nachfolgend Pure Plastic Technology (PPT) genannt, ist die Gewinnung technisch verwertbarer Kunststoffe aus dem in der Mechanisch-Biologischen Abfallbehandlungsanlage (MBA) angelieferten Hausmüll.

Als weitere Rohstoffquelle kann der Kunststoff im Sperrmüll dienen, der ebenfalls in den MBA angeliefert wird.

Bislang wird der Anteil an RDF, welcher ca. 40% des angelieferten Inputmaterials ausmacht, thermisch verwertet. Die Betreiber der Mechanisch-Biologischen Abfallbehandlungsanlagen (MBA) zahlen in der Regel für das von Ihnen produzierte RDF eine Gebühr an die Betreiber von Verbrennungsanlagen.

Da kunststoffreiche Fraktionen viele verschiedene Kunststofftypen mit unterschiedlichen Eigenschaften und Störstoffen enthalten können, können solche komplexe Mischungen bislang nicht für weitere technische Anwendungen genutzt und müssen einem Verbrennungsprozess zugeführt werden.

In der RDF Fraktion sind ca. 60% Papier und ca. 40 % Kunststoffe enthalten. Ein Teil dieser Kunststoffe im RDF kann effektiv unter Beachtung wirtschaftlicher Vorteile recycelt werden.

Mit der Pure Plastic Technology (PPT) wurde ein mehrstufiges technologisches Konzept entwickelt, welches es zum einen erlaubt verfahrenstechnisch Hartkunststoffe (3-D Materialanteil ca. 40% im Kunststoffanteil des RDF) und zum anderen Kunststoffe/Folien (2-D Materialanteil ca. 60% im Kunststoffanteil des RDF) aus dem MBA Prozess zu schleusen und aufzubereiten.

Damit wird ein Beitrag zu einer Reduzierung der fossilen Rohstoffe für die Kunststoffproduktion und die politisch gewünschte Erhöhung der Recyclingquote auf einfache und kostengünstige Weise geleistet. Weiterhin kommt es zu einer finanziellen Entlastung der Mechanisch-Biologischen Abfallbehandlungsanlagen (MBA) durch verminderte Anliefermengen zur Verbrennung.

Das Verfahren von Pure Plastic Technology (PPT) arbeitet mit einem 3-stufigen Prozess:

Stufe:

Ausschleusung einer Kunststofffraktion aus dem angelieferten und mechanisch vorbehandelten Hausmüll durch ein optisch gesteuertes Trenngerät

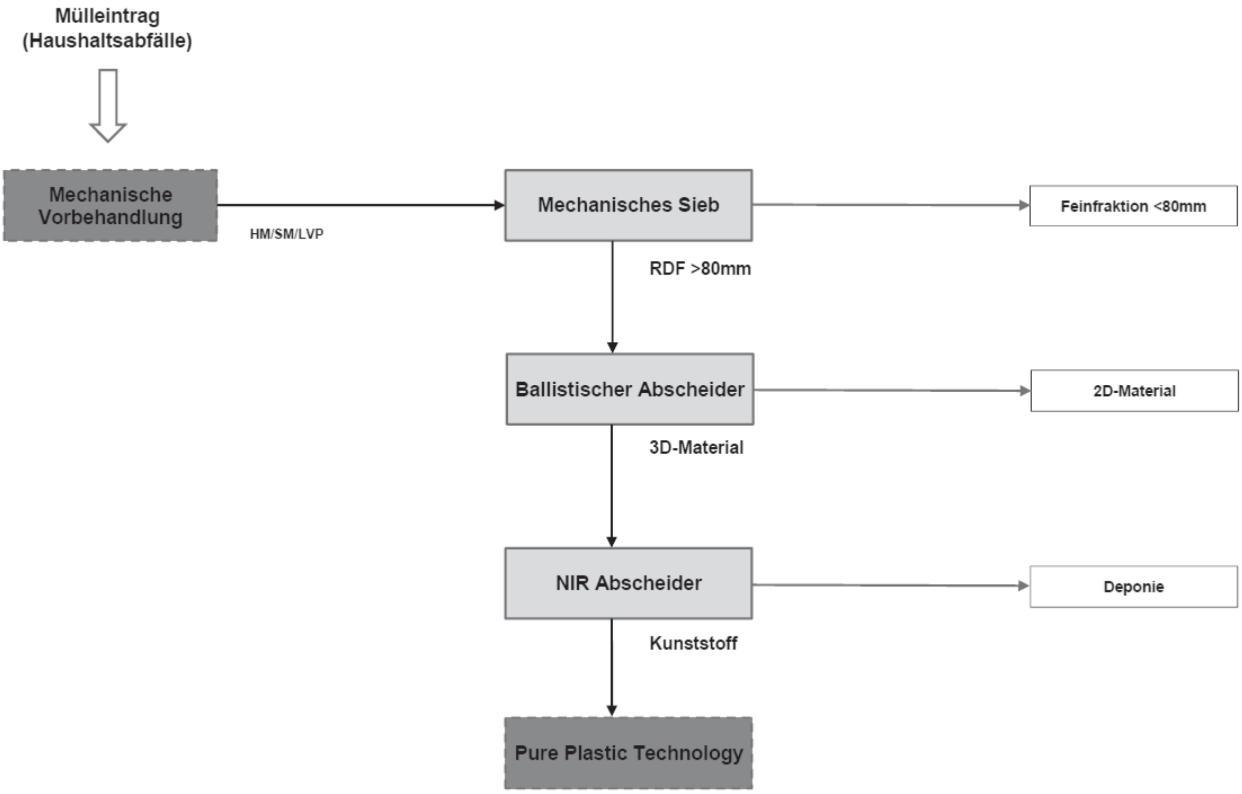

Abbildung 1: Mechanische Vorbehandlung/Ausschleusung

1. Stufe:
   Aufbereitung mit Zerkleinerung, Wäsche, Trocknung

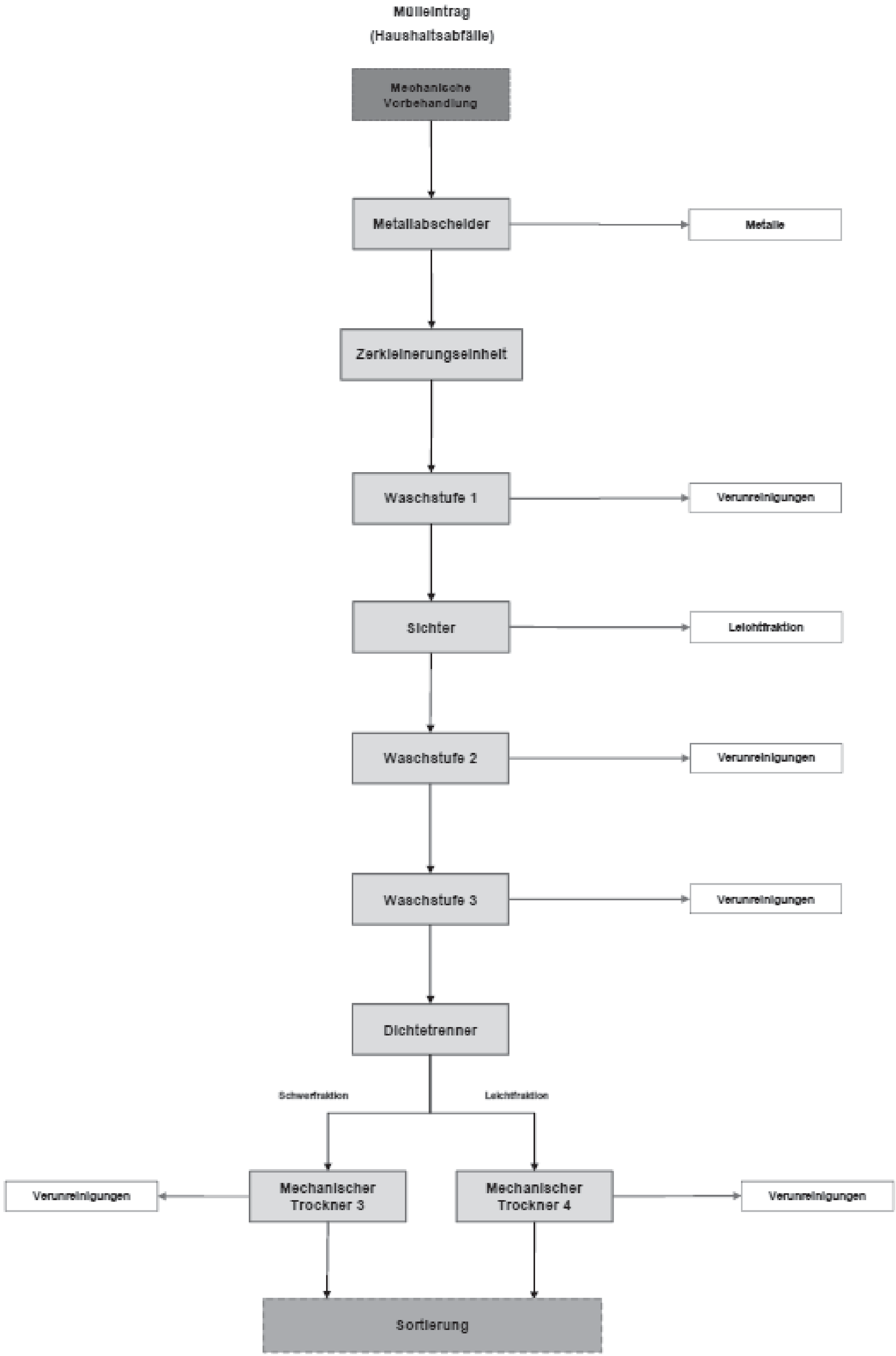

Abbildung 2: Pure Plastik Technology

2. Stufe:
   Sortierung mittels optisch gesteuerten Trenngerätes in die gewünschten Kunststofffraktionen und Lagerung des Endproduktes

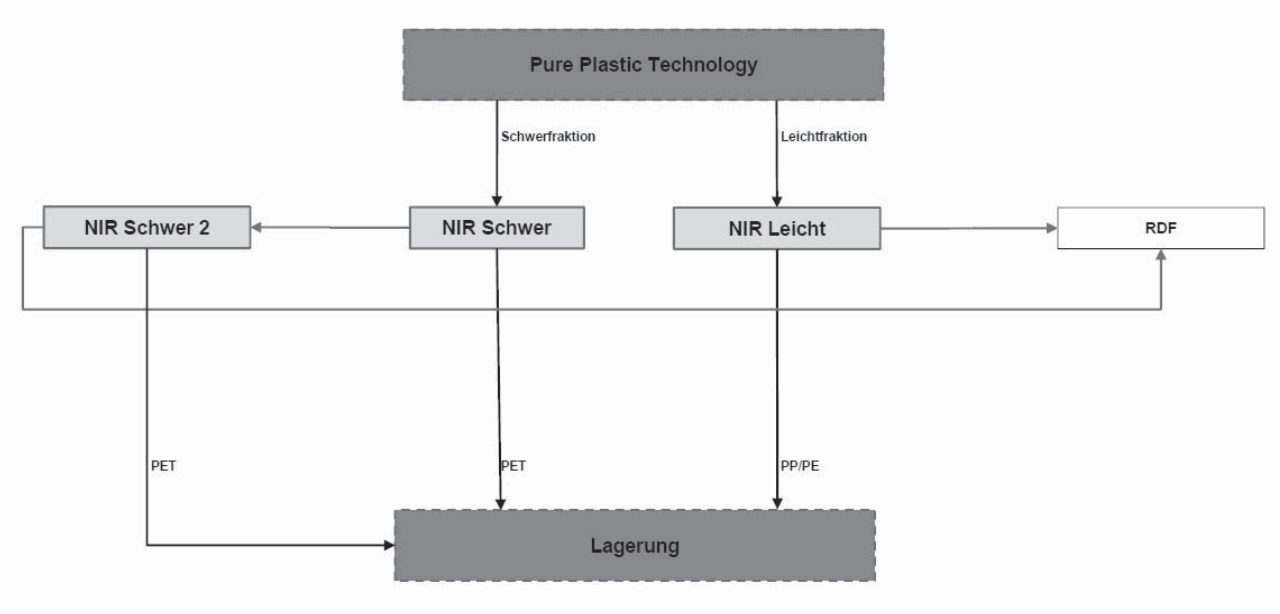

Abbildung 3: Sortierung

Ein für den Sortierprozess standardmäßig integrierter ballistischer Abscheider in einer Mechanisch-Biologischen Abfallbehandlungsanlagen (MBA) wird für die Pure Plastic Technology (PPT) optimiert eingesetzt, um aus dem Schwergut (3-D Teile) über ein optisch gesteuertes Trenngerät die Hartkunststoffe zu detektieren und auszuschleusen.

Verfahrenstechnisch nachgeschaltet sind Zerkleinerungsstufen, Waschstufen, Trocknungsstufen und kunststoffspezifische Trennstufen (Polyethylenterephthalat (PET), Polyethylen (PE), Polypropylen (PP)-Kunststoffe und weitere).

Durch Integration des neuen Verfahrens der Pure Plastic Technology (PPT) in den Gesamtprozess der Mechanisch-Biologischen Abfallbehandlungsanlagen (MBA) können, anstelle der thermischen Verwertung, erhebliche Mengen des stofflichen Recyclings mit signifikanten ökologischen und volkswirtschaftlichen Vorteilen zugeführt werden. Aus dem Abfall wird ein marktfähiger Wertstoff erzeugt.

Die Einführung einer Sortier- und Waschtechnologie für Kunststoffe im Abfallmarkt durch die Pure Plastic Technology (PPT) ist ein innovativer Prozeßschritt und schließt die Lücke zwischen Abfallbehandlung und Recycling durch die Entwicklung eines tragfähigen Konzepts für eine industrielle Umsetzung.

2.2 Stand der Wissenschaft und Technik

Durch Pure Plastic Technology (PPT) hat HEC ein Kunststoff-Recycling-Verfahren entwickelt, das die Gewinnung eines hochwertigen Kunststoffrecyclates aus dem Haus- und Sperrmüll ermöglicht, das bisher stofflich nicht verwertbar war.

Die verwendeten Apparate sind am Markt verfügbar und Stand der Technik.

Durch die Verwendung von Standard-Komponenten, die jedoch für Pure Plastic Technology (PPT) und den Einsatz im Abfall modifiziert werden können, ist der Prozess technisch kontrollierbar und im Businessmodell wirtschaftlich attraktiv darstellbar.

Pure Plastic Technology (PPT) stellt die erste industrielle Anlage zur Produktion von sortenreinen Kunststoffen aus Haus- und Sperrmüll dar. Abfall wird hier zur Ressource.

Der derzeit marktübliche Ansatz der thermischen Entsorgung (Waste-to-Energy) und/oder Export steht hier einem Waste-to-Value-Konzept gegenüber bei dem die Pure Plastic Technology (PPT) genutzt wird um die Fraktion der hochkalorischen Komponenten in vermarktungsfähige Produkte umzuwandeln. Somit gehen eine Minimierung der Abfallkosten mit einer gewinnbringenden Vermarktung der Kunststoff-Flakes.

Zahlreiche Studienergebnisse aus der Wissenschaft belegen das Potential durch Recycling von Kunststoffen. Beispielsweise aus der Studie der Columbia University (USA) vom 16.08.2011[2] ergibt sich aus seiner Untersuchung für das Jahr 2008 folgende Übersicht:

Aus 33,7 Millionen Tonnen erzeugtem Kunststoff für das Jahr 2008 in den USA resultieren

- 2,2 Millionen Tonnen (**6,5%**) Gesamtmenge an recyceltem Kunststoff aus dem Hausmüll (MSW)
- 2,6 Millionen Tonnen (**7,7%**) Gesamtmenge an Kunststoffen die der Verbrennung zugeführt wurden (Waste-to-Energy)
- 28,9 Millionen Tonnen (**85,8%**) Gesamtmenge an Kunststoffen die der Deponie zugeführt und somit nicht weiter genutzt wurden

[2] *Energy and economic value of non-recycled plastics (NRP) and municipal solid waste (MSW) that are currently landfilled in the fifty states*

Der recycelte Kunststoffanteil aus dem Hausmüll teilt sich wiederum auf in:

Kunststoff-Fraktion	Tonnen	%
PET Flaschen	722.000	32,6
HDPE Flaschen	490.000	22,2
PP Flaschen	13.500	0,6
Kunststoff-Taschen/Folien	416.000	18,8
Hartkunststoffe	180.000	8,1
langlebige Kunststoffe	390.000	17,6
Gesamtmenge	**2.211.500**	**100**

Die Studie zeigt weiterhin auf, dass eine zusätzliche Nutzung von 25% des deponierten Hausmülls eine jährliche Erzeugung von 40 Millionen MWh Elektrizität entspräche, ausreichend um ca. 4 Millionen Haushalte zu versorgen.

Würden die zur Verbrennung genutzten bzw. die deponierten hochkalorischen Komponenten nun in einem weiteren Verfahren, wie der Pure Plastic Technology (PPT) genutzt, entstünde zusätzliches Potential des bisher verbrannten bzw. deponierten Kunststoffes durch die weitere Verarbeitung und würde nachhaltig den Treibhauseffekt und damit einhergehend das CO_2-Äquivalent (CO_2e) deutlich reduzieren.

2.3 Marktpotenzial und Marktumfeld

Der Markt für häusliche Abfälle wird vorwiegend von den Kommunen betrieben. Unter diesem Aspekt gibt es keinen Wettbewerb aus dem Recyclingsektor.

Es gibt Unternehmen für Kunststoffrecycling, auch für verschmutzte Kunststoffe wie z.B. Agrarfolien. Vorwiegend handelt es sich aber hierbei um industrielle Verpackungsmaterialien, Getränkeflaschen und getrennte Sammlungen aus Haushalten z.B. DSD (Duales System Deutschland). Diese Unternehmen bewegen sich außerhalb des Marktes für Restabfall aus Haushalten.

Kunststoffe aus der Abfalltonne zu recyceln liegt ebenfalls nicht im Fokus existierender Recyclingunternehmen.

Im Recyclingsektor gibt es Eigenentwicklungen von Unternehmen die in produzierenden Anlagen münden (z.B. in Hohenwestedt, Rostock, Schwerin).

Die hier verwendeten Rohmaterialien sind bedingt durch die Sammlung schon weit vorsortiert und im Vergleich zu Kunststoffen aus Haushaltsabfall sauber. Es ist technologisch wesentlich einfacher diese Kunststoffe zu behandeln und in den Produktionsprozess zurückzuführen als Kunststoff aus dem Hausmüll zu recyceln.

Die Einführung einer Wasch- und Sortiertechnologie durch Pure Plastic Technology (PPT) für Kunststoffe im Abfallmarkt ist daher neu.

Es gibt europaweit derzeit ca. 350 Mechanisch-Biologischen Abfallbehandlungsanlagen (MBA) die sich in der Errichtung und/oder Betrieb befinden – weitere sind darüber hinaus noch in Planung. In Deutschland sind 48 Mechanisch-Biologischen Abfallbehandlungsanlagen (MBA) in Betrieb, davon zwei in Schleswig-Holstein und drei in Mecklenburg Vorpommern.

Das Recyclingpotential für Hartkunststoff (3-D Material) aus Haushaltsabfällen liegt in Deutschland alleine bei 370.000 t pro Jahr. Bezogen auf Hartkunststoff (3-D Material) kommt es bei einer Anlage für 120.000 t Abfall pro Jahr zu einer finanziellen Entlastung des MBA bei einer Ausschleusung mit einem Wirkungsgrad von ca. 80% und einer (eingesparten) Gebühr für die thermische Verwertung von € 60,- pro Tonne von ca. € 250.600,- pro Jahr für den Betreiber.

Legt man eine mittlere Inputmenge von 120.000 t Abfall pro Jahr zugrunde ergibt sich durch die Sortierung der Mechanisch-Biologischen Abfallbehandlungsanlage (MBA) für den Anteil an hochkalorischen Komponenten:

- Refuse Derived Fuel (RDF) :ca. 50.000 t pro Jahr, davon
    - Papier :ca. 30.000 t pro Jahr
    - Kunststoffe :ca. 20.000 t pro Jahr, davon
        - Folien :ca. 13.000 t pro Jahr
        - Hartkunststoffe :ca. 7.000 t pro Jahr

Diese Komponenten können gewinnbringend recycelt und dem Produktionsprozess wieder zurückgeführt werden.

Somit ergibt sich folgende grobe Kostenschätzung für:

<u>Deutschland</u>

370.000 t/a x 0,8 x € 60,- = € 17.760.000,- Einsparungspotential aus verringerter Verbrennungsmenge

370.000 t/a x 0,8 x 0,5 x € 400,- = € 59.200.000,- Verkaufserlös aus Kunststoffrecycling

Europa

300 Anlagen x 5.000 t/a x 0,8 x € 40,- = € 48.000.000,- Einsparungspotential aus verringerter Verbrennungsmenge und

1.500.000 t/a x 0,8 x 0,5 x € 400,- = € 240.000.000,- Verkaufserlös aus Kunststoffrecycling

Ein weiteres Marktpotential mit einem modifizierten Verfahren nach der Pure Plastic Technology (PPT) könnte speziell in Schwellenländern Anwendung finden. Dort hat die Entsorgung von Kunststoffen besorgniserregende Einflüsse auf Umwelt und die menschliche Gesundheit, da z.B. gefärbte Kunststoffe verwendet werden, deren Pigmente Schwermetalle enthalten, die hochgiftig sind.

Eine gezielte Sortierung und Ausschleusung und/oder Wiederverwendung bzw. Weiterverarbeitung der Kunststoffe würde somit das gesundheitsgefährdende Risiko durch kontaminierte Kunststoffe minimieren oder handhabbarer machen.

Zu erwartendes Kunststoff-Recycling durch das Pure Plastic Technology (PPT)-Verfahren auf Basis von einer mittleren Inputmenge von 120.000 t Abfall pro Jahr:

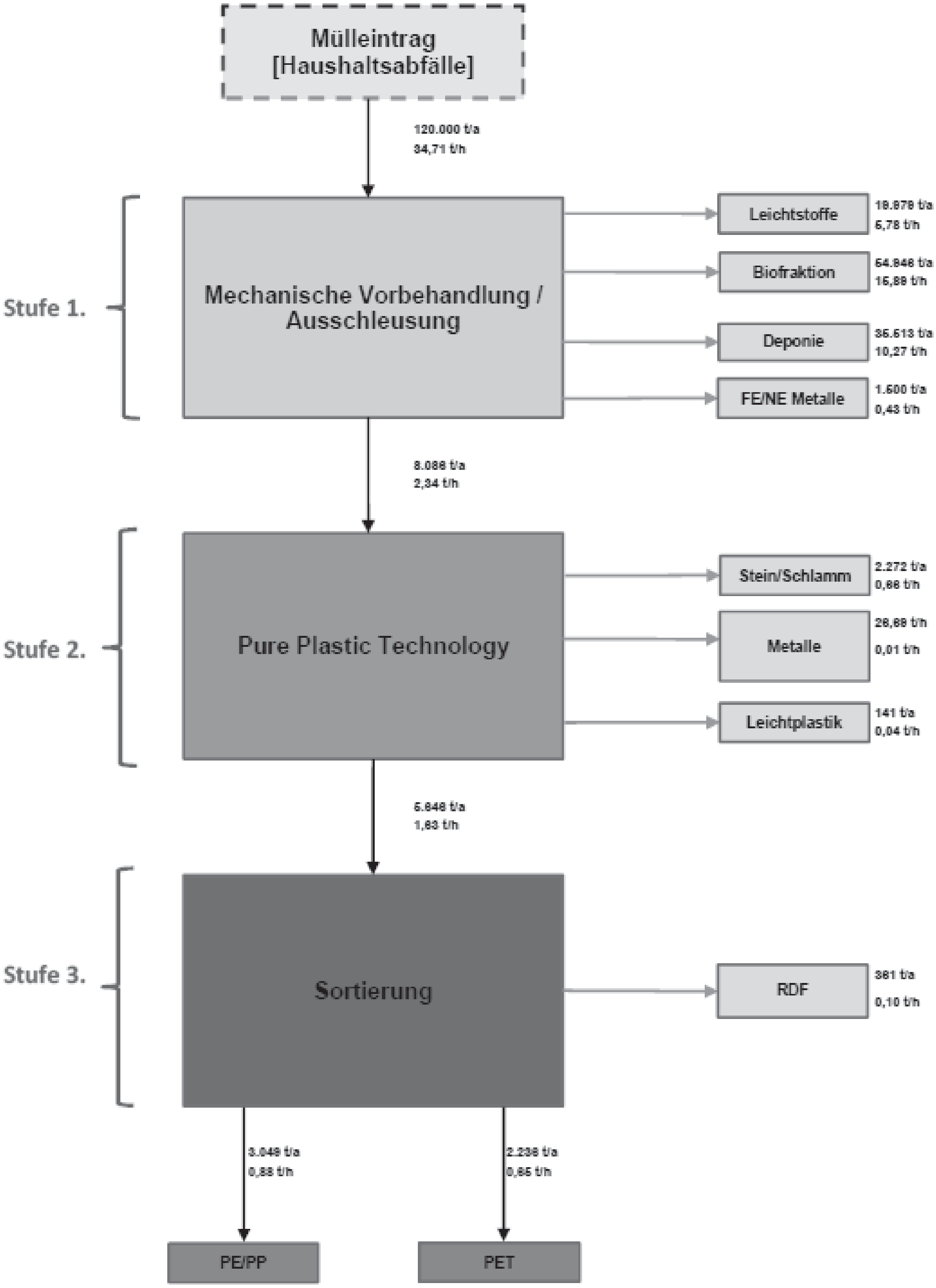

Abbildung 4: 3 Stufen System_PPT

System for mixing the contents of a biogas digester by means of cyclically drawing off the product gas

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Abstract

Anaerobic digestion of high total solids, fibrous matter (manure, vegetable, straw) poses plugging problems which in turn make it essential to dilute the fermenting mass. In adddition to a larger digester volume, such dilution leads to stratification and crust formation which impose the use of energy and cost consuming agitating systems in the digester.

Qays has developed and patented a biomethanization system able to solve all these problems in letting the internal pressure rise in the digester under the action of the bacterias which produce biogas, and in opening then the biogas outlet valve under the control of a pressure sensor. The gas bubbles thus created cyclically in the fermenting mass lead to a thorough mixing of the mass and make it possible to work without any mechanical mixing and/or agitating device in the digester, whereas diluting the fermenting mass in the digester becomes superfluous.

This "passive" mixing system proved itself very efficient at the lab and pilot scale, and offers many advantages in relation to classical systems:

- the ability to feed the digester with 25 ... 30%TS fibrous matter, with a smaller digester volume (no dilution)

- no more mechanical mixing devices in the digester

- the ability to work in thermophilic conditions with higher output and higher efficiency,

all this resulting in a biomethanization process less costly and producing more energy.

1 The conventional way

Conventional digesters fed on high solids material like manure, energy crops and/or other fibrous matter suffer from various disadvantages, among which :

- the need to use powerful agitating and mixing systems in the digester in order to avoid the formation of a floating crust on top of the contents
- the need to dilute the contents of the digester in order to be able to mix it, with as a result an increase of the size of the digester
- the high thermal needs of the digester due to its size

- the high electricity consumption of the mixing system
- the high investment costs of the system (size and auxiliary equipment).

All of these either reduce the energy produced by the system, or increase investment and/or maintenance costs.

Other ways have been or are being used to help solving the mixing and floating crust problems in the digesters, like two-phase fermentation or helically moving systems in horizontal digesters, but again these systems are complex, costly, need intensive maintenance, and are not globally more cost efficient than the conventional ones.

As a consequence, the industry has followed a trend towards ever larger plants in an effort to alleviate the low productivity and high cost of the systems by means of increasing their global output (heat, electrical power, and fertilizer in some cases).

However, the very size of these huge plants (several tens of thousands of cubic meters in digester capacity with outputs of a few MW in electrical power) faces other problems, one of which being that the daily feed amounts then to several hundred tons per day, which means tens of heavy lorries a day, with all the inconvenience for the surroundings and the energy cost for transportation both ways - in for the feed and out for the digested sludge.

Moreover, the size and the number of these plants (little less than ten thousands in Germany only) has opened a new market for wastes nobody wanted in the past, with the result that the plant operators have now to pay to get their digesters fed, which in turn puts a heavy load on their overall economics.

The use of energy crops like maize for feeding digesters faces the same problems, and does not seem to be able to mitigate or alleviate the above disadvantages.

In an effort to improve the situation, and accounting for the alleged benefits of turning wastes into resources, the industry has lobbied public authorities in asking them to guarantee a high price for the electrical power produced from biogas, but these measures are prone to be halted or written off at any time and will never replace an intrinsic economic viability of a process.

Another technology that has met some popularity in the treatment of high solids, fibrous matter is what may be called the "garage digester". Several boxes about the size of a car garage or larger are fed in an alternate way and produce biogas in shifted cycles, in order to obtain a biogas production rate as uniform as possible. Although these systems are quite simple, their load settles down quickly under its own weight, which impairs the exchanges between the digesting mass and the bacterias and restrains the efficiency of the biogas production. Systems have been designed to collect the liquid fraction at the bottom of the mass and pump it to spray the fermenting load from its top. However, this does not seem to be efficient enough to avoid the formation of dense, heavy lumps in the mass and to counteract the settling effect. Biogas production efficiency remains low, and the economics of the garage digester face the same problems as the conventional way.

2 A new process and system

In an effort aiming at solving the above problems, Qays has developed, tested, and validated an entirely new digester design that is at the same time simple, elegant, low-cost and efficient.

It is based on the basic principle of using the biogas produced by the fermenting mass for mixing said mass without breaking the stratification proces in a plug-flow vertical continuous digestion tank loaded from the top, wherein the movement of the mass towards the bottom is created by the force of gravity.

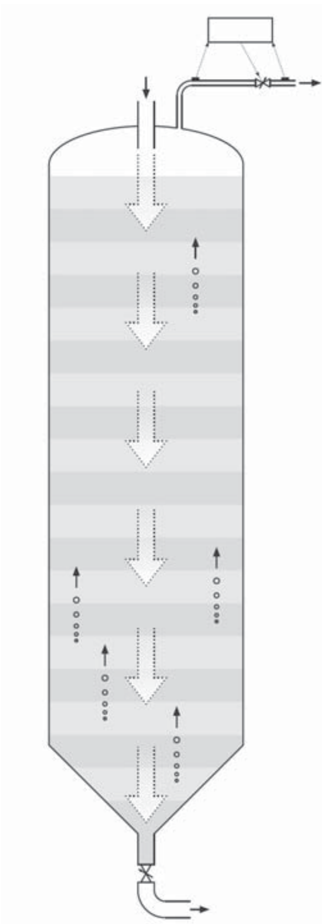

Fig. 1 Principle of the Qays digester

While the feed moves downwards before being drawn off at the bottom of the digester, the fermentation process creates biogas in the mass. The particular feature of the system is that this gas is prevented to flow freely out of the digester by a valve that remains closed until the pressure that builds up in the digester has reached a set value, usually of a few hundreds millibars above atmospheric pressure. At this point, a sudden opening of the valve will create an expansion and an upward movement of the gas bubbles in the mass. This expansion and upward movement of the gas bubbles have a strong mixing effect on the mass, this effect being independent of the solids concentration in the digester, and allowing the use of very high solids feeds in a so-called "dry" fermentation.

3 Advantages

This very simple principle has a number of interesting consequences.

The first one is that it does not need any mixing system to obtain a very stable fermentation of high solids feeds, with no clogging at all. This results in considerable savings in investment, maintenance and energy costs for a mechanical mixing system.

Second, it allows the use of high solids feeds, which results in higher biogas production rates, and in an increased productivity of the digester volume.

Third, as the digester volume needed to treat a given daily feed can thus be reduced since the organic matter content of the digester can be increased, the surface area of the digester envelope is reduced and so are the heat losses. It is then possible to operate in the thermophilic range of fermentation temperatures while keeping heat losses at a reasonable level, and this higher fermentation temperature in turn speeds up the fermentation rate (as expressed in m^3 of biogas per m^3 of digester and per day) as well as the conversion efficiency (as expressed in m^3 of biogas or methane per kg of organic matter). This, combined with the higher feed rate (as expressed in kg of organic matter fed by m^3 of digester and per day) allowed by the thorough mixing of the digester contents, results in another increase in the overall efficiency and the production of the system.

Fourth and not least, the smaller digester volume needed to treat a given daily feed involves a smaller space needed to build the system, with the corresponding possible reduction in investment costs.

4 Test results

Tests were realized at the laboratory scale on various feeds. The digesters built in carbon steel and equipped with the new gas mixing systeme had a volume of 10 liters and were operated in the thermophilic range. The results are shown in the following table.

Table 1. Summary of results obtained at the laboratory scale

Feed	kg OM/kg	kg OM/m³.day	m³ CH_4/kg OM	m³ CH_4/m³.day
Cattle manure on straw	0.25	4	0.27	1.080
Chopped vegetables	0.2	4.5	0.45	2.025
Poultry litter on wood choppings	0.5	8	0.2	1.600
Comparative example	0.2	3.5	0.38	1.330

In this table, the comparative example relates to a commercial, conventional, fully mixed digester, fed on maize and cereals and operated in the mesophilic range (38-40°C). The comparison between the second and the last line of the table shows that with a similar feed, the new system allows a methane production rate which is nearly 50 % higher than a conventional system. At the same time, the feeding rate can be increased and the methane production efficiency is higher.

PILOT PLANT

A 3 m³ digester volume pilot plant equipped with our new biogas mixing system was erected recently at the Centre des Technologies Agronomiques at Strée (Modave) in Belgium, where the laboratory scale tests had also been conducted. The excellent performance of the system is in the course of being confirmed on this digester loaded with cattle manure on straw, and batch operated at 55 °C. By the 5th day of the test (5th March), the methane production rate was at 1.16 m³ CH_4/m³.day. More recent results will be disclosed at the Conference.

5 Case study

The table below sums up the comparison between the conventional biogas technology and our new system in the following case study.

Suppose we want to operate a biogas system for feeding a engine-generator group able to produce 50 kW of electrical power on a permanent base.

Table 2. Comparison conventional vs. Qays system

Objective

Produce enough biogas to feed a 50 kW engine on a permanent base

Biogas = 55 % CH_4 = 5.5 kWh/m³

Electrical power conversion efficiency = 30 %

Engine power = 50 kW = 30 m³ biogas/h or 720 m³ biogas/day

	Conventional	Qays
Biogas production (m³/day)	720	720
CH_4 in the biogas (%)	0,55	0,55
CH_4 production (m³/day)	396	396
Methane conversion efficiency (m³ CH_4/kg OM)	0,38	0,45
Methane production rate (m³ CH_4/m³.day)	1,330	2,025
Digester volume (m³)	298	196
Daily feed (kg OM/m³.day)	3,5	4,5
OM in the feed (kg OM/kg)	0,2	0,2
Feed (kg/day)	5 215	4 410

The effective results will of course be dependent on the particular feed used and the methane conversion rate obtained, but these figures speak for themselves.

6 Conclusion

To sum up, it can be said that

- higher loading rates lead to reduced digester volumes, and that
- higher methane conversion efficiencies lead to higher energy outputs.

If this can be achieved with a reliable, less complicated, simpler, and less costly system, a big step will be done towards an improvement in the economics of biogas production.

We are confident that our system is such a step.

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3D-Geospatial Data using Unmanned Airborne Vehicles

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Abstract

3D-geospatial information is in many areas a fundamental, operational infrastructure. It serves planning, visualization, documentation and communication of operational processes and is in daily use. Large scale changes of site as well as local changes of volumes are important and constantly to-be-updated spatial data sets. For the generation of digital surface models in combination with volume determination and change of volume monitoring one lately uses unmanned airborne vehicles (UAV) equipped with cameras. Miniaturization, new materials and technologies permitted construction and use of UAVs for geospatial monitoring tasks. This paper presents several examples of UAV-applications for spatial monitoring tasks of landfill sites. The UAVs in use are of less than 5 kg total weight, yet very powerful. The technology behind delivers millions of highly accurate digital surface 3D-points, which thus describe in high detail the existing surface and to a very high degree of realism the actual volume present in the landfill site. Further, this paper gives an overview on this technology and a number of real world application examples.

Keywords

landfill, surveying, 3D-geospatial information, UAV, aerial image

1 Introduction

The use of aerial images for 3D-geospatial information extraction is a known and precise technology. This technology, called photogrammetry, finds application also in monitoring tasks of landfill sites. One obtains 3D-geospatial information such as volumes, terrain models, profiles, or contours all of which describe the area in a particular way, either for planning or for documentation purposes. Typically, one associates the capturing of aerial images with use of manned aircraft equipped with large format – nowadays digital – aerial camera systems. As aircrafts serve either fixed wing airplanes or rotary wing aircrafts, see Figure 1 for examples.

Well, the selection of flying platforms expanded. Today, one can apply unmanned airborne vehicles (UAV), flying automatically over smaller areas of terrain and capturing aerial images at predefined locations. The subsequent aerial image data processing follows basically the same principles as earlier on. However, one gains far more flexibility, cost-wise as well as in its frequency of application. Small, lightweight flying systems cover areas such as of landfills in one or two flight missions and can be accomplished at almost any time and are affordable. Their results in terms of accuracy are equivalent to deliverables derived from the traditional approach of aerial images made by manned survey aircrafts, but are also equivalent to the accuracy of surfaces, volumes, and other

3D-geospatial info derived via classic terrestrial surveying; yet, this UAV-Mapping called overall technology seems to have economic appealing.

Figure 1 Fixed wing airplane G220 (left) and rotor wing aircraft G47-X8 (right)

One finds in younger literature a number of places with reports on UAV technology such as (EISENBEISS, 2011), (GRENZDÖRFFER, 2011), (MAYR, 2009, 2011, 2013). The terminology is not yet well settled. Mainly one sees as acronyms UAV, UAS (= Unmanned Aerial System), or RPAS (= Remotely Piloted Aircraft System) each defining slightly different properties, but all intending to express the same: the use of automatically flying aircrafts. This paper attempts to present to the reader UAV-Mapping technology, explaining its core components and gives demonstration of its application 3D-geospatial data acquisition for landfill operators in form of some examples, all of which are completed and delivered UAV-Mapping service projects.

2 RPAS – Its Major Components

A remotely piloted aircraft system (= RPAS), as the naming indicates, primarily is a system consisting of an unmanned aircraft, potentially equipped with an autopilot, and a human pilot who controls the overall system and carries the responsibility. The type of aircraft is not specified. In the context of this paper all UAVs have an autopilot integrated. While the autopilot flies the aircraft on its own but according to an externally predefined flight path, the human pilot is the ultimate decision maker who at any given time may take over manual flight control from remote. For a graphical overview see (MAYR, 2013).

The autopilot is a tiny, light-weight electronics board and the core component of RPAS, next to the airframe which it has to control and to navigate. An example of an autopilot shows Figure 2. It displays the open source autopilot implementation titled “Paparazzi”, (“PAPARAZZI”).

More autopilots are readily available on the market. A method applying automatically flying aircrafts for the purpose of obtaining remotely sensed data, e.g. aerial images, may be called “RPAS-Mapping” or “UAV-Mapping”; latter one being used throughout this paper.

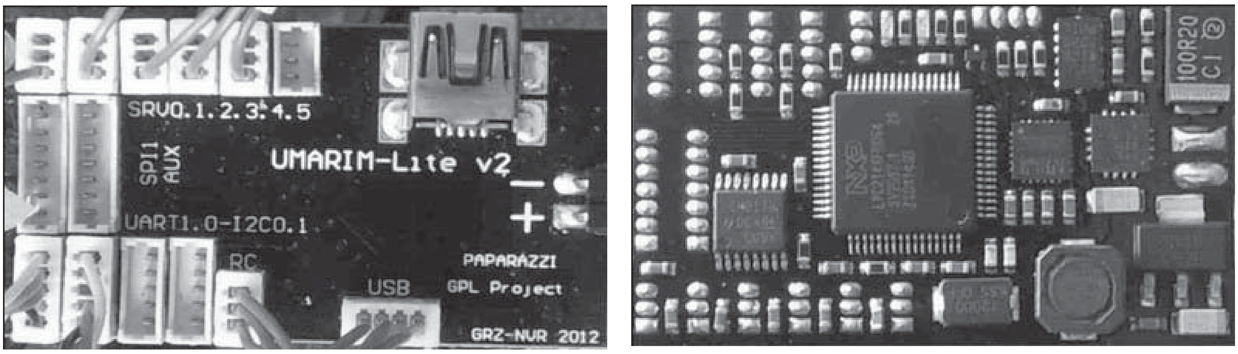

Figure 2 Autopilot, type: “Paparazzi – Umarim lite”, 11 g, upper + lower side

Common to all RPAS, resp. automatically flying UAV, is the fact, that a human pilot is in charge of operation and has the ultimate degree of freedom and responsibility to take over 100% manual control of the flying aircraft at any given time. A system without this property is not a RPAS, and is unlikely to obtain insurance or a permit to fly in Europe.

3 Examples

According to our experiences UAV-Mapping is well suited for objects of some spatial extent. Those objects are from an economical point of view too small to be served with manned aerial survey aircrafts or very cumbersome for the terrestrial surveying approach. At GerMAP unmanned fixed wing aircraft are mainly in use for such areas, e.g. landfill sites, quarries, or open pit mine sites. Multicopters, which GerMAP operates as well, find their use preferably in vertically oriented tasks e.g. inspection of towers, bridges, walls and the like. Table 1 informs about some RPAS-projects and reflects their most prominent project parameters and deliverables.

Landfill sites, open pit mine areas, golf courses, new housing areas, and cadastral areas were flown and their aerial images processed to images maps (= orthomosaics) and to digital terrain or surface models. The planimetric accuracy of the geodata is in the magnitude of half a pixel of the ground sampling distance (GSD), and the height accuracy typically ranges between 0.8 to 1.3 of GSD. All listed projects were imaged using Canon S95, Canon S100, or RicohGR digital still cameras.

The following landfill examples, see Figures 3 through 6, represent typical services which a UAV-Mapping company such as GerMAP executes. The client orders different deliverables, e.g. various volume modelings, an orthomosaic, which is an image with map properties, in digital and analog form, a digital surface model (DSM) with or without re-cultivation masses, perspective 3D-views, several other 3D-modelings, and as well the integration of the results into existing situation maps, see Figure 6, or into an existing geoinformation system (GIS). For absolute volume computation the client often hands out the construction plans of the landfill site, where one finds and models different basins reserved for specific types of waste resp. landfill masses.

Table 1 RPAS – examples with important project parameters

Proj. ID	Application	Deliverables	# of flights	# aerial images	Ortho-GSD [cm]	DSM-Raster Spacing [cm]	Planimetric acc. ± [cm]	Height acc. ± [cm]	Area [ha]
1	Landfill-1	Volume, profiles, orthomosaic, DTM, DSM, 3D-views	1	193	7.5	50	3	3.1	33
2	Landfill-2	Volume, profiles, orthomosaic, DTM, DSM, 3D-views	3	691	8	35	3.5	5.2	113
3	Landfill-3	Volume, profiles, orthomosaic, DTM, DSM, 3D-views	3	983	6	50	2.5	3.8	117
4	Golf course 1	Orthomosaic, DTM, DSM, 3D-views	4	1126	8	50	3	3.8	170
5	Golf course 2	Orthomosaic, DSM, 3D-views	2	332	7.5	50	3	7.2	70
6	Golf course 3	Orthomosaic, DTM, DSM, 3D-views	2	346	7.5	50	3.5	6.4	88
7	Quarry	Volume, orthomosaic, DSM	3	707	10	30	2.5	6	117
8	Cadastral	Orthomosaic, 3D-views	2	445	6	40	2	1.5	64
9	New housing area	Orthomosaic, DTM	3	557	6	40	3	6.8	104
10	Landfill site of a coal-based power plant	Volume, orthomosaic, DSM	2	1047	5	40	3	3.8	180

Often, the plans for re-cultivation as well as the final, planned shape of the landfill, i.e. its final cover, are available. Using this information one can derive absolute volumes, remaining “fillable” volume/s, volume of re-cultivation required, and difference volumes. Furthermore, it is possible to localize, to quantify, and to visualize spots where there is already too much fill-in mass versus the final landfill cover and vice versa where there is still too little fill-in. The digital surface description is a square grid of 3D-points with a raster spacing between 30 cm to 50 cm. The height accuracy of each such 3D-surface-point is between ±3 cm to ±7 cm, see Table 1, and depends on the resolution of the aerial image and some geometrical constraints. A landfill of e.g. 1.200 m x 600 m, i.e. 0.72 km² area, and 30 cm DSM-raster-spacing will be described with 8.000.000 3D-surface-points of aforementioned quality. This quantity of simple data sometimes seems to be a handling issue on the landfill operator side .

Typically, 1 to 3 flight missions, called blocks, cover one landfill which depends on its extents and shape. One block takes about 20 min to 30 min of flying time. Overall, with setup, flying, image checking, dismantling, and transfer to the next start point one may count about 1 hour of time. Some 500 to 1000 aerial images get exposed for one landfill. For a larger landfill project with 3 blocks 15 ground control points (GCP) were measured by one surveyor in less than one day. These GCP served several purposes. One purpose is quality control, another one is the integration of the resulting orthomosaic, DSM and other 3D-geospatial data into the existing and applied coordinate system of the client, and third, the GCPs were used to fine-tune, i.e. calibrate, the camera used for the aerial image exposure. Data processing from georeferencing aerial images over orthomosaic, DSM, down to determination of volumes and profiles as well as the generation of 3D-views mostly takes about 1-3 office days and depends on the number of deliverables to be produced, see project ID 3 in Table 1. Figures 3 through 6 give an impression of the deliverables.

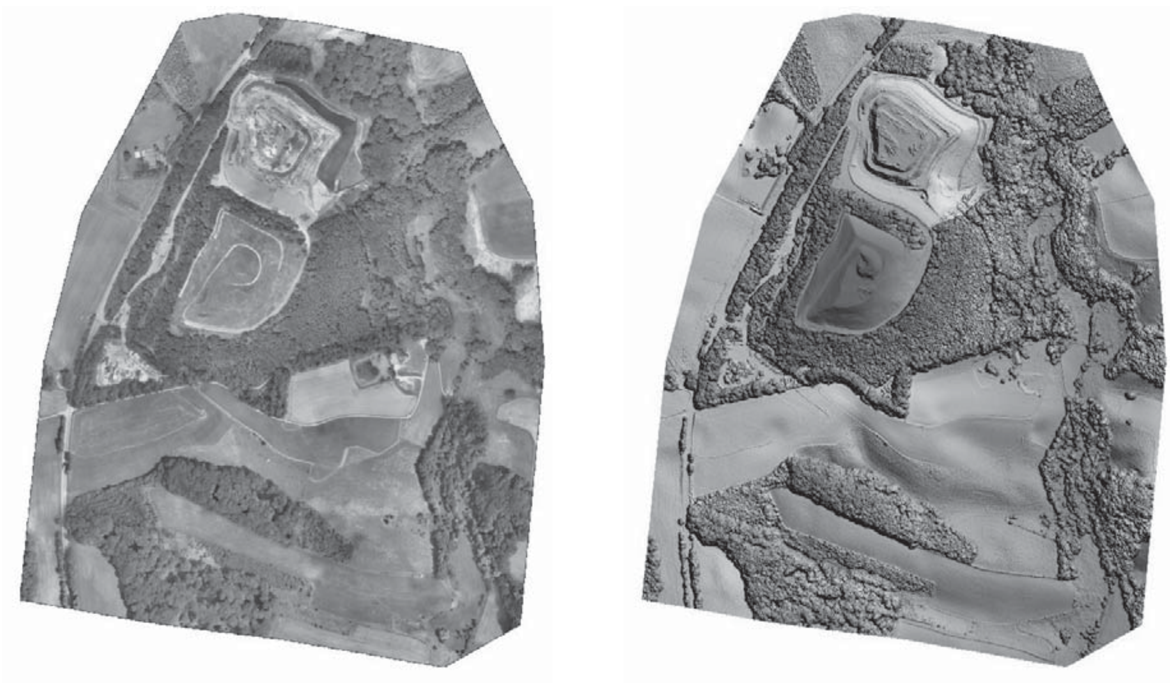

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Figure 3 Orthomosaic (left) and DSM (right) of landfill 3; 3 RPAS-blocks, 983 aerial images

The originally build initial status quo of the land fill as well as its designed final shape can be 3D-modeled and can this way get integrated into the existing landfill-surrounding, see Figure 4. Construction activities, which are common to happen on landfills, are thus quickly integrated into official plans and easily visualized for e.g. presentation purposes.

The reference surface, which is kind if the floor of the basement, gets extracted from construction plans and transferred into the official map coordinate system, see left Figure 4. This way exists the link to the orthomosaic and to the surface model. The same procedure gets applied for the planned final cover of the landfill, see right Figure 4, which thus serves to derive the remaining, usable volume of the landfill.

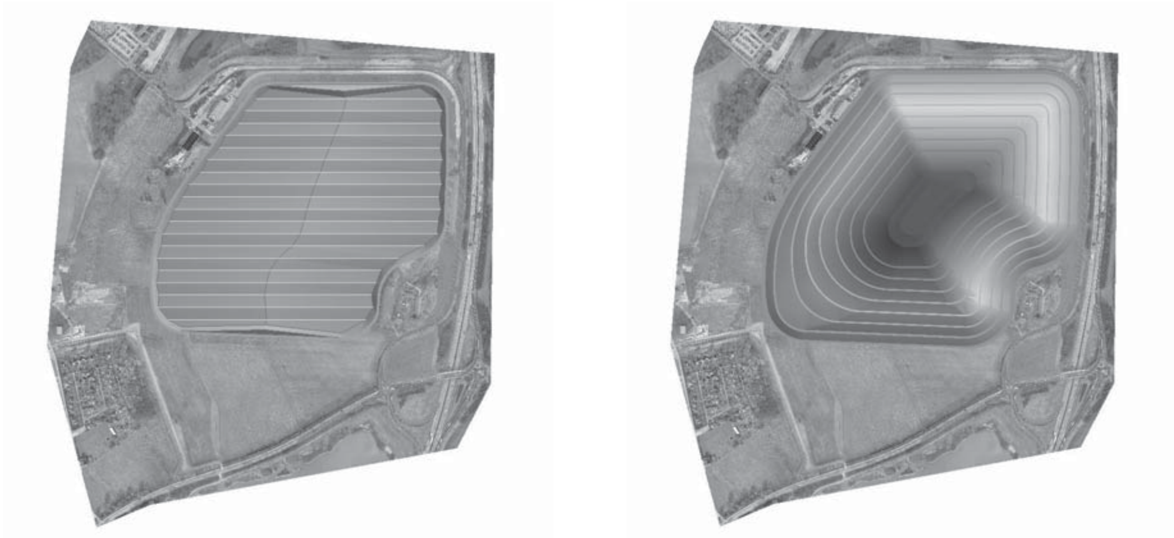

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Figure 4 Modeling of the basin of a landfill (left), and its planned final shape (right)

Due to its high spatial resolution of a few centimeters distance between neighboring DSM-raster-points the UAV-Mapping approach delivers a very high degree of spatial 3D-detail in surface modeling, see Figure 5. Traditional ground-survey methods could deliver such richness of exact surface descriptions only with an enormous economic and labour-intensive effort.

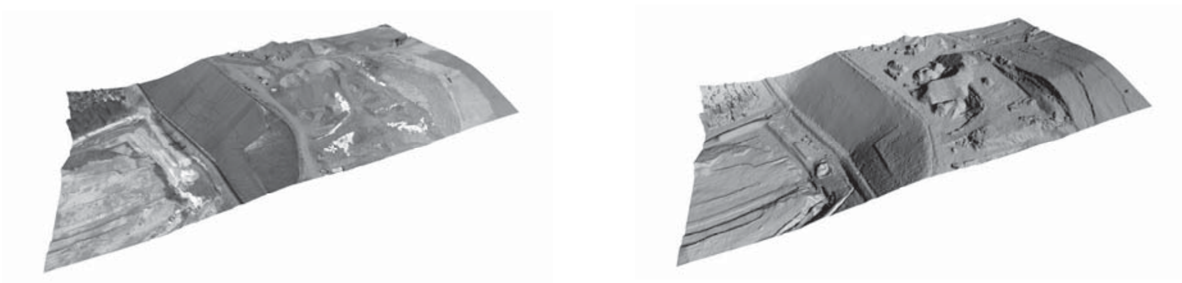

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Figure 5 Perspective 3D-view of a part of a landfill draped with orthomosaic (left) and colorcoded DSM (right)

Furthermore, the operator of a landfill can extract from a UAV-Mapping based DSM locations and quantities of either too much or too few filled-in masses versus the planned, final shape of the landfill. Figure 6 illustrates this with green = too little and red = too much fill-in and color-intensity indicating quantity.

4 Conclusions and Outlook

RPAS is a functioning technology and found its way into spatial data acquisition and spatial data processing. It's established as another tool and opened a wide variety of useful applications. To learn flying an UAV is accomplished in very little time; realizing the responsibility one takes over may take a little longer, though. Control electronics in form of autopilots or flight-stabilization components only heavily support getting an UAV in air and landing it again easily and safely. Even fully automatic take-offs and landings are possible.

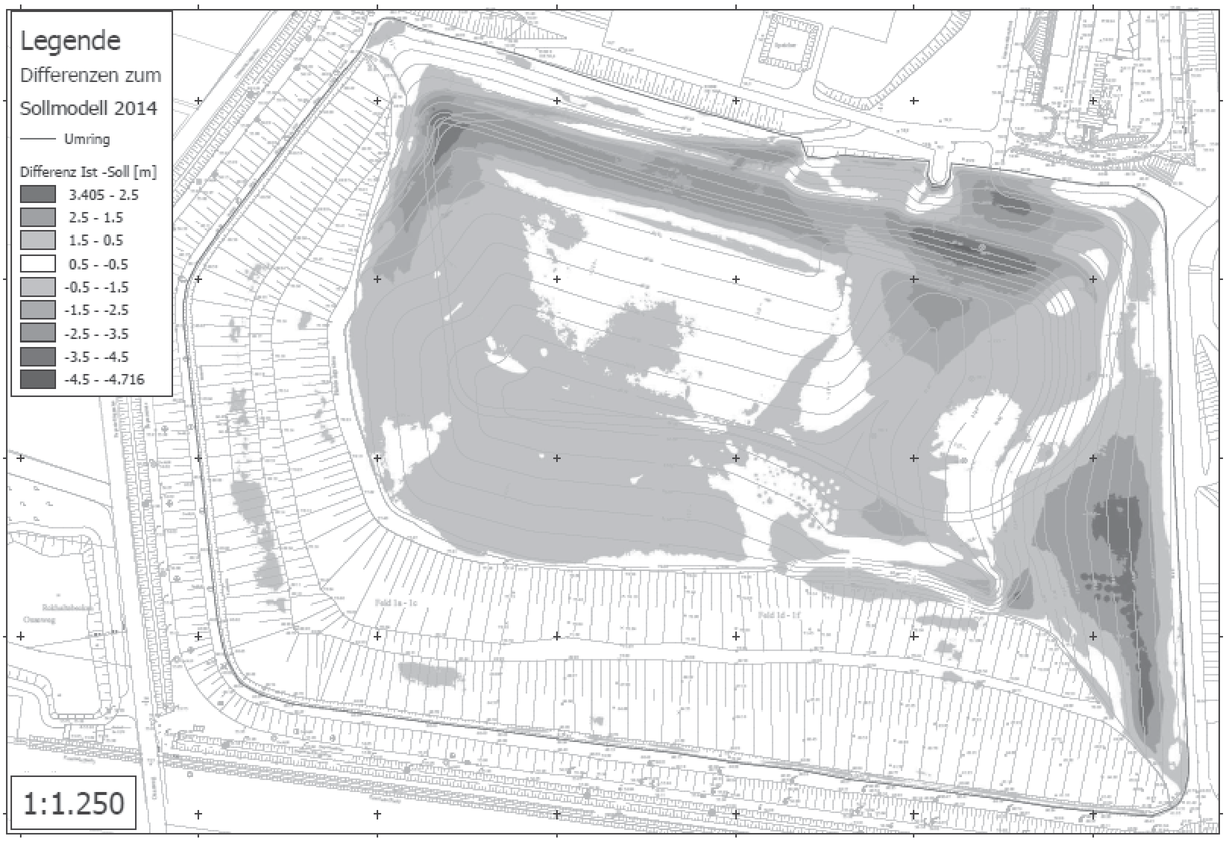

Figure 6: situation plan with superimposed, colorcoded representation of differences towards planned, final shape, derived from an UAV-Mapping based DSM

The processing of UAV-Mapping based aerial images may be accomplished with existing, professional photogrammetric software infrastructure. Also, new and to a high degree fully automated software packages allow a wide spectrum of users to derive 3D-geospatial valuable results and deliverables. The handling of aerial images in geomatics became significantly easier. Nevertheless, from a landfill operator's point of view it might be a consideration to leave geospatial image processing up to the specialists, while flying can be accomplished on their own. All of these properties support the acceptance and widen the use of RPAS-based aerial mapping for 3D-geospatial data processing and analysis. An increase in requests from landfill operators for UAV-Mapping shows this as well. In particular its cost efficiency over manned aircraft and its speed in data acquisition and delivery make UAV-Mapping highly attractive. The resulting deliverables are of high quality and give new visualization options, e.g. 3D-perspective views, animations, time-series-visualization, detailed surface descriptions, or videos, all of which were earlier on available under high costs only.

Multicopters are so-called VTOL-devices (vertical takeoff and landing). Typically, they consist a wire-frame skeleton with 4, 6, 8, or even more rotors. One can see them, depending on their size, up to e.g. 150 m distance from takeoff point. Beyond that range these UAV are not anymore visible. However, European legislation requires the pilot to be able to see the UAV at all the times such that s/he can take over manual flight control. In so far multicopters have a smaller radius of action as e.g. a fixed wing airplane UAV with 200 cm wingspan or more which is visible still in 1500 m, see Figure 1 left. Further, multicopters fly a shorter amount of time with same payload as compared to fixed wing. More motors for rotors require more energy. From an aerodynamic point of view multicopters do not fly and glide like airplanes. They move and hover. However, multicopters are due to their mandatory control electronics far easier and quicker to learn to operate as compared to learn to fly a model airplane, which boosts their wide acceptance. They are ideally suited for vertically oriented tasks, e.g. inspection of towers, chimneys, pylons, bridges, wind mills, and other elevated objects, where it is too difficult, time consuming, or expensive to build up a rigid structure. Also, multicopters are the choice when taking single images from specific view points, or when a movie from an elevated view-path is to be done, or when operating in narrow surroundings such as in urban areas is a demand. This is why multicopters are the majority of UAV-aircrafts which most people associate with UAVs.

Regulation and handling of commercial RPAS is under intensive discussion on European community level and advancing towards a harmonization of regulations. Until then, however, national airspace regulations are valid for commercial RPAS applications. There major common rule is that the human pilot is ultimately responsible for the flying UAV and not the processor chip of the control electronics.

RPAS is not only in use for aerial mapping. It also fulfills tasks in meteorology, movie industry and other domains. The application opportunities of RPAS are manifold. This is why RPAS technology as part of robotics represents a new element of basic infrastructural commodity in remote sensing, transportation, and other economic areas. May all RPAS pilots have safe landings all the time!

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Mechanical Biological Waste Treatment

Integration among traditional businesses, existing waste facilities and new technologies can trigger environmental and economic benefits

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Abstract

Population growth, increase in waste production and climate change represent some of the greatest environmental, social and economic threats facing the Planet. A number of actions have been undertaken by the European Union in order to limit the environmental impact of organic waste.

In industrial terms the need is to have flexible plants and technologies available that, starting from low levels of separate collection, can progressively be switched from the Mechanical Biological Treatment of residual MSW to the source segregated kitchen waste composting, as far as separate collection schemes evolve.

The best European experiences combine existing waste management facilities, traditional businesses like cement production and new technologies in order to provide an effective and custom made solution for each territory.

Keywords

SRF, Solid Recovered Fuel, MBT, Mechanical Biological Treatment, Waste.

1 Introduction

Since the early ‘90s the European Union issued the Council Directive 91/156 on the landfill of waste better known as **Landfill Directive**, to be implemented by its member states. The Directive's overall aim is "to prevent or reduce as far as possible negative effects on the environment, in particular the pollution of surface water, groundwater, soil and air, and on the global environment, including the greenhouse effect, as well as any resulting risk to human health, from the landfilling of waste, during the whole life-cycle of the landfill".

In few words, since then, landfilling has no longer been considered an acceptable way to get rid of waste and the principle of the waste treatment hierarchy was established. Following on from the waste hierarchy, the landfill should be used only as a last resource. All available eco-efficient recovery options, from recycling to energy recovery, should be made available.

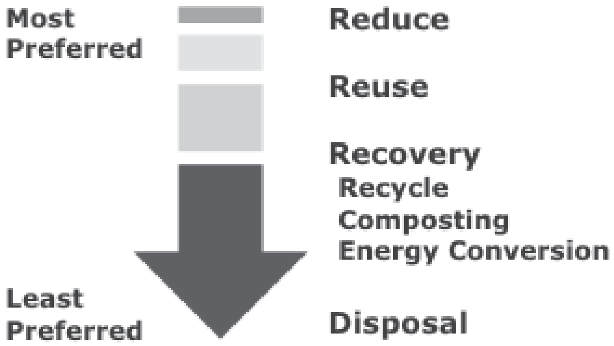


Figure 1 The European waste treatment hierarchy

In order to achieve the landfill diversion target a number of actions have been undertaken and a number of different technologies and treatment models have been implemented, the balance between the different options can vary from Country to Country. The keystone to achieving diversion targets is the separate collection of some waste streams that can trigger an easier recycling and recovery.

In the present paper we will discuss the treatment of the residual MSW that is the waste that remains unselected after the separate collection of other waste streams (glass, paper, cardboard, plastic and maybe kitchen waste) has been activated.

Moreover, together with separately collected wastes, Italian and European strategies, exhort residual waste pre-treatment before final landfilling (Favoino 2005, Stegmann 2005), for example through mechanical-biological treatments for general impact reduction and secondary fuel production for final energy recovery.

Even where the separate collection of kitchen waste has been activated the residual Municipal Solid Waste (rMSW) is characterised by a highly putrescible organic content and what we will discuss with reference to the rMSW will be valid for unselected MSW as well.

This preamble is useful to understand the recent strong incentive to the development of innovative solutions created in order to face the growing and variable needs linked to putrescible waste management that is responsible for methane emission from the landfills that is a Green House Gas (GHG) whose impact is 21 times greater than CO_2.

The rising opposition towards traditional Energy from Waste plants, the increasing needs of new solutions to achieve the zero landfill target and the energy need in the western world together have further stimulated the growth of versatile technologies, able to work efficiently and at low costs in order to produce a fuel from waste under a specification that can be used in a number of different situations.

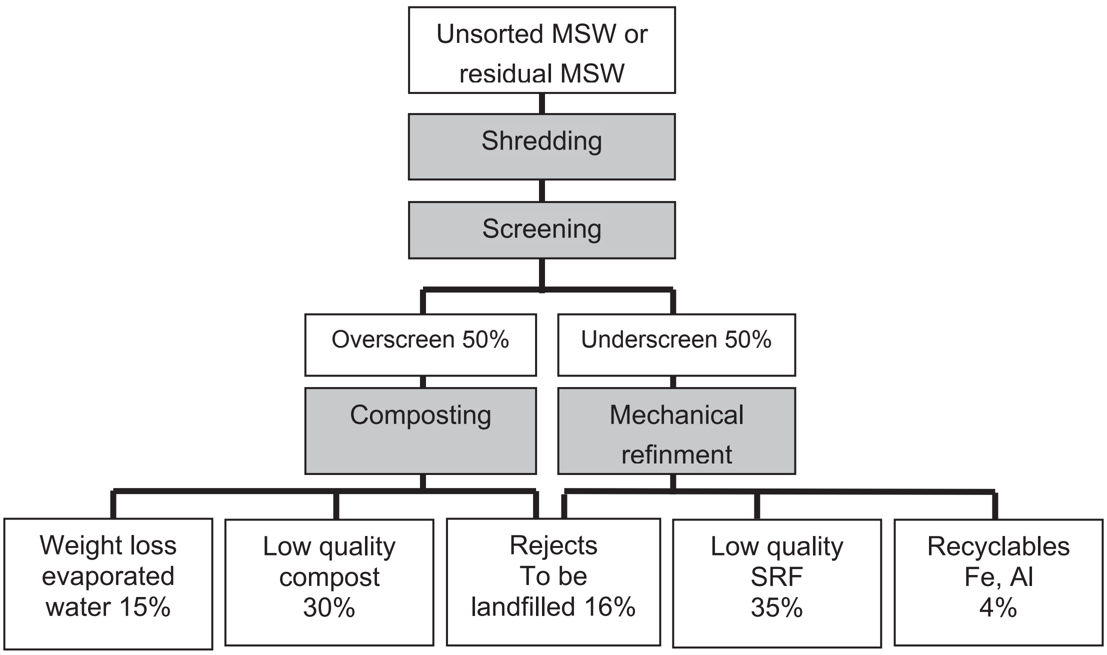
2 The Mechanical Biological Treatment (MBT)

The first problem arising from approaching the production of a suitable SRF from rMSW is the moisture of the waste. The most efficient idea from both the economic and the environmental perspective is to use the bio-energy within the putrescible fraction of the waste to trigger an aerobic fermentation that develops the heat to be used for waste drying.

Once the waste is dehydrated it is possible to execute a more convenient mechanical refinement of the product with the purpose of removing unwanted materials and obtaining a product under specification in terms of calorific value (low heating value) , chemical composition, dimension, moisture suitable for use in a wide variety of cases.

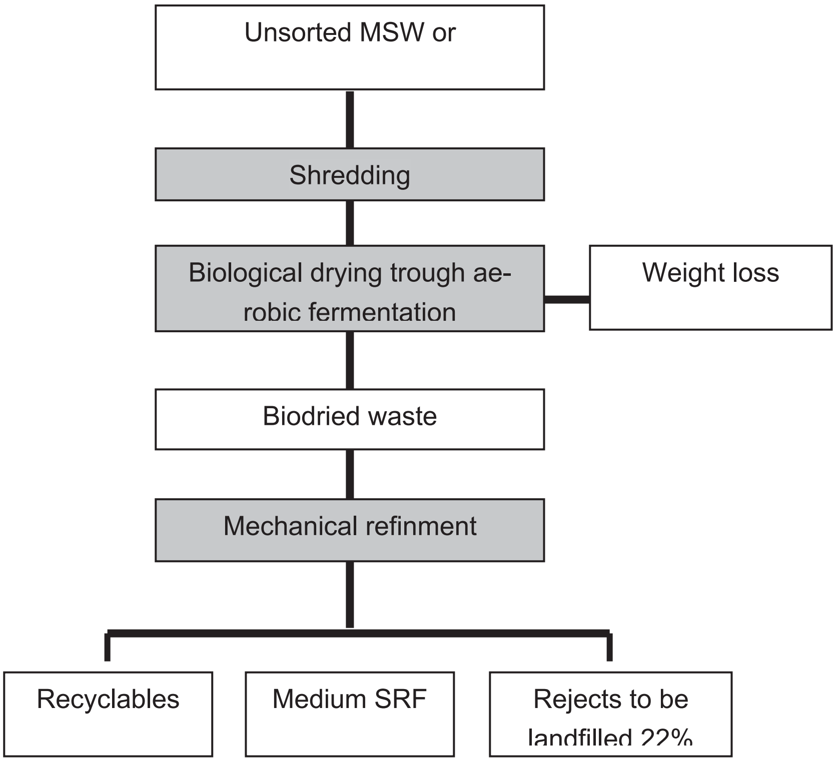
The traditional pre-selection (set up in Germany in the late ‘80s and early ‘90s) of waste by shredding and screening at 80 mm splitting the waste into two streams the over-screen and the underscreen, has been proven to be ineffective due to the fact that the overscreen supposed to be dry still contained an amount of putrescible making it im-possible to use it as a fuel without a prior stabilization; on the other hand the under-screen supposed to be compostable was so contaminated by various pollutants as to be no longer usable in agriculture.

Mechanical pre-selection of unsorted MSW flow chart



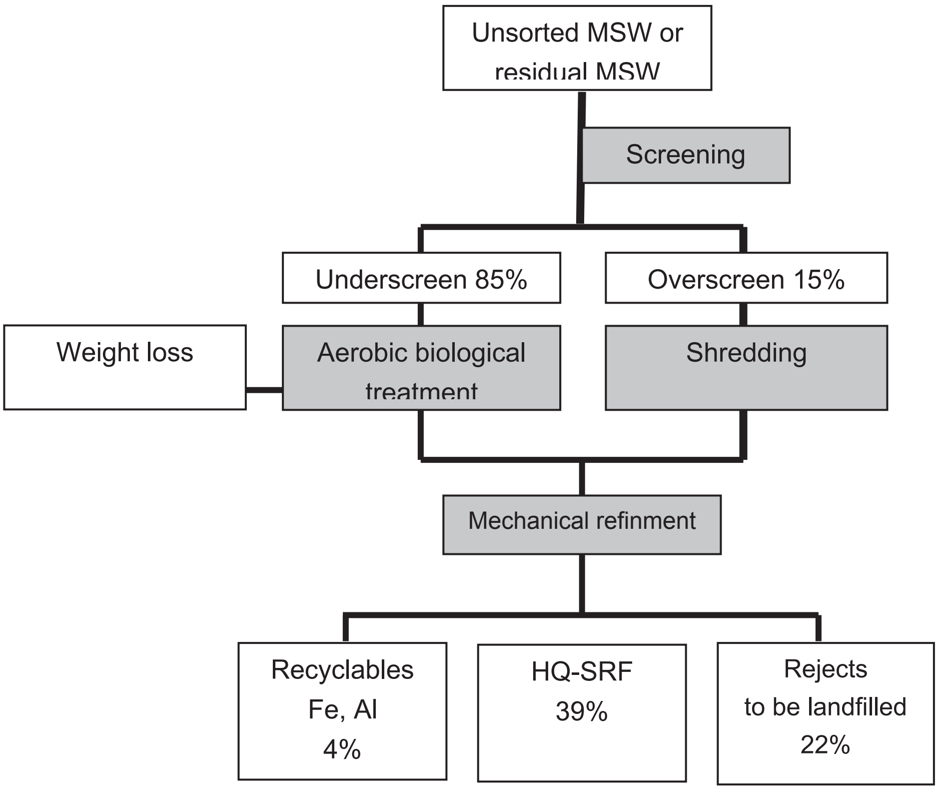
In the mid ‘90s, the so-called single flow treatment (Cella 2003, Adani 2004) came into use. This treatment consists in a pre-treatment based on a simple bags open-ing/shredding of the whole waste throughput which then undergoes an aerobic biologi-cal treatment by forced aeration. The double goal is obtained of both stabilising and dry-ing the mass, consequently and consistently reducing weight and volume.

Single flow treatment flow chart



A further step towards optimization was made some years later with the innovative double-flow approach with a substantial simplification of mechanical pre-treatment of waste, thus greatly reducing energy requirement and machinery wear and tear, and improving the feasibility of biological process.

Simplified double flow treatment



Plant simplification and footprint reduction have been followed, in the most modern solutions, by an automation of all the operations, which allow the operators not to come into contact with waste, and all the work to be rationalised.

The process is managed through forced aeration automatically controlled by specific algorithms, which control act on source, direction and amount of air given to the mass, allowing significantly improved treatment performances.

In this paper we have focused the attention on the biological process, whose improvement is based on three main factors:

- Input waste preconditioning by means of forcedly blown warm air that is particularly useful in cold climates
- bidirectional (top-down and down-top) aeration of waste during biological step allowing a homogeneous stabilisation and drying of the waste
- precise process control based on a temperature feed-back.

On this subject, it must be underlined that the plant works on exhaust air temperature monitoring instead of mass temperature, with advantages mainly based on the possibility of obtaining an average temperature representing all the mass instead of a single point situation, and in the avoidance of manually moving probes throughout the plant.

The mechanical refinement can be declined in a number of possible solutions; the two most relevant trends can be considered the following:

1. The mechanical refinement is finalized to maximize the SRF quality thus implying to landfill some rejects (unwanted fractions) and to select as RDF only the most valuable fractions (plastic films). In doing so the SRF quality from rMSW is medium-high quality with a calorific value of 17-18 MJ/kg. The SRF quality can be further increased by blending the SRF with C&I waste (plastic and rubber scraps) properly conditioned (shredded).
2. The mechanical refinement is finalized to maximize the landfill avoidance and consequently the amount of SRF produced. In this case, the average calorific value of the SRF will be lower 14-15 MJ/kg and a blending with more valuable C&I waste will be mandatory to comply with high SRF standards.

Both option can be envisage optical sorting device in order to comply with recycling targets by selecting some valuable streams (i.e. PET bottles) or by removing chlorine source as PVC.

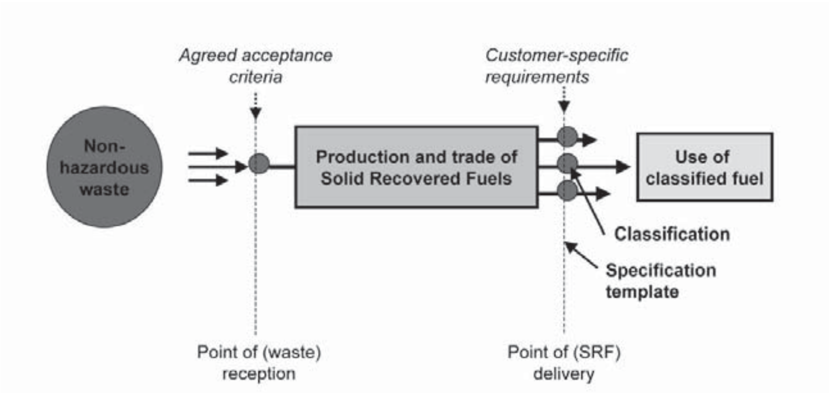
It is pretty evident that does not exist a preferred solution that can be proposed, carbon copy, in every situation but each proposal must be composed taking into account the peculiarity of a territory, its infrastructures, its industrial vocation and the possible SRF outlets (cement kilns, power plants, energy recovery plants).

3 The SRF and its classification

“Solid Recovered Fuels (SRF) are fuels prepared from non hazardous waste to be utilised for energy recovery in waste incineration or co-incineration plants regulated under the EU Community environmental legislation.”[1]

In practice the optimal use of SRF requires a stable supply of pre-treated and homogenised waste upgraded to a fuel quality that can be traded amongst producers and users of SRF. This implies specifications that are included in commercial transactions for SRF.

SRFs may be composed of a variety of materials of which some although recyclable may have been made available in such a form that recycling is not environmentally sound. On the one hand, materials collected and/or sorted and prepared into a recyclable form should not be considered as SRFs. On the other hand, recyclable materials should not be excluded from SRFs because such an exclusion could lead to disposal of these materials and wastage of the resources embedded in them.



The *CEN*, the European Committee for Standardization published a number of necessary standards on solid recovered fuels (SRF) in order to classify the fuel and fix the methodologies to asses the fuel quality.

The main specification is the CEN TS 15359-2006 “Solid recovered fuel – Specification and classes” with the objective to provide unambiguous and clear classification and specification principles for Solid Recovered Fuels (SRFs) and it aims at serving as a tool to enable efficient trading of SRFs, promoting their acceptability on the fuel market and increasing the public trust. The Technical Specification facilitates a good understanding between seller and buyer, facilitates purchase, transborder movements, use and supervision as well as a good communication with equipment manufacturers. It also

[1] CEN TS 15359 Solid recovered fuels - Specifications and classes

facilitates authority permission procedures and eases the reporting on the use of fuels from renewable energy sources and on other environmental issues.

Table 1 CEN TS 15359 Solid recovered fuels - Specifications and classes

Classification Parameter	**Statistical Measure**	**Unit**	**Classes**				
			1	**2**	**3**	**4**	**5**
Net calorific value (NCV)	Mean	MJ/kg (ar)	>25	>20	>15	>10	≥3
Chlorine (Cl)	Median	% (d)	≤0.2	≤0.6	≤1.0	≤1.5	≤3.0
Mercury (Hg)	Median	mg/MJ (ar)	≤0.02	≤0.03	≤0.08	≤0.15	≤0.50
	80th percentile	mg/MJ (ar)	≤0.04	≤0.06	≤0.16	≤0.30	≤1.00

Despite all this background, the SRF still remains waste thus implicating a number of administrative obligations that makes it difficult to properly “market” the fuel.

4 Cement kilns an energy intensive industry

Over 3 billion tonnes of cement were produced globally in 2009. China's cement consumption alone reached over 1.6 billion tonnes (54%); 72 million tonnes (2.4%) is the consumption in the USA while 258 million tonnes (8.6%) is the consumption in Europe (EU27). [2]

Coal is used as an energy source in cement production. Large amounts of energy are required to produce cement: each tonnes of cement produced requires 60 to 130 kilogrammes of fuel oil or its equivalent, depending on the cement variety and the process used, and about 105 KWh of electricity. Kilns usually burn coal in the form of powder and consume around 450g of coal for about 900g of cement produced.[2]

The overall consumption of coal is massive and the table below gives an overall view of the impact simulating a substitution rate of only 10% of the amount of coal used in the cement kilns under the following assumptions:

- The SRF has a calorific value of 70% of the calorific value of coal
- One tonne of rMSW produces 500 kg of SRF

[2] Source of data CEMBUREAU European Cement Association - Rue d'Arlon 55 - BE-1040 Brussels

- One tonne of SRF used in a cement kiln triggers a CO2 emission reduction of 500 kg of CO2eq. compared to the correspondent amount of rMSW if landfilled.[3]

Table 2 – Carbon emission reduction from using the SRF in substitution of coal

	Cement produced		Coal consumption	Substitution	SRF	rMSW to be landfilled 3	inhabitants	Landfill diversion achieved	CO2eq. reductio n
	million tonnes 1		million tonnes 1	%	million tonnes 1	kg/y	million		million tonnes 1
World	3000		1.263		180				90
USA	72	13333,3%	30		4	496	17.463.012		2
EU 27	258	47777,8%	109	10%	16	325	95.500.289	80-100%	8
India	186	6,2%	78		11	146	153.259.862		6
China	1620	54,0%	682		97	288	676.691.729		49
1 - metric tonnes									
2 - Source CEMBUREAU Brussell - PCA Portland Cement Associacion Washington									
3 - Source EUROSTAT and EPA USA									

It is evident that SRF makes available a significant quantity of fuel and triggers a massive environmental benefit in terms of carbon reduction.

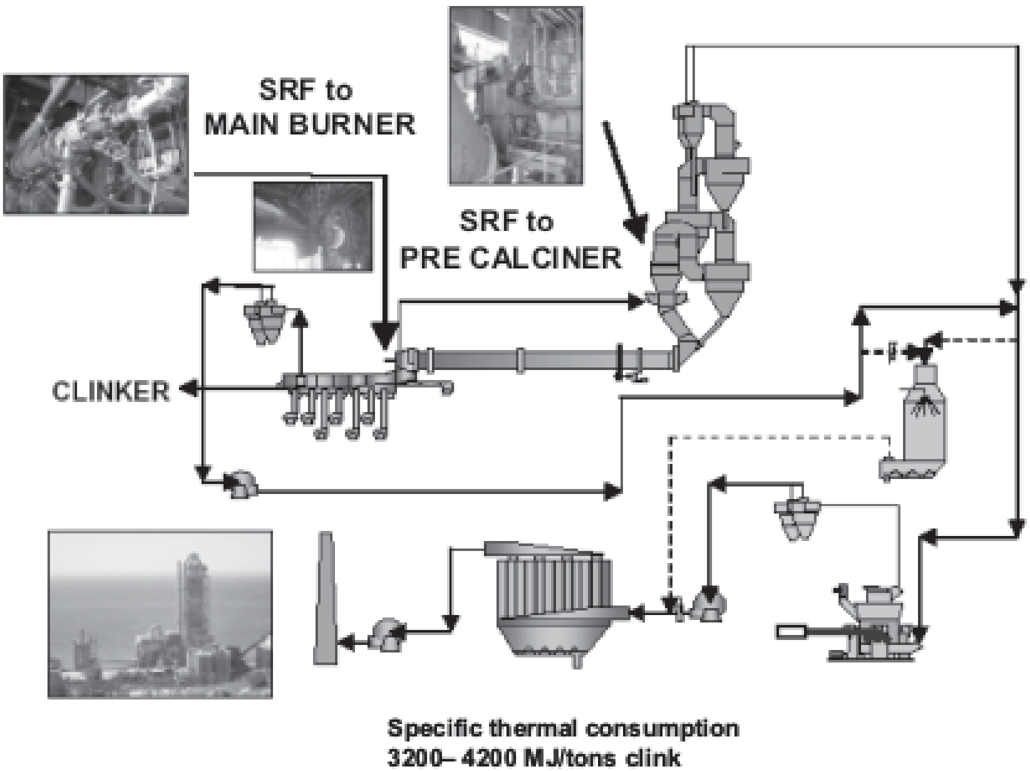


Figure 2 Use of SRF in the cement production cycle

[3] Entsorga S.p.A. - assessment 2010

Other advantages of the use of SRF in cement manufacturing are:

- The utilisation of SRF under specification as alternative fuel, is compatible with the general principles and with existing EU and national policies on energy efficiency, climate change and waste management.
- In the cement manufacturing process, the use of alternative fuels and raw materials has the potential to reduce emissions to the environment relative to the use of conventional fossil fuels, and conserves non-renewable resources.
- The cement kilns offer a safe alternative to conventional disposal of waste in dedicated waste incinerators or in landfills, again resulting in overall benefits by reducing environmental burdens and reducing the need for dedicated treatment capacity.
- The excess of oxygen during and after combustion improves the efficiency of combustion;
- High residence time and high temperature (1400 °C see table below) in the furnace makes the complete destruction of organic compounds and re-training of PCDD/DF possible;
- Total neutralisation of acid gases, sulphur oxides and hydrogen chloride, by the active lime that is loaded into the kiln in large excess if compared to stoichiometry need;
- Embedding of the traces of heavy metals and ashes in the clinker structure with very stable links (metallic silicates formation); and there is no production of by-products such as ash or liquid residue from gas or liquid residues from gas cleaning;

Table 3 – Temperature and time involved in the cement manufacturing process

Characteristics	Temperature and time	
Temperature at main burner	>1450℃: >1800℃:	material flame temperature
Residence time at main burner	>12-15 sec and > 1200℃ > 5-6 sec and >1800℃	
Temperature at precalciner	>850℃: >1000℃:	material flame temperature
Residence time al precalciner	>2-6 sec and >800℃	

In conclusion, the cement industry is the preferred outlet, at the moment, for SRF, because it makes a relevant number of possible users available and immediately triggers both environmental and economical advantages. Moreover the investments required to upgrade the plant in order to use the SRF are negligible and are limited to providing the suitable storage and feeding system for the SRF into the burners.

5 Other possible outlets for the SRF

The substitution of coal in power plant using such fuel is straightforward as it is in a cement kiln and it is triggering same environmental benefits.

Power plants operating with noble fossil fuels such as methane or LPG can be upgraded and completed with a dedicated burner for SRF generating heated gas that can be fed to the existing turbines in the plant. This makes it possible to preserve fossil fuel and cut the costs of power generation because of the cheaper cost of the SRF.

With regard to new waste treatment technologies and bio-fuel production based on new thermal treatment, gasification and pyrolisys, SRF represent a more homogeneous reliable and with a granted quality over the time making it possible a n easier implementation of such technologies for which the industrialization was made very difficult for the non homogeneity and substantial unforeseen characteristics of unsorted municipal solid waste.

6 MBT - NORTHACRE RRC – Wiltshire UK

Plant throughput 70,000 tpa of rMSW - Inhabitants served 250,000
The SRF is produced for a number of different users (EfW plants, cement kilns), each one having its own specification.The flexibility of the plant makes it possible to produce a specific SRF for each user by changing the settings of the refinement equipment.
This plant represents one of the most modern and highly efficient facilities in Europe. It entered into operation in February 2013.

Figure 3 The Northacre RRC - Wiltshire MBT plant

The mechanical and biological treatment of mixed municipal waste is aimed at reducing collected waste at the landfill in the most economical and ecologically acceptable manner.

The process is made up of the following steps:

- waste intake in the plant's reception area,
- pre-treatment of the waste by bag opening and screening separating the waste into two flows
- biological treatment of the mass (biostabilization and biodrying for 14-15days)
- mechanical refinement of the biodried material in order to produce an SRF under specification

The biological treatment is conducted in the biostabilization facility.

During the 14 days of bioxidation an aerobic process within the mass occurs. The rise of temperature within the mass and the properly dosed air flow will dry out the material, at the same time the bioxidation transforms the organic carbon in the putrescible fraction into mineral carbon thus reducing the VOCs of the mass.

The results of the process are as follows:

- the weight of the waste is reduced by 1/3 of the initial weight, the weight loss is 95% due to evaporated water and 5% due to SOV reduction.
- The above combined effects will make the material stable thus preventing odour release and vermin proliferation.
- By getting rid of the water within the waste the LHV of the waste is improved and the subsequent refinement is made easier.
- Because of the stabilization effect the refinement residues will have the leachate and methane generation reduced by 95% when landfilled[4].

The entire process is conducted in an enclosed hall kept in negative pressure thus prevent any odour leaks. The processed air and the air extracted from the hall are deodorized by means of a large biofilter that guarantees a very high cleaning rate (99%).

All material handling is done by two automated overhead cranes that with no operator intervention move the waste along the various steps in the plant and record every process parameter.

The final mechanical treatment aims to remove the unwanted fractions such as glass, inerts, dust, to sort out the most energetically viable fraction made up of plastic films and to properly shred it to the required dimension.

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7 The DECO S.p.A. plant in Chieti - Italy

The plant is located in Chieti a populated area on the east coast of central Italy. The plant was designed to treat a maximum waste throughput of 270,000 tpa

The waste is on a daily basis for 6 days a week and operates 24/7 in treating the waste. The reception stage is carried out in a common area where the waste is tipped into suitable pits under the supervision of an operator from a control cabin. The material is handled by an automatic crane system and eventual unwanted materials are manually removed and properly landfilled.

The pre-treatment consists again in a bag opening operation and screening in order to divide the waste flow into two streams: the underscreen and the over screen.

The overscreen is deposited into a suitable pit and immediately sent to the final refinement for SRF production while the underscreen will be allocated into the biological section where the material will be processed for 10-15 days in order to dry out the moisture.

The biological section is divided into 2 production lines as the capacity of such a plant is really massive. All handling and processing operations are automated and supervised by means of a computerized system making the operation of the plant very low labour intensive.

Once the material is properly dried is removed by means of the automated overhead cranes and loaded into the mechanical refinement system in order to sort out the unwanted material and provide the production of the suitable SRF.

The SRF outlet is destined for a number of different users (EfW plants, cement kilns), each one having its own specification. The peculiarity of the plant is its flexibility that makes it possible to produce a specific SRF for each user by changing the regulation of the refinement equipment.

This plant represents one of the biggest and most modern facilities in Europe, it entered into operation in November 2009, achieved its design capacity of 270.000 tpa in June 2010.

Figure 4 The Deco S.p.A. plant in Chieti - Italy

8 Conclusions

The topics and the case studies here discussed are part of the European experience which is driven by the political policy that actually banned the traditional waste landfilling and created economic and regulatory conditions in order to develop an industrial sector linked to the Green Economy.

MBT technologies represent a viable solution for waste management in partial substitution of landfill, its flexibility makes it possible to produce a fuel under specification that can be used in a number of possible use in substitution of fossil fuels. The organic fraction within the waste is considered as a renewable energy source and the correspondent CO_2 emission can be considered neutral with reference to climate change.

The question now is if such technology, apart from future use in conjunction with innovative technologies like gasification, is viable in the USA situation.

If we compare the European landfill gate fee of 110 €/tonnes (metric tonnes) that with the present exchange rate makes 141 $/t (US tons) with the average landfill gate fee in the west coast 65 $/tons it seems difficult to implant such solutions in the USA. Nevertheless on further analysis we may completely overturn the judgment for the following reasons:

- Technologies evolve rapidly: investment (capex) and treatment (opex) costs decrease continuously.
- Fossil fuels are more and more a limited and expansive (100 $/ton for coal)
- In Europe because of the high landfill gate fee and the limited outlets available, users are entitled to be paid for receiving the SRF.
- in the rest of the world where the SRF market is not affected by the regulatory policies users and especially cement producers are available to pay for having the SRF in substitution of coal.

Because of all the reasons above there exists a margin made of the sum of the cost of the fossil fuel and the cost of the landfill that makes the MBT and SRF production economically viable.

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Operation experiences at the MBT Maresme, the latest wet anaerobic digestion plant for MSW built in Spain

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Abstract

The MBT Maresme is the latest wet anaerobic digestion plant for the Organic Fraction from Municipal Solid Waste (MOR -Materia Orgánica Residual), that has been built in Spain, in countercurrent to the observed development towards MBT plants with only composting technology. In the present paper a short presentation of the MBT Maresme is given before the operation experiences during the start-up phase and the guarantee tests are discussed. Despite the challenge the operation of this facility under aggravating circumstances implied, the achieved performance and clearly advantageous energetic balance confirm the integration of a digestion step in MBT plants as a valid and valuable concept.

Keywords

Mechanical Biological Waste Treatment, Municipal Solid Waste, BTA® Process, wet mechanical pre-treatment, removal of impurities, wet anaerobic digestion, plant start-up, operation experiences.

1 Introduction

The history of MBT-AD Plants in Spain as in Europe is a quite painful story. In the last 14 years, since 2001, 30 AD plants were built in the country, of which 4 were never commissioned, 4 are forsaken and 22 are currently in operation. In total, 20 facilities went through a reengineering. As presented in past editions of the Waste to Resources conference, two of them were successfully refurbished by BTA International GmbH and Biotedc Sistemi s.r.l.: the methanization line at Ecoparc I in Barcelona and the methanization line at the Ecoparque Burgos. In total, less than 10 facilities are currently operating at nominal production. Due to this two tendencies can be observed: towards composting as biological step instead of anaerobic digestion followed by composting and away from the treatment of MOR (Materia Orgánica Residual), which is residual waste.

Being the main reasons for this difficulties that the AD facilities in Spain where designed as a solution to, the residual waste fraction of selective collection which means that we will have the lowest quality of Organic fraction either for composting or AD.

In countercurrent to these tendencies, the MBT Maresme was designed to treat organic fraction from MOR through wet anaerobic digestion. This article presents the technology implemented in MBT Maresme and discusses the experiences during the commissioning and first year of operation.

2 Maresme Integrated Waste-to-Energy Plant

1.1 Overall facility

The MBT Mataró is the latest MBT plant including a wet anaerobic digestion line for the Organic Fraction from residual waste (OF MOR) built in Spain. The methani-zation line is embedded within the Centre Integral de Valorització de Residus de Maresme. This integrated waste operation plant incorporates different processing lines including mechanical pre-treatment, anaerobic digestion, biostabilization or composting, thermal valorization, bulky waste recovery and transfer stations for selectively collected waste fractions. From 190.000 ton/year of MOR, approx. 35.000 ton of OF MOR are treated in the methanization line.

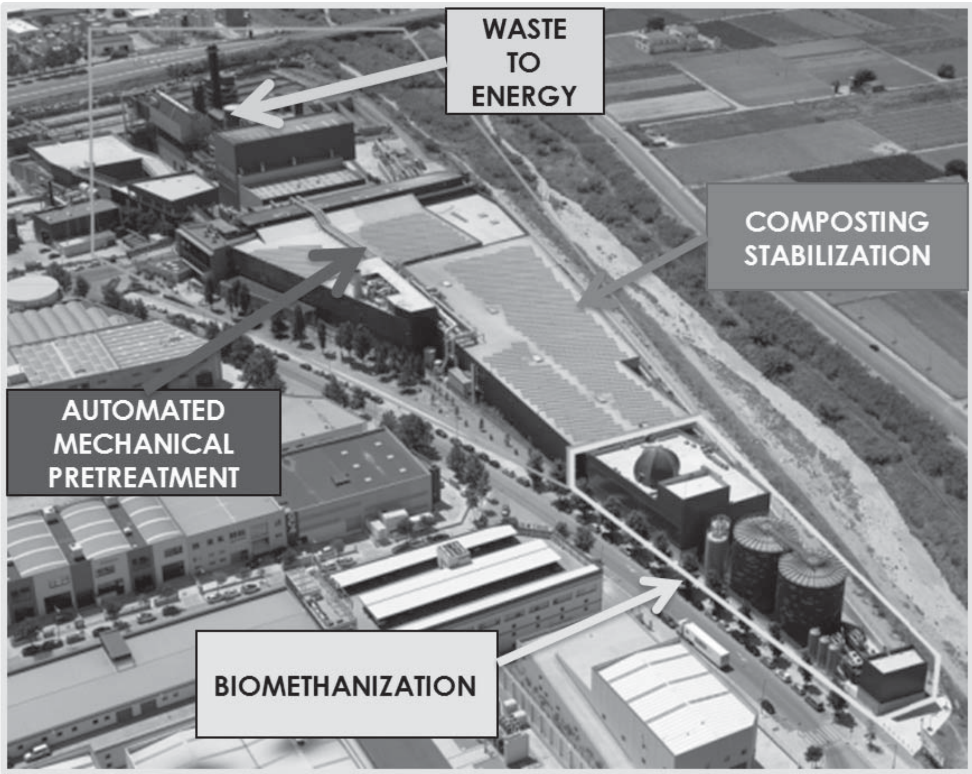

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Figure 1 Main processing lines at the Centre Integral de Valorització de Residus de Maresme

The MBT Mataró was built by the Consortium UTE TEM Constructora, leaded by the Spanish company Valoriza Servicios Medioambientales S.A., which is, together with Veolia Proprieté, also part of the Operating Consortium

1.2 Methanization line

In the mechanical pre-treatment, the sieve underflow < 70 mm from a drum sieve undergoes the following pre-treatment steps before this fraction is sent either to biostabilization or to the methanization line: magnetic separation of ferrous metals, pneumatic collection of plastic film, removal of rolling fraction through ballistic separation and partial removal of fines by a vibration screen with an original mesh size of 15 mm. Out of the OF MSW fraction, approx. 35.000 ton/year are further processed in the methanization line, 40.000 ton/year in the biostabilization.

The methanization line was designed and built according to the BTA® Process. Firstly, the remaining impurities in the OF MSW are efficiently removed within the BTA® Hydromechanical Pre-treatment, which consists of two Waste Pulpers for the removal of coarse impurities like stones, glass, metals, bones, batteries (heavy fraction) and plastic, foils, wood, textile (light fraction) and three Grit Removal Systems for the widely separation of fine impurities like sand, glass splitters or egg shells. At the same time, the digestible organics are dissolved and defibred in the Waste Pulper into an organic suspension, which undergoes a thickening step previous to the digestion in order to reduce the dimensioning of tanks and equipments. The filtrate is returned to the wet mechanical pre-treatment

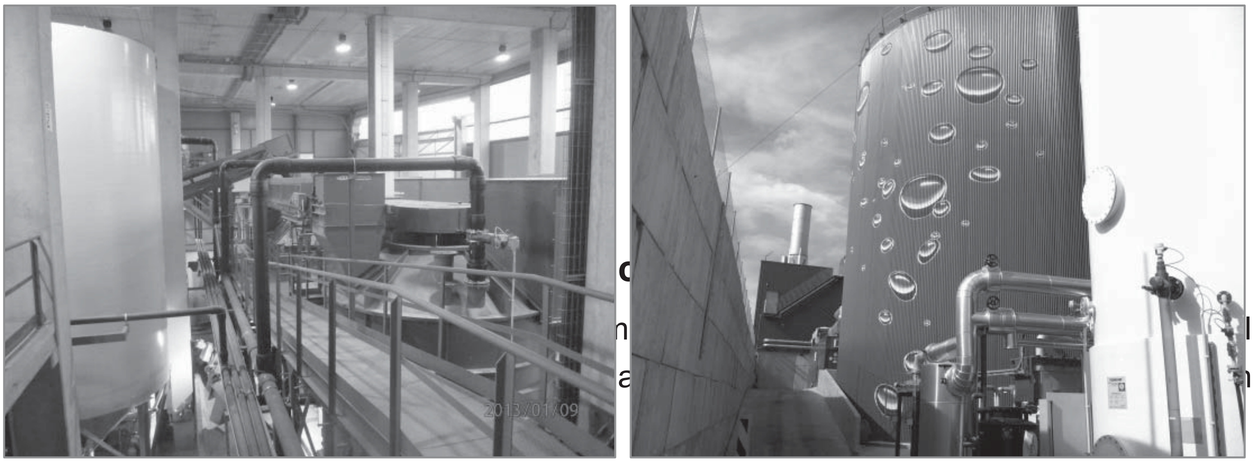

Figure 2 Methanization line: wet pre-treatment line (left) and anaerobic digestion area (right)

The thickened organic suspension is then processed in the second step, the anaerobic digestion: A mesophilic, one-stage wet anaerobic digestion with two digesters of 3000 m³ fully mixed with injected gas by gas lances. The average hydraulic retention time is 20 days. The integration of a suspension buffer with a capacity of 600 m³ allows the continuous feeding of the digesters also during the nights and the weekends. Before its valorization in two CHP units with a capacity of 800 kWe each, the biogas is treated in an external biological desulfurization.

The methanization plant is connected to the district heating and cooling circuit of Mataro. Approx. 1,2 MWthermal are exported to the circuit, leading to a saving of approx.. 2.926 ton CO2eq/year by substitution of natural gas.

On the other side, being connected to the district heating and cooling circuit, saved about 30.000l of gasoil during the start-up, corresponding to approx. 77 ton CO2eq. Furthermore, CHP cooling expenses might be reduced by 50% up to roughly. 18.000 €/year.

After the anaerobic digestion the digestate is sanitised at 70°C during one hour transferring heat from CHP heating circuits. Previous to the solid-liquid separation, the digestate is cooled down again under 40 °C to facilitate the dewatering process with three screw presses.

The solid digestate is treated in the biostabilization process together with the remaining fraction of the OF MSW non-treated in the anaerobic digestion plant. The liquid phase is widely recirculated without any further treatment to the wet mechanical treatment for the dry matter adjustment in the pulper. A second stream is recirculated for rinsing purposes after a removal of suspended solids through a mechanical pre-treatment. The surplus water is treated together with the effluents from the other areas of the Integrated Waste Treatment Centre in a central wastewater treatment plant.

3 Experiences during start-up and acceptance

3.1 Design vs. operating conditions

Difficult circumstances were faced during the start-up and acceptance tests carried out in during 2012 and 2013, extending duration of this phase (10 plus 3 months):

- The operating days per year were reduced from 299 days/year (design conditions) to 249 days. Instead of 117 ton/day, it was necessary to process 140 ton/day in the wet pre-treatment, which is approximately 20% higher. Therefore, it was required to increase the number of pulper batchesper day from 13 to 16.
- The composition of the OF MSW differed importantly from the design specifications. . This is a direct consecuence of a high quality in the origin selective collection which makes this fraction harder to process. With 51% the average dry matter content was approx. 25% higher than as-sumed under design conditions (40,7%), while the amount of the organic fraction was much lower than foreseen.

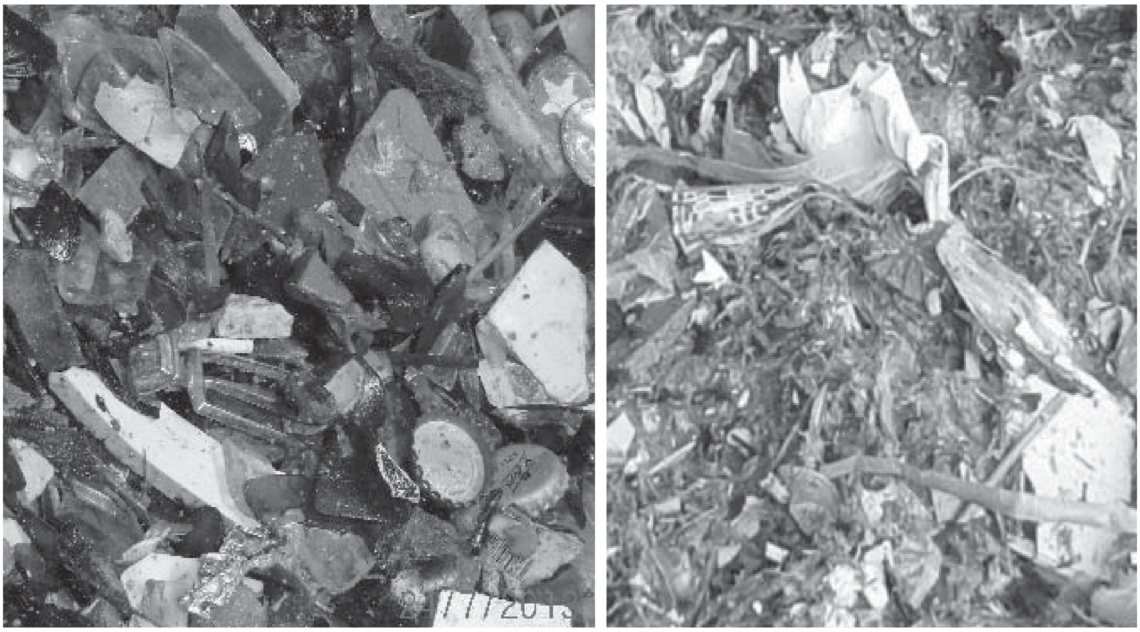

Figure 3 Heavy fraction and light fraction removed at the wet mechanical pre-treatment)

Table 1 outlines the operation parameter assumed under design conditions versus real conditions. Between 150 and 200% more impurities were removed in the wet pre-treatment than considered in the design mass balance, although the requirements to the content of digestible organics in the rejects were observed. On the other side, due to the lower content of digestible organics in the input to the anaerobic digestion phase, the achieved biogas production was nearly 20% lower than predicted. Nevertheless, the overall energy balance is very positive. The facility currently supplies 7.000 MWh/yr to the Mataro's District Heating system, thus preventing the emission of 2.926 tnCO2eq/year.

3.2 Improvements on methanization line during start-up and operation

Different conditions challenged the implementation and commission of this technology, requiring different re-adjustments to optimize conditions to enable full capacity.

In order to reduce the amount of impurities in the OF MSW, the following modifications were introduced upfront the wet pre-treatment:

- Widening of the vibration Increase of the mesh size for the removal of fines from 15 to 20 mm.

- A Foucault Separator was integrated for the removal of aluminium paper in the OF MSW going both to the biostabiilzation and the methanization lines, reducing the risk of accumulation in the digesters.

Table 1 Operation parameter under design and real conditions

Parameter	Unit	Design	Start up and Acceptance	Difference
Capacity	ton/day	117	154	+31,6%
Pulper batches	n°/day	13	17	+30,8%
Heavy fraction	ton/day	6,85	17,05	+148,9%
Grit fraction	ton/day	6,86	18,15	+164,6%
Light fraction	ton/day	12,69	38,34	+202,1%
Biogas production	Nm^3/year	4.200.000	3.383.000	-19,5%
Biogas production	Nm^3/ton MOR	120	84,4	-29,7%
Biogas production	Nm^3/ton VS input digester	420	422	+0,4%
Methane content	%	60,9	57,68	-5,3%
Dewatered digestate	ton/day	54		-100,0%
Dry matter content dewatered digestate	% WM	30	32	+6,7%

In order to further improve the quality of the input material to the wet mechanical pre-treatment, the implementation of x-ray sorting for the fraction 20 to 70 mm was studied. This method has been successfully applied at the Ecoparque La Rioja, in Spain. This possibility was not further developed due to the on-site space limitations.

The possibility to fine-tune the operation modus of the BTA® Hydromechanical Pre-treatment did offer further possibilities to cope with the real waste composition. The duration of the pulper batches were extended to give more time for the heavy fraction removal in the heavy fraction traps as well as the light fraction removal. Also the number of recirculations of the organic suspension in the BTA® Grit Removal System was increased in order to increase the removal efficiency of the grit fraction. Furthermore the operation routines of the belt conveyors for the rejects were modified to increase the storage capacity of the rejects on the belts during the exchange of the containers with rejects.

Furthermore, in order to reduce the wear and the associated costs and maintenance time, new materials for the wear parts have been implemented or will be tested, e.g. a new bimetallic lining of the Pulper bottom, successfully tested in other MBT plants (see fig. 4).

In October 2013, incrustations were observed for the first time in the Process Water 2 circuit on the dewatering screw presses, pumps and pipes. This could be solved by the addition of scaling inhibitors.

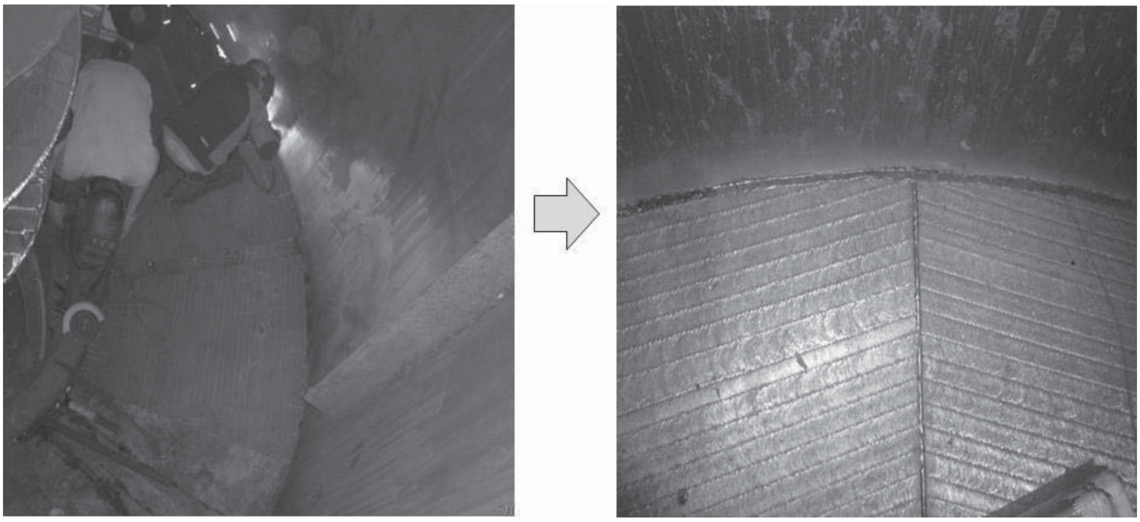

Figure 4 Bimetallic bottom installed at BTA® Waste Pulper at CVO Valorlis in August 2012 (left) and still in operation October 2014

The high requirements we are asking the technology have faced out in some premature wear failures in January 2015, that have been successfully addressed and improved. As example:

- The Baler, for the light fraction of the pulper has been working at twice the design capacity and so it had to be refurbished and reinforced, as can be seen in the figure 5.
- As said the light fraction removal is the most affected for the deviation on the input material, So the Rake that removes it in the pulper was the other part that had to be reinforced during the January maintenance overall of the facility.

4 Outlook

The operation of a mechanical biological treatment plant is always challenging. Difficult conditions, as observed in Mataró, rather than an exception, are common as the OF MSW composition tends often to be worse than previously indicated. And trend is that it will get worse as the people improve the selective collection. For this reason, it is of capital importance to introduce an adaptable technological approach to deal with these conditions. On the other hand, it is equally important to have an experienced operation and maintenance team and a pragmatic and hands-on attitude.

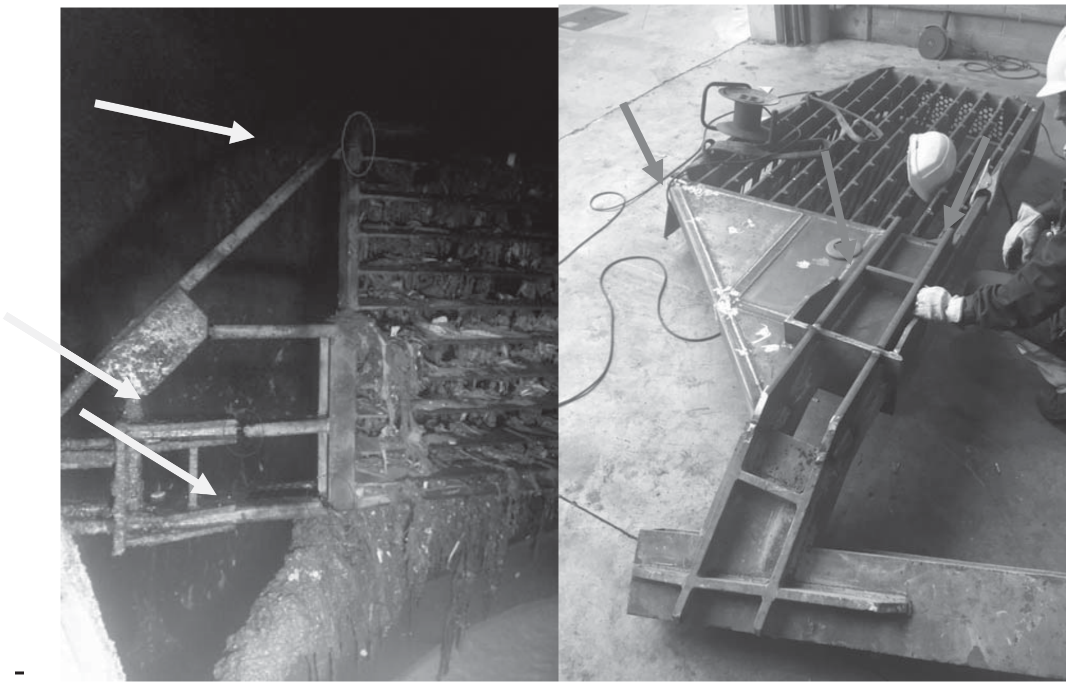

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Figure 5 Reinforcement of the LRS Rake for the light fraction removal

The operation experiences and the positive energy balance in Maresme show that mechanical biological treatment plants with an anaerobic digestion step are technologically viable and an interesting alternative even for the treatment of difficult streams like residual waste (MOR).

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Efficient Treatment of Municipal Solid Waste by Percolation and Dewatering

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Abstract

Municipal solid waste has to be treated under economic and environmental commitments. Anaerobic digestion reduces the emissions by degradation of organic waste and promotes the expansion of renewable energy. One type of dry anaerobic digestion is processing organic solid waste in large concrete tunnel digesters usually operated by wheel loader. The biological treatment is supported by percolation to achieve biogas from organic waste. But the water content of digestate is increased after anaerobic digestion and often inhibits the rotting process. Residual organic acids and little void volume often complicate aerobic degradation and sanitation of digestate. Mechanical dewatering gives a start to powerful aerobic treatment of digestate. Results from several treatment plants confirm that dewatering of digestate increases the yield of biogas and improves the conditions of rotting.

Keywords

anaerobic digestion, biodegradation, biogas yield, dewatering, dry anaerobic digestion, mechanical-biological treatment, percolation, rotting, tunnel digester

1 Mechanical-Biological Treatment of Municipal Solid Waste

The Mechanical-Biological Treatment (MBT) is a system of processing municipal solid waste that combines mechanical processing with biological treatment (s. Figure 1). The terms MBT relate to a group of systems for treatment of municipal solid waste which enables recycling and energetic utilisation of waste fractions and biological processing for degradation and stabilization.

The mechanical processing is a physical stage and is designed to recycle waste fractions (paper, metals, packaging, glass) and to sort out harmful solid waste. The main output of mechanical pre-treatment is an organic-rich fraction or biodegradable fraction which will be ideal for biological treatment.

The biological treatment aims aerobic rotting or drying or anaerobic digestion in combination with post-rotting. The anaerobic digestion generates biogas from organic fraction which is used as a source of renewable energy to generate electricity and heat. Rotting produces compost as a soil conditioner or stabilizes the organic fraction prior to landfilling (EU Landfill Directive). During aerobic stabilization the solid waste undergoes a rapid heating by aerobic degradation to reduce moisture. Aerobic drying with subsequent mechanical separation is used to produce refuse derived fuel (RDF) which is another source of waste-to-energy.

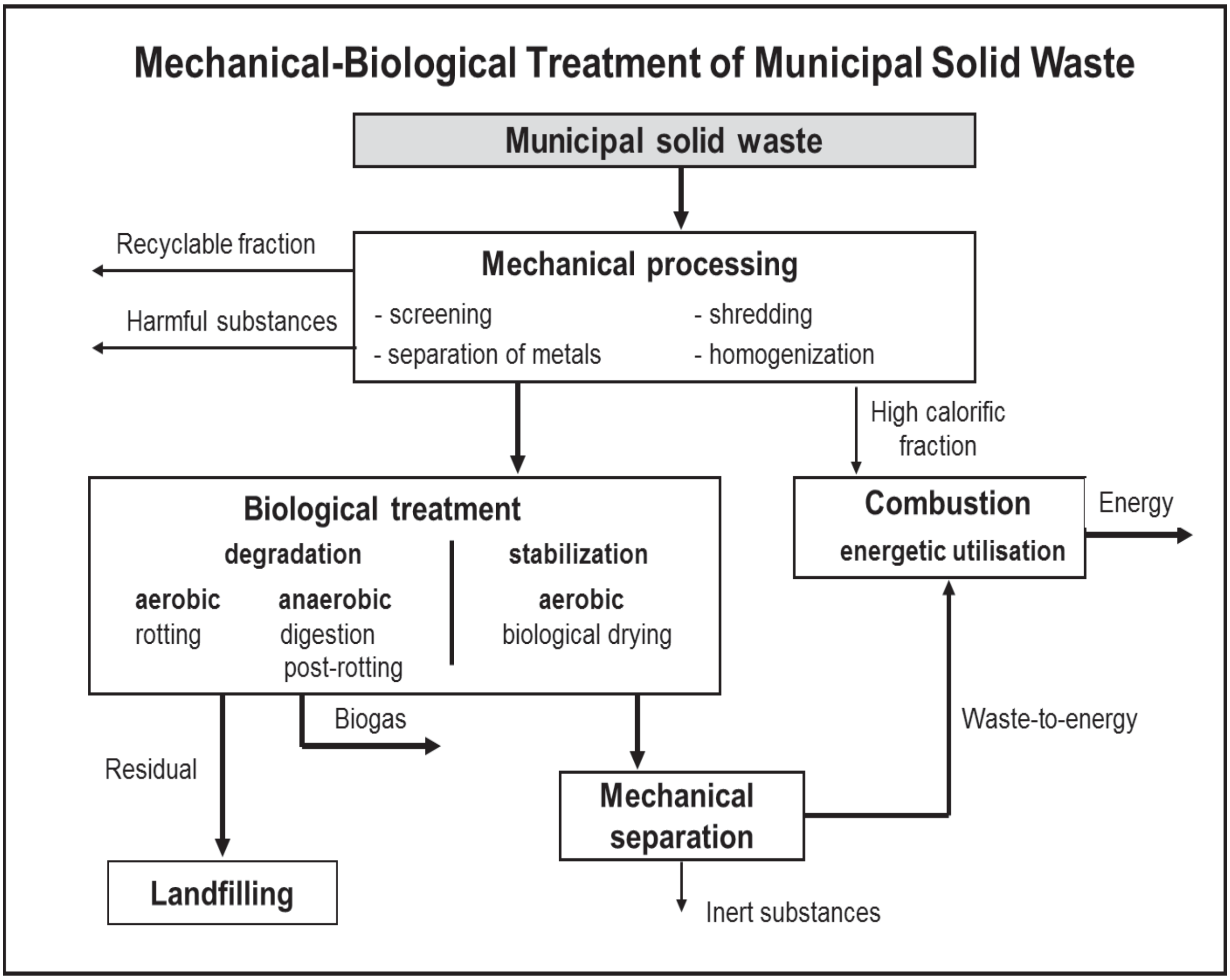


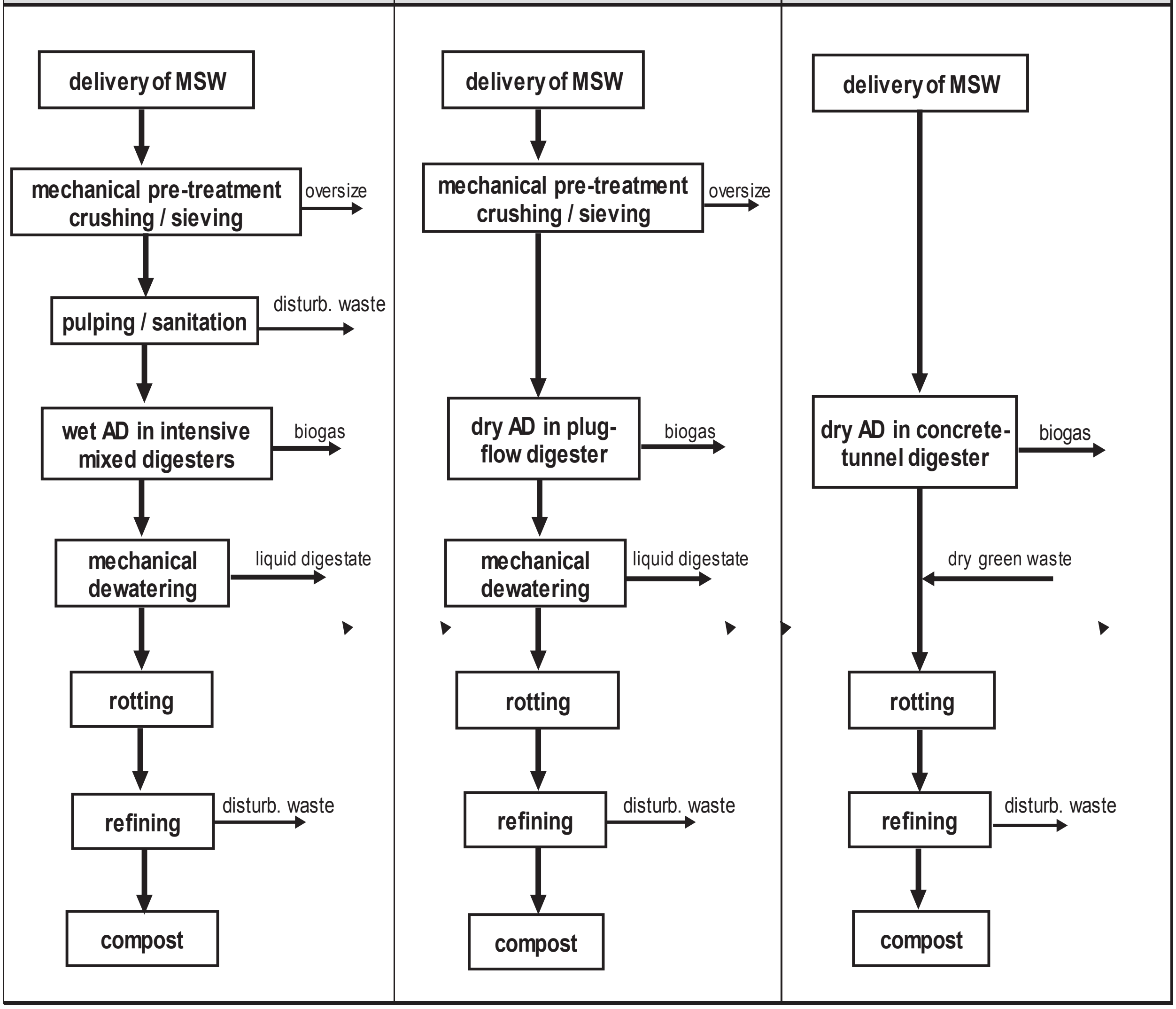
Figure 1 Mechanical-Biological Treatment of municipal solid waste

1.1 Anaerobic Digestion

Anaerobic digestion (AD) is possible in case of an organic-rich fraction of mixed municipal solid waste or source collected biowaste (e. g. green waste, kitchen waste). The systems of AD can be classified in wet and dry AD (see Table 1).

Table 1 Wet and dry anaerobic digestion (AD)

Wet AD DM < 12 - 15%	Dry AD in Plug-Flow Digester DM > 20 - 30%	Dry AD in Concrete-Tunnel Digester DM > 30 - 40%



Referring dry matter (DM) in digester the wet systems have 12 – 15 % DM the dry AD is operating up to 40 % DM. Contrary to dry AD in concrete-tunnel digesters the other AD systems contain a mechanical pre-treatment, a mixing digester and dewatering of digestate. The intensive mixing of solid waste (pulping, agitator in digester) demands a pre-treated solid waste with specific size in solid fraction and free of harmful substances. On the other hand dry AD in tunnel digester is charged and discharged by wheel loader and accepts a wide range of solid waste different in size fraction and harmful substances (not-biodegradable waste) because lack of a mixing system.

At this time dry AD of tunnel digester contains no dewatering of digestate but which is often rising trouble for rotting process (see Chapter 2.1). Nevertheless rotting and quality of compost require the separation of disturbing solid waste at the end of process.

1.2 Percolation

Biological process needs water in a specific range which has to be optimized in facility process. Water is the main component of solid waste and it plays a key role in biological processes such as hydrolysis and aerobic treatment (see Figure 2).

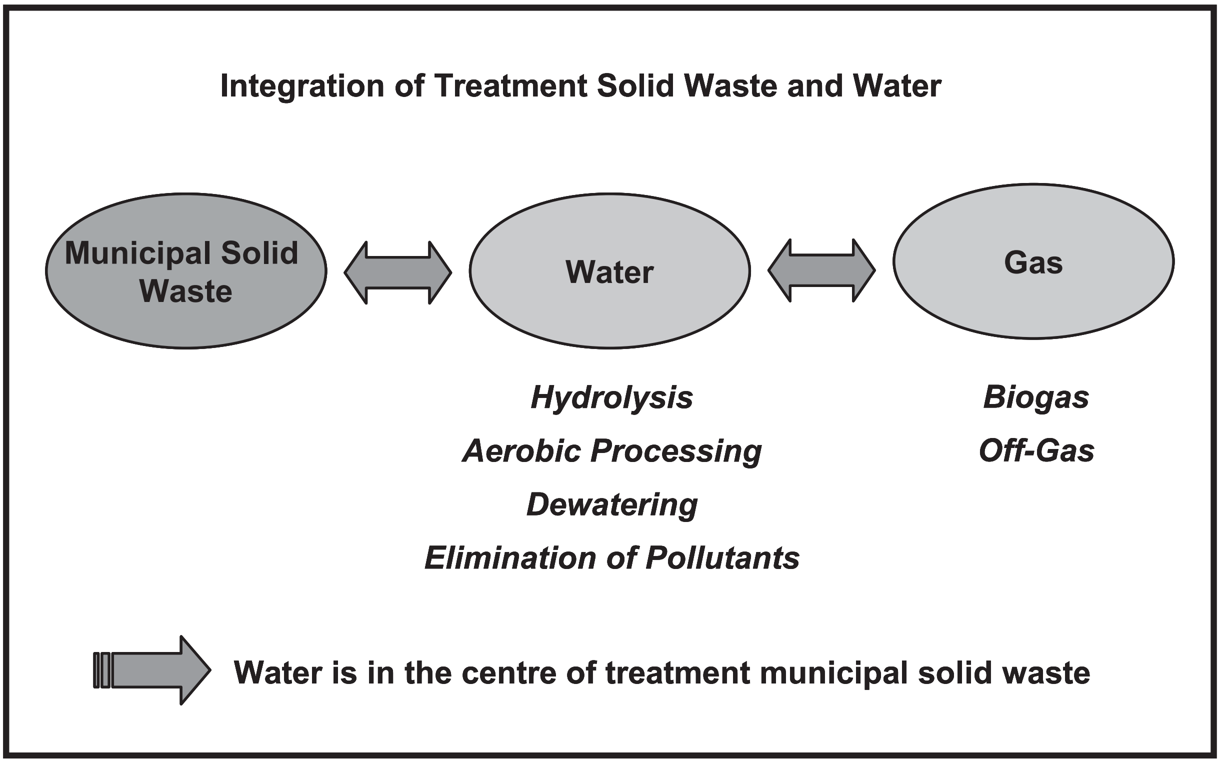


Figure 2 Water at the centre of mechanical biological treatment (Schalk 2011)

Process water could be added as fresh water or recirculated water to support biological degradation. In case of percolation process water is admixed into process for humidification or seeding (see Figure 3). Another purpose of percolation is leaching of soluble substances (extraction, evacuation) to gain a liquid fraction for wet AD or to reduce pollutants (ammonia, chlorine, persistent organic substances) in solid waste.

Percolation is used for aerobic rotting and anaerobic digestion. At dry AD process water is irrigated in concrete-tunnel digesters.

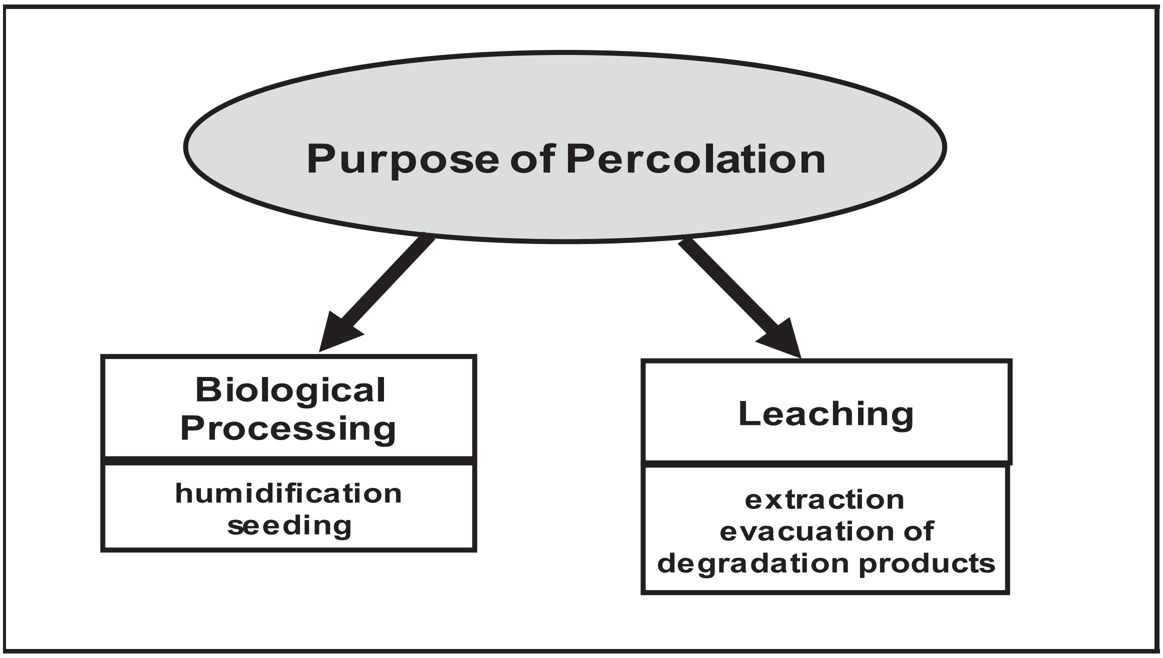


Figure 3 Purpose of percolation

1.3 Dewatering

The AD requires a higher humidity in process than rotting. Dewatering of digestate intends to reduce the mass of digestate and to improve conditions for rotting or drying (see Figure 4). Another purpose of dewatering is to recycle process water which is re-circulated to AD process. It could also be an option to eliminate liquid pollutants (e. g. ammonia) out of press water before recirculation back to AD process.

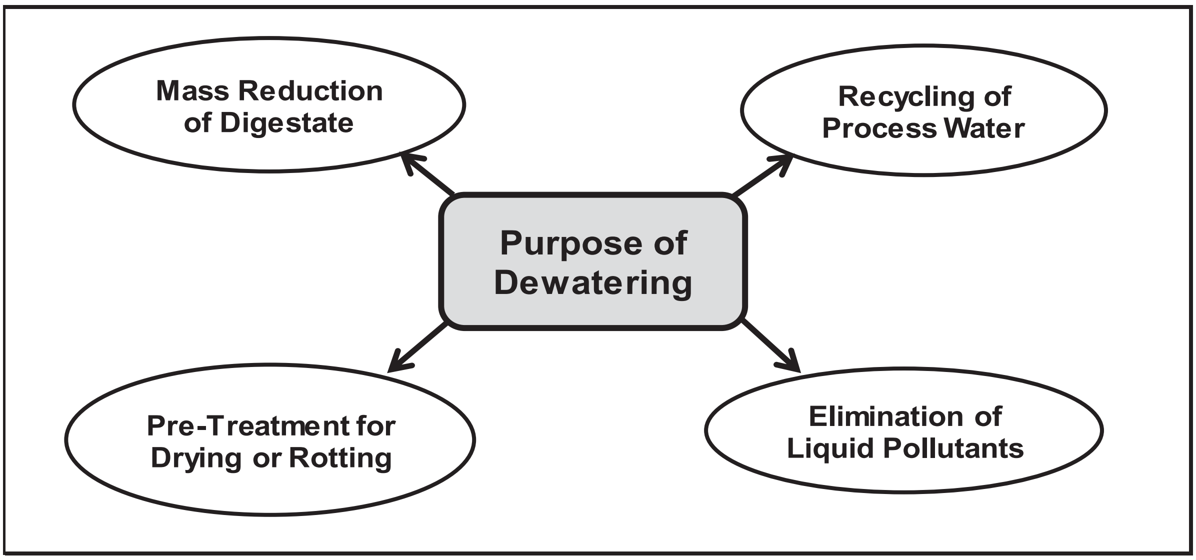


Figure 4 Purpose of dewatering

Several technologies for mechanical dewatering are available and approved in treatment of solid waste (see Figure 5). The range of application depends on dry matter of input.

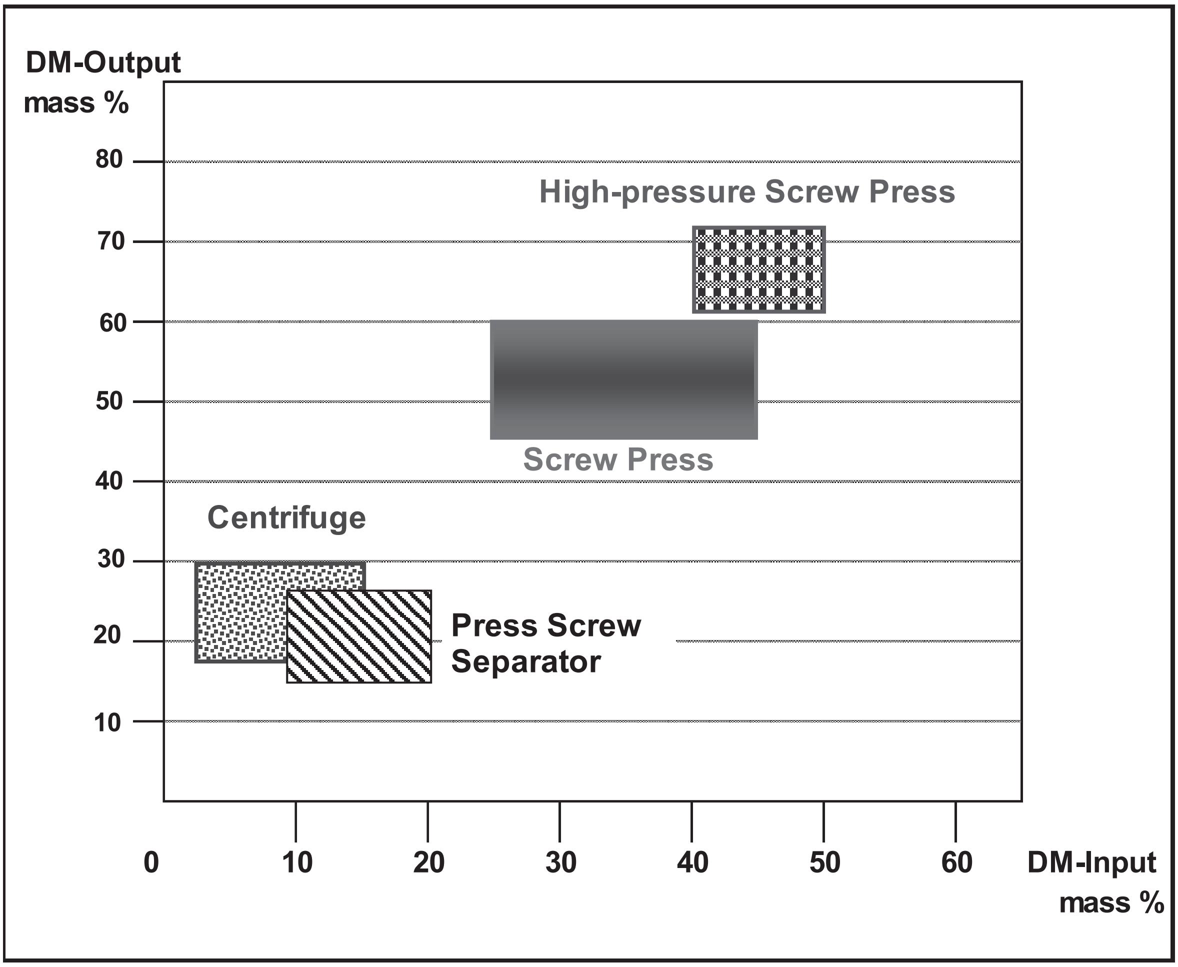


Figure 5 Systems of mechanical dewatering (Schalk, 2011)

Dewatering is mainly done by mechanical process at systems with wet AD or plug-flow digesters. At this time dry AD in tunnel digesters is not designed with mechanical dewatering. At the end of AD percolation is stopped and there is a kind of static drainage out of digester. In conclusion wet digestate is going to rotting process (see Chapter 2.1).

The screw press is generally used to dewater digestate from mixed municipal solid waste or source collected biowaste. The precondition of this mechanical process is that digestate contains enough bulking solid to build a press cake layer in the screw press. In conclusion dewatering process is operating without requiring additional chemicals for flocculation.

2 Repowering Dry AD in Tunnel Digester

2.1 Situation of Dry AD in Tunnel Digester

At this time dry AD in tunnel digesters are mainly applied for source collected biowaste. This system is an ordinary procedure formerly developed for small size facilities (throughput of 10,000 – 20,000 t/y biowaste). It is a cost-efficient procedure for treating biowaste under a cascade concept which means supplementary the installation of AD to an existing compost facility. The dry AD in tunnel digester can resign to any mechanical pre-treatment of biowaste which is definitely required at the wet AD and dry plug-flow systems (see Capture 1.1). Since 2010 InnoWaste has intensely worked at different operating facilities with dry AD tunnel digesters which are treating source collected biowaste. However dry AD in tunnel digester has disadvantages and difficulties as followed:

(1) No mechanical pre-treatment

In most facilities the delivered biowaste is loaded into tunnel digesters without any mechanical pre-treatment. The wheel loader-system doesn´t require crushing or rectification of biowaste as received. But wet biowaste (kitchen waste) is often wrapped in a plastic bag which will not be opened. Accordingly organic waste is enclosed and not available for biological degradation in this dry AD. Referring quality of compost disturbing fraction (e. g. packaging, residual waste) is not removed before wet biological process and remains in digestate.

(2) No intermixing in tunnel digester

Charging and discharging of tunnel digester is done by wheel loader. Thus it is not possible to install any mixing system. The AD is operated by percolation in a static system which is not best practice for biological processes.

(3) Less biogas yield

The dry AD in tunnel digester generates less biogas yield compared to wet AD or plug-flow digesters although retention time is equal or often longer. The biogas yield of dry AD in tunnel digester at technical facilities is round about 25 – 35 % less than wet AD. The dry AD in tunnel digester is operating at dry matter (DM) 30 – 40 %. Li et al. (2014) has investigated that in dry anaerobic reactors (lab scale) with 30 % DM there is little methane production from biowaste. Only at 20 % DM the biogas production is equal to those of wet AD.

(4) Difficult management of process water and soaking of digestate

Percolation of process water into tunnel digester has to be modified to biowaste as received. In case of too much percolation and rising tare weight the filling of solid waste is to be compacted (self-compression) hence the balance of irrigation and drainage is breaking down.

(5) Often starting-up problems of aerobic rotting

The digestate of dry AD tunnel digester is not dewatered before rotting by technical process but by static drainage. Composting requires enough void volume for aerobic degradation. Wet digestate is often a trouble for starting-up rotting process. Residual organic acids and little void volume complicate aerobic rotting and sanitation of digestate. Most of facilities add dry green waste to improve composting (aeration and deaeration)

2.2 Concept for Repowering Dry AD in Tunnel Digester

Percolation and dewatering cohere at dry AD of biowaste in tunnel digesters (see Figure 6). Mechanical dewatering of digestate solves several difficulties of dry AD. InnoWaste has more than 15 years of experience with the dewatering of municipal solid waste on a technical scale. The percolation process treating mixed municipal solid waste used the screw press for dewatering solid waste for the first time, and it has been modified and continuously improved over the years. The advantages of the screw press are:

- Solely mechanical dewatering without additional flocculation chemicals.
- Comparatively low consumption of electrical power
- Mechanical disintegration improves biodegradation (AD and rotting)

The screw press operates in a range of input at 25 – 45% DM and has an output of 45% to 60% DM. The dewatering yield can be modified by varying the rotational speed and the pressure of cone. The press water can be treated in wet AD and generates additional biogas. The dewatered digestate is well prepared for aerobic rotting.

Since 2010 InnoWaste has tested the mechanical dewatering by screw press in technical scale and at different dry AD facilities with tunnel digesters. All pilot projects achieved success and confirmed the concept for repowering. Repowering aims to an efficient biowaste treatment in AD and subsequent rotting.

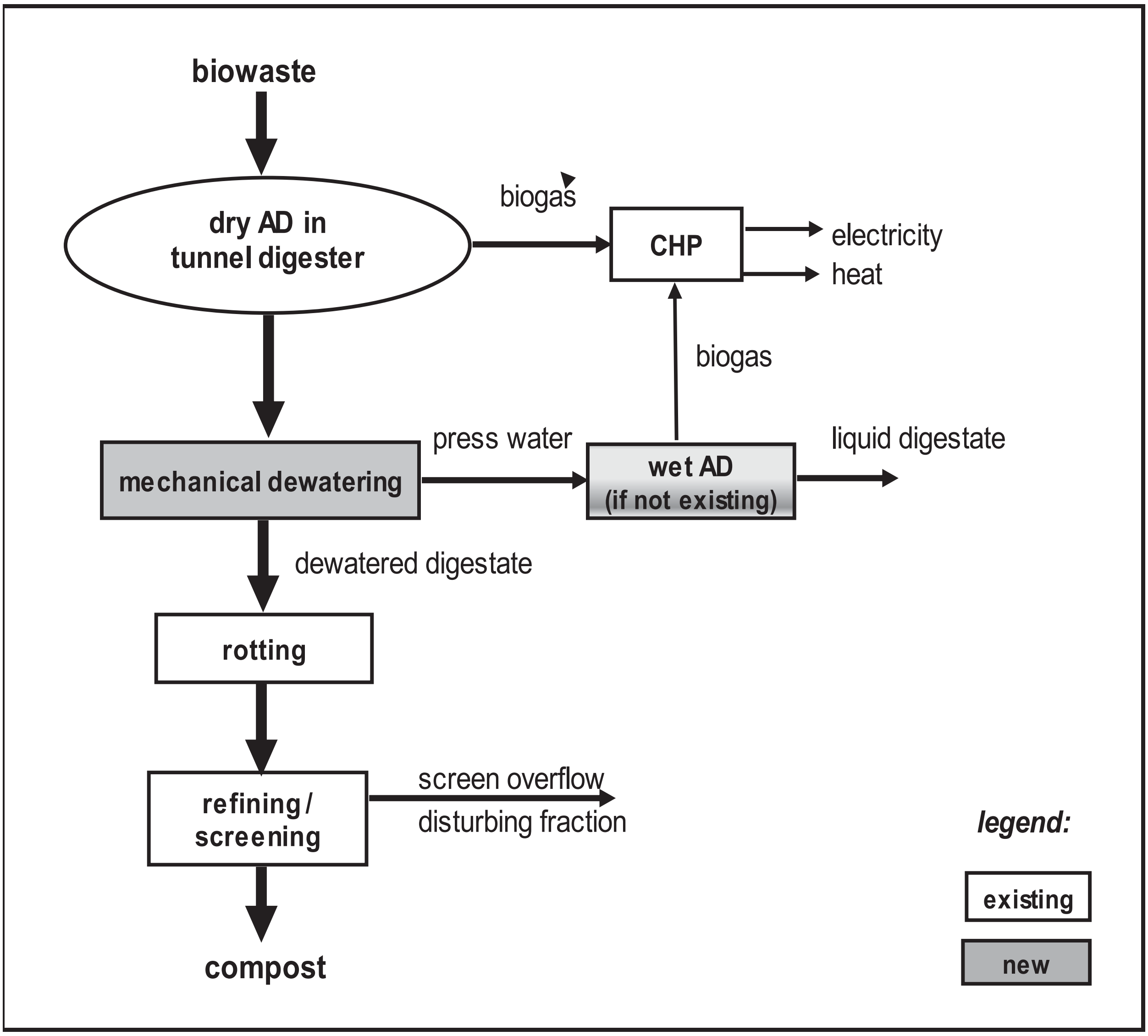


Figure 6 Concept for repowering dry AD in tunnel digester

2.3 Higher Biogas Yield

The mechanical dewatering of digestate generates process water with a high concentration of soluble organics (see Table 2). Surprising is the fact, that even press water contains much COD and volatile fatty acid (VFA) although solid waste was treated more than 20 days under anaerobic digestion in tunnel digester. The anaerobic digestion is not finished and will proceed uncontrolled in digestate. The incomplete AD causes greenhouse gas emissions (e. g. methane) during rotting if there is no closed rotting hall with a thermal off-gas treatment (Hrad, M. et. al. 2014). Without mechanical dewatering this high loaded water remains in digestate and in addition burdens the aerobic rotting by its very high oxygen demand.

Table 2 Composition of process water from mechanical dewatering of digestate

Parameter	Unit	Mean Value	Peak Value
COD_{total}	mg/l	70,000	120,000
$COD_{filt.}$	mg/l	25,000	51,000
NH_4-N	mg/l	1,100	1,800
volatile fatty acid (VFA)	mg/l	6,800	9,800

The press water from dewatering of digestate was investigated to biogas potential at Karlsruhe Institute for Technology (KIT). All facilities achieved an additional biogas yield of 50 – 60 Nm³/t press water (methane 64 % vol.). The press water is well prepared to anaerobic digestion approx. 80 % of total biogas yield is produced within 9 days. Converted into input of biowaste dewatering of digestate and wet AD generate an additional biogas yield of 35 – 50 % on top (see Figure 7).

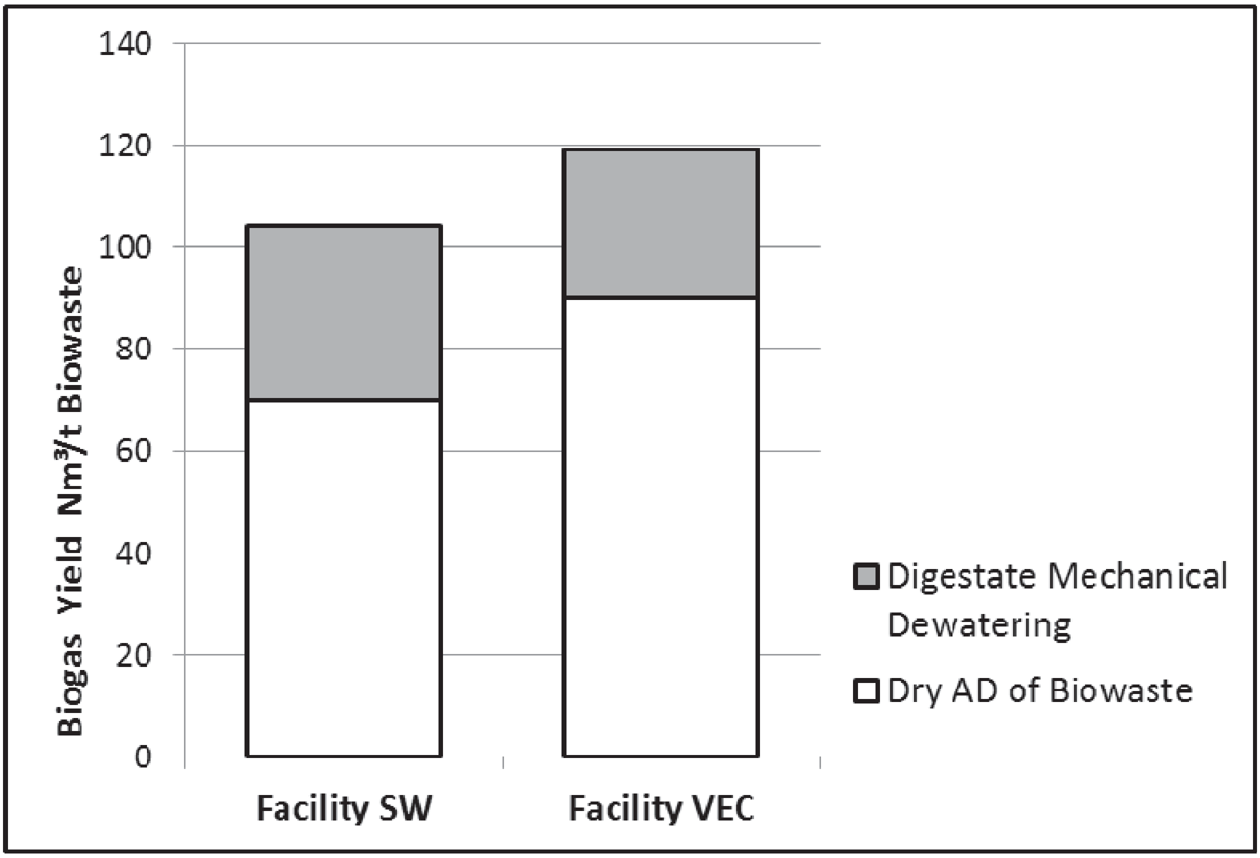


Figure 7 Biogas yield of dry AD and digestate of mechanical dewatering

2.4 Optimized Rotting of Digestate

Mechanical-biological treatment of biowaste has to produce compost if possible in a quality sufficient for soil conditioning (agriculture, landscaping, gardening). As described many facilities of dry AD with tunnel digester have problems with aerobic rotting of wet digestate. In Figure 8 rotting process of dewatered digestate is compared with untreated digestate.

Within 2 days after dewatering the temperature of the dewatered digestate increases rapidly up to 55°C. This self-heating is welcome and required to sanitize digestate for compost quality. The composting temperature is maintained for more than 4 weeks up to 75°C and after 5 turnovers all digestate is sanitized. The composting process is virtually odour-free. In contrast untreated digestate if at all requires more than 7 weeks to reach the temperature range required for sanitation. The windrow of untreated digestate produces unpleasant odours (organic acids, ammonia) for more than 4 weeks.

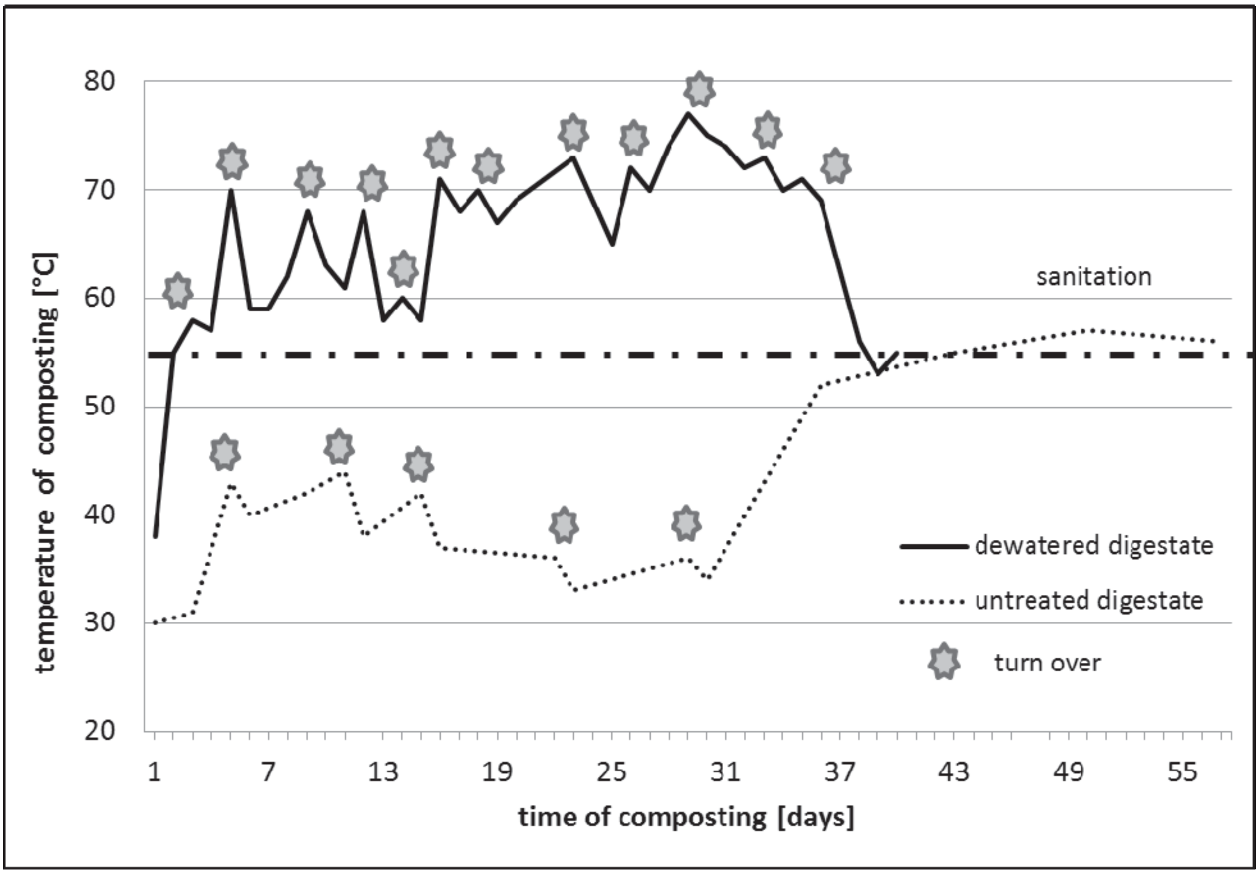


Figure 8 Composting temperatures of dewatered and untreated digestate

The intensive rotting of dewatered digestate gains considerable advantages towards refining of compost. Long-lasting rotting process and high temperature generate biological drying of digestate which is necessary for subsequent screening and removal of not-biodegradable fraction (plastics, glass etc.).

2.5 Costs for Mechanical Dewatering of Digestate

Costs for mechanical dewatering of digestate (sample):

- Throughput 20,000 t/y
- Working hours 2,000 h/y
- Specific throughput 10 t/h
- DM input approx. 25 – 35% by mass
- DM output approx. 38 – 45% by mass

Table 3 Costs: mechanical dewatering of digestate (German price level)

Item	Budget Price EUR (net)
Investment costs (technical equipement)	
dosing unit, conveyors	120,000
dewatering screw press	220,000
total investment costs	***340,000***
Operating costs	
electric current	1.20 EUR/t
consumable parts	0.80 EUR/t
staff	from existing plant
Operating costs excluding capital costs	***2.00 EUR/t***
Operating costs including capital costs	***3.95 EUR/t***

The calculation of profitability has also to incorporate the benefits of mechanical dewatering digestate as described before. Costs are justified by the benefits of dewatering:

- Higher yield of biogas
- Improved rotting of digestate (duration, temperature, sanitation, emissions)
- Secured and higher quality of compost (sanitation, refining)

- Better percolation in dry AD in tunnel digester (technical dewatering instead of uncontrolled static drainage)

With reference to investment costs mechanical dewatering of digestate makes up less than 10% of the total investment cost of an aerobic digestion facility.

3 Conclusions

Biological processing remains at the centre of the mechanical-biological treatment of municipal solid waste. Water keeps the main component of solid waste and has to be managed in anaerobic digestion and aerobic rotting. Mechanical dewatering of digestate generates a higher yield of biogas and better conditions of rotting even in dry anaerobic digestion as tunnel digester.

Referring to expenses of source-collection of biowaste, production of renewable energy by anaerobic digestion and reduction of greenhouse emission the facilities for waste treatment should be developed to a higher efficiency. The dewatering of digestate from tunnel digestion is an essential and cost-efficient process for repowering the concept of dry anaerobic digestion in this system.

4 Literature

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The dry anaerobic DRANCO technology applied to the organic fraction of MSW

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Abstract

The DRANCO technology was developed in the eighties as one of the very first anaerobic digestion technologies for municipal solid waste (MSW). A first demonstration plant was erected in 1984 in Ghent, Belgium. At present about thirty DRANCO installations are constructed in about fifteen different countries. This paper describes these DRANCO installations treating the organic fraction of MSW, integrated in a mechanical-biological treatment plant (MBT). It does not describe DRANCO installations dealing with source separated biowaste.

MSW is a heterogeneous substrate, and, depending on how far the closing of the circle of material recycling and energy recovery is envisioned, resulting in different concepts of treating the waste. Several concepts of integrating anaerobic digestion in a MBT plant are discussed, such as partial and full stream digestion. By applying partial stream digestion mechanical dewatering of the digestate and excess waste water are avoided, while by applying full stream digestion maximum biogas recovery and minimum post-composting surfaces are obtained. Concepts of upstream and downstream elimination of the impurities, before or after the digestion, are proposed and effects of sending paper waste items to the digester are discussed. Results of different DRANCO installations treating the organic fraction of MSW are shown, as waste composition entering the digester, biogas production, digestate composition,….The SORDISEP technology is also presented, this technology includes dry sorting, dry digestion and a wet separation technology treating the digestate coming from the digestion in order to remove inerts and impurities and to produce a compost conform to the standards, as applied in the new DRANCO plant at Bourg-en-Bresse, France.

Keywords

Anaerobic digestion, MSW, biogas, DRANCO technology, partial stream digestion, full stream digestion, SORDISEP technology

1 The DRANCO technology

The DRANCO technology was developed in the eighties as one of the very first anaerobic digestion technologies for municipal solid waste (MSW). A first demonstration plant was erected in 1984 in Ghent, Belgium. Source separate collection of biowaste not being applied yet at that time, the digester concept and the electro-mechanical aggregates were chosen to be able to deal with MSW, a heterogeneous and abrasive substrate.

Figure 1 DRANCO pilot plant for the digestion of MSW, constructed in 1984

A high total solids content of the digestate in the digester was envisioned in order to minimize addition of water, reduce digester volumes and prevent the formation of a flotation or sedimentation layer. Depending on the composition of the organic fraction of MSW sent to the digester, the total solids content of the digestate varies between 30 to 45%, resulting in compact, high-rate digesters.

Due to this high total solids content in the digester no internal mixing device is present in the digester. The inoculation of fresh waste with methanogenic bacteria, being recycled digestate, is performed by an external double mixing screw. A positive displacement pump sends the mixture to the top of the digester by means of three to four internal feeding tubes distributing the fresh incoming waste over the surface of the digester.

In order to control the temperature in the digester either steam is introduced in the device mixing the fresh waste with digestate or hot water is used around the extraction screw between the digester and the mixing device. The huge mass inside the insulated digester, the high solids concentration inside the digester, the exothermic biochemical reaction and the small contact surface between digestate and biogas result in minimum heating requirements.

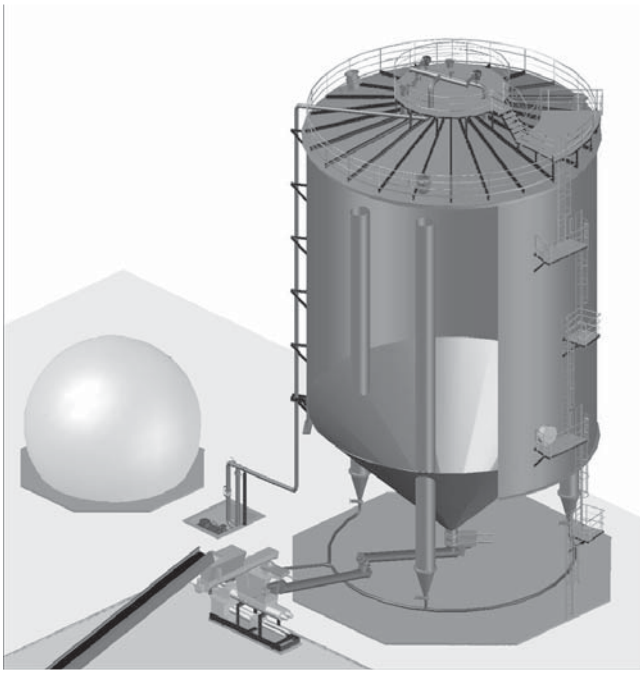

Figure 2 DRANCO vertical digester with external inoculation and internal feeding tubes

If the composition of the substrate allows it, a thermophilic operation of the digester is envisioned in order to rise the biological loading leading to smaller digester volumes, and increasing the biogas production.

The digester volume in full-scale DRANCO installations is between 750 and 4000 m³, treating 10,000 to 60,000 tons of waste per year.

2 DRANCO references on MSW

The DRANCO technology is applied on a wide range of substrates as biowaste, MSW (or residual municipal waste) and energy crops. At present about thirty DRANCO installations are constructed in about fifteen different countries. The technology is very well suited for the treatment of all these substrates but in this paper only references dealing with MSW are discussed.

Due to its vertical design with a conical bottom together with an external inoculation and a high solids content in the digester, the process can handle organic fractions contaminated with impurities well. MSW is a heterogeneous substrate, and, depending on how far the closing of the circle of material recycling and energy recovery is envisioned, resulting in different concepts treating the waste.

The organic fraction in the composition of the MSW varies from region to region, depending on, whether or not source separated collection of biowaste and paper are introduced, home composting is widely spread, house animals are fed with organic refuse,… The organic fraction sent to the digester further depends on the pretreatment of the MSW.

The table below gives mean values of several DRANCO installations dealing with MSW. The total solids content (TS) of the organic fraction of the MSW sent to the digester after pretreatment varies between 47 and 58% and the volatile solids content (VS) on the TS varies between 46 and 65%.

The TS content of the digestate varies between 33 and 45% and the biogas production between 91 and 165 Nm³/ton waste fed to the digester.

The pretreated waste has an average TS content of 54% and an average VS on TS content of 53%. The digestate has an average TS content of 40% and an average VS on TS content of 36%. In average 53% of the VS are transferred into biogas. The mean biogas production is 120 Nm³/ton with a mean methane content of about 55%.

Table 1 Data DRANCO installations dealing with MSW

DRANCO installation	Organic fraction of MSW		Digestate		Biogas-production Nm³/ton	VS transferred into biogas (%)
	% TS	%VS/TS	% TS	%VS/TS		
Bassum, Germany	55	55	40	32	124	54
Kaiserlautern, Germany	47	65	39	37	165	67
Hille, Germany	58	51	42	38	106	46
Münster, Germany	57	51	40	37	112	49
Vitoria, Spain	51	52	38	39	129	62
Alicante, Spain	55	53	33	38	122	53
Mirandela, Portugal	51	46	40	31	91	50
Wijster, The Netherlands	56	52	45	36	106	46

In most cases it is necessary to slightly reduce the TS content of the incoming waste, wherefore an average of about 140 liter/ton of process water is added, meaning that the average TS content of the waste entering the digester is 46%. The added process water can be condense coming from the post-composting or this water can also be added in the form of sludge or industrial organic fluids.

3 Concepts integrating anaerobic digestion

3.1 Partial stream digestion

Due to the high total solids content of the digestate, the DRANCO process is well suited for partial stream digestion whereby the digestate is mixed with a bye-pass of fresh waste coming from the pre-treatment, and sent to the following compost installation. In the pre-treatment metals, recyclable plastics and RDF can be separated, and inert materials can be partially removed if needed. An organic fraction less than 40 – 60 mm is produced and sent to the anaerobic digestion.

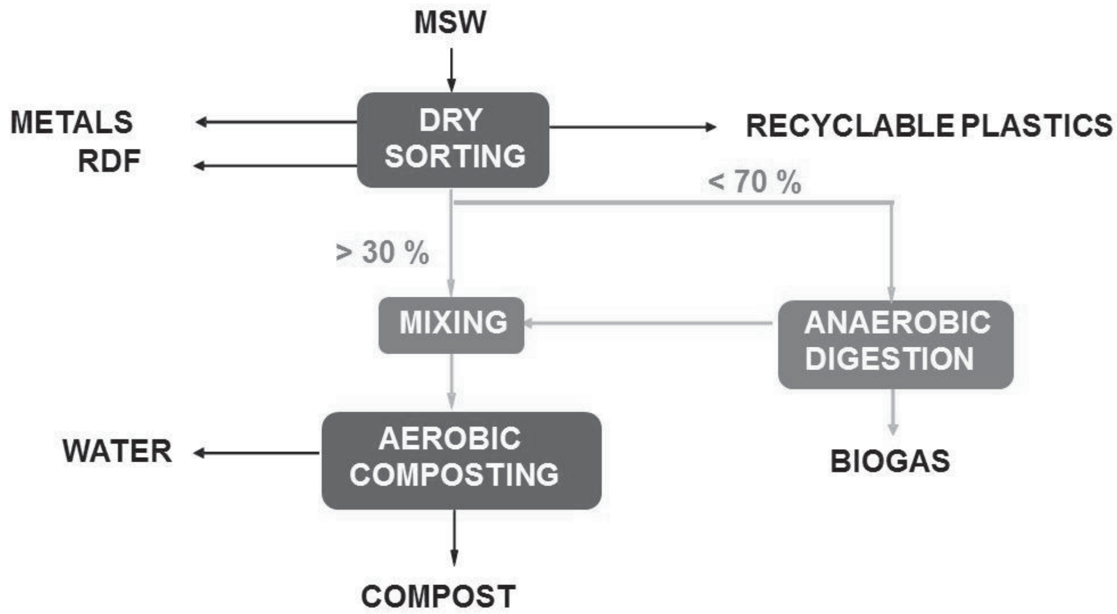

Figure 3 Partial stream digestion

In partial stream digestion up to 70% of the organic fraction can be sent to the DRANCO digester, as indicated in figure 3. The digestate is mixed with the by-pass of the organic fraction and the energy produced during the aerobic degradation is used to dry the digestate.

The total solids content of the mixture is about 45% which allows for efficient aeration and aerobic degradation. The composting time depends on the ratio between digestate and by-passed fresh waste and the desired degree of maturity of the compost, and varies between three and seven weeks.

Figure 4 DRANCO installation in Hille ,Germany with partial stream digestion

By partial stream digestion mechanical dewatering of the digestate and excess waste water production are avoided while on the other hand less biogas is produced and post-composting times are longer leading to larger composting areas. Each project needs to be individually looked at in order to set-off the advantage of avoiding the dewatering step against the loss of green energy and the need of larger composting surfaces.

Partial stream digestion is often of interest if the anaerobic digestion is integrated with an already existing composting plant, because composting surfaces are available and connection to the sewage system is often lacking.

In figure 5 the process flow sheet of the partial stream digestion installation of Hille is shown. The installation is designed to treat 80.000 tons per year of MSW of which 37.000 tons per year represents the organic fraction less than 60 mm. About 24.000 tons per year of this organic fraction are digested while 13.000 tons are by-passed and mixed with the digestate before being sent to the tunnel composting unit.

About 5000 tons per year of dewatered sludge coming from waste water treatment plants are also fed to the digester.

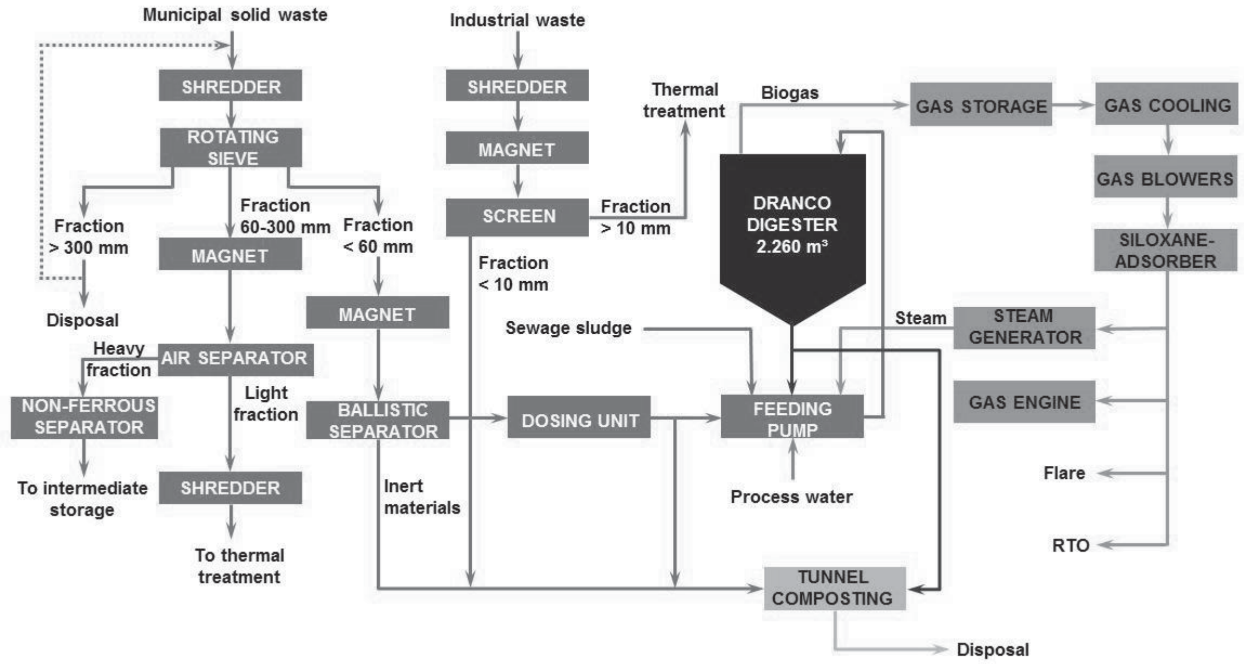

Figure 5 DRANCO installation in Hille,Germany with partial stream digestion

3.2 Full stream digestion and the SORDISEP technology

For maximum biogas yield full stream digestion is applied followed by a dewatering step of the digestate in order to produce a dewatered cake which can be aerated in the following composting step.

As an example, the flow sheet of the DRANCO installation at Bourg-en-Bresse, France is hereby given. The installation starts-up in springtime 2015.

Figure 6 SORDISEP installation in Bourg en Bresse, France

The SORDISEP process is applied in this installation and it includes a dry sorting step followed by the DRANCO process and a wet separation technology treating the digestate in order to obtain clean inerts, RDF and high quality compost.

The organic fraction together with the paper and cardboard fractions are reduced in size by means of a comminuting drum, a slow turning closed drum filled with waste. The frictions in the drum cause a selective size reduction of the putrescible waste. Organics and paper products are reduced in size in contrast to plastics and textiles. After the drum the biodegradable fraction is separated from the non-biodegradable fraction by means of a 50 mm screen. Ferrous metals and a part of the inerts are removed from the organic fraction by means of magnets and ballistic separators.

This pre-treatment results in a high quantity of organics being sent to the digester. The capacity of the Bourg-en-Bresse plant is 66.000 tons per year of MSW and 40.000 tons per year are sent to the digester. Due to the presence of the paper and cardboard fractions in the fines, the organic fraction has an optimal C/N ratio and has a high biogas potential.

As shown in figure 7 paper products can yield a high biogas production, especially paper products with a high percentage of cellulose as office paper and cardboard. A mixture of different paper products yields 300 - 350 Nm³/ton, which is higher than for example kitchen waste which yields 120-150 Nm³/ton.

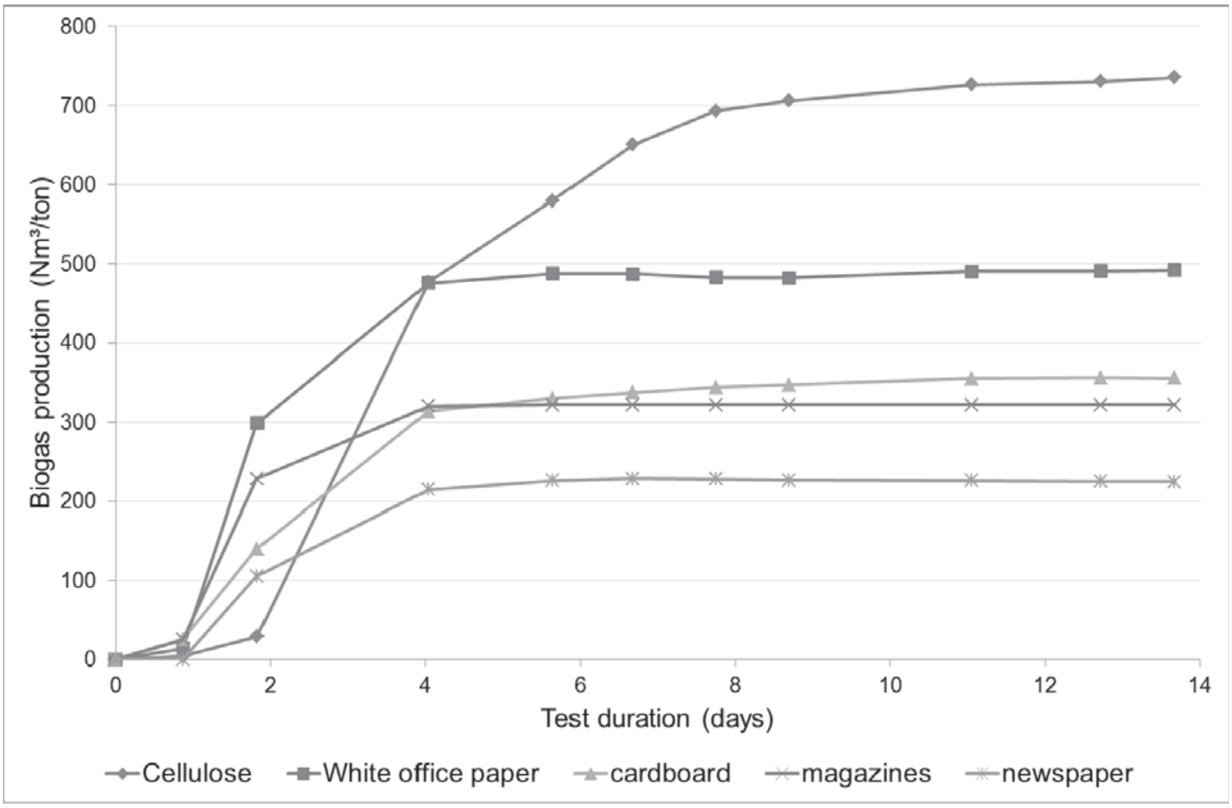

Figure 7 Biogas production of different paper products

A wet separation technology treats the digestate in order to remove inerts and impurities and to produce a compost conform to the standards.

After the anaerobic digestion it is much easier than before the digestion, to separate the digestate. The organic fraction is converted in the anaerobic digester to biogas, sticky organic components are removed, which allows an easy separation of the free sand, inerts as glass and stones, plastics, textiles and compost.

The digestate is mixed with process water and screened on a fine vibrating screen. The undersize contains the organics and sand. The sand is removed by means of a sand screw in order to protect the following centrifuge which dewaters the organic fraction. The centrifuge cake is mixed with shredded green waste and composted during a three week composting period with forced aeration.

The oversize of the screen passes through a wet separation of lights and heavies. The inerts are washed and fulfill the standard for discharge in a landfill for inert material, and the light fraction is dewatered.

The centrifuge cake is mixed with 7,500 tons per year of shredded green waste and composted in a hall composting system with forced aeration during three weeks followed by a maturation step.

After pretreatment and anaerobic digestion, about 21,000 tons per year of compost will be sold, and 10,000 MWh of electricity will be produced annually.

Due to source separation of batteries, chemicals, electronics, and so on, and the contaminant reduction of heavy metals in many products such as inks and cleaning products, compost from MSW can be produced meeting the local compost standards.

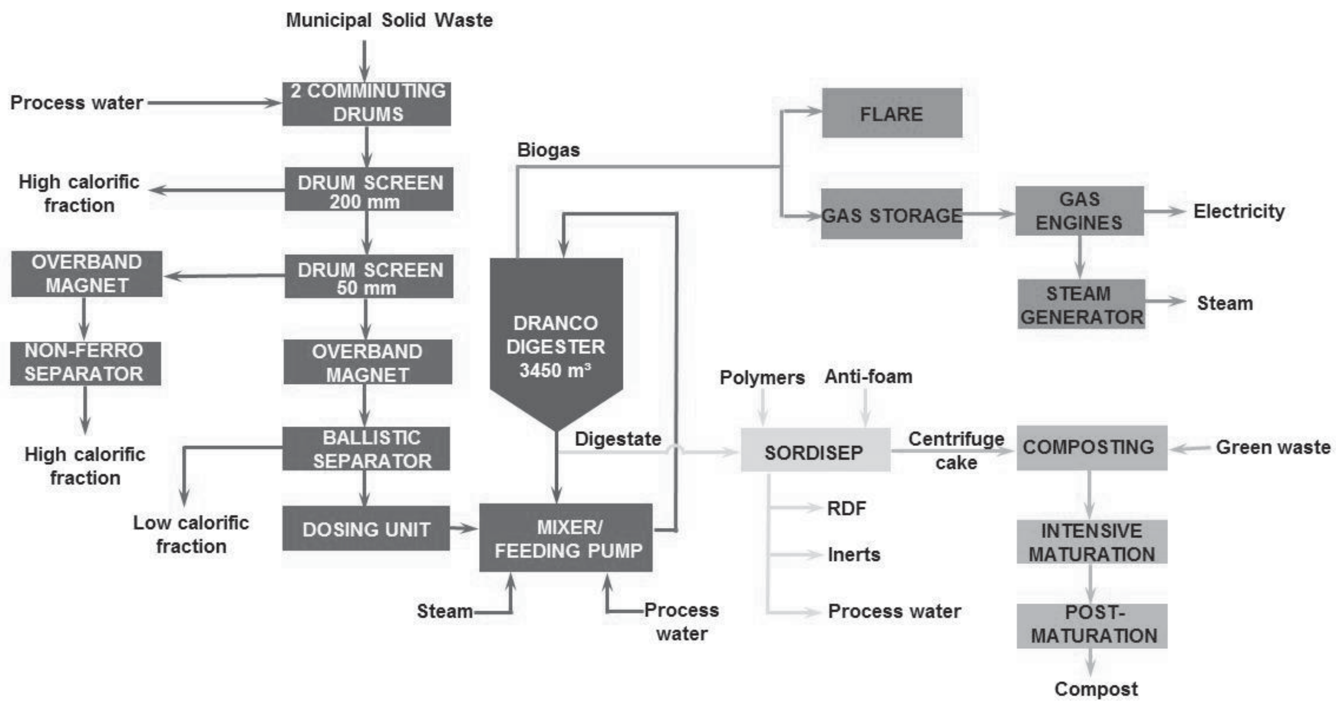

Figure 8 SORDISEP installation in Bourg-en-Bresse, France

4 Conclusions

Anaerobic digestion of MSW is well established and is integrated in waste management schemes aiming at recycling, green energy production and environmental benefits.

The DRANCO process, with its absence of internal mixing devices in the digester, and its high total solids content in the digester, is well suited for treating the organic fraction of MSW.

The mean value of data of several DRANCO installations shows that the organic fraction of the pretreated MSW has an average TS content of 54% and an average VS on TS content of 53%. The digestate has an average TS content of 40% and the mean biogas production is 120 Nm³/ton.

Partial stream digestion can be of interest in order to avoid dewatering equipment and production of excess water. Full stream digestion can be of interest in order to maximize green energy production and minimize post-composting surfaces.

The SORDISEP process is an integrated process consisting of a dry sorting step, a DRANCO digestion and a wet separation technology treating the digestate, in order to maximize recycling and green energy production and minimize landfilling.

Liquid Digestate-free Anaerobic Digestion with the HZI-KOMPOGAS® plug flow digester

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Abstract

The KOMPOGAS® plug flow fermentation is a highly efficient process for generate energy from waste. The digestate from the fermentation has in this case due to the system to a water content between 70 and 75 percent. Due to its high content of nutrient salts press water can generally be used without further purification as liquid manure in agriculture. In many regions or even countries, there is due to intensive livestock farming, already a large oversupply of liquid manures or spreading is not allowed by law. Also the logistic could be difficult and expensive. The utter avoidance of press water by not dewatering of the digestate is therefore a proven alternative. The digestate from the fermentation can be brought to the required conditions for composting, by mixing with dry and structured material. As a structural material Green waste, coarse fraction from the compost pretreatment or untreated waste, as a partial stream that will not be fermentated, can be used.

The practical experience show that for roughly a ratio of 50% digestate from the fermentation and 50% of structural material is necessary. The press water free process with a plug flow digester is tested in practice and represents a proven alternative to the conventional dewatering of the digestate. Different variations can be adjusted to the local conditions. This can be shown by four different plants in three different countries.

Keywords

KOMPOGAS, plug flow, liquid digestate, Hitachi Zosen Inova, dewatering, anaerobic digestion, biowaste, msw

1 Introduction

Hitachi Zosen Inova AG (HZI) - KOMPOGAS® is a pioneer in continuous high-solids fermentation, specialized in the digestion of municipal, commercial and industrial organic wastes.

In 1991 Kompogas® has developed a modular Anaerobic Digestion (AD)-system concept that meets the high requirements treatment a vast range of organic feedstock in terms of reliability, efficiency and economy. Today, more than 75 Kompogas fermentation plants are operating worldwide.

2 Kompogas® - Process Description

The Kompogas® digester is continuously fed 24/7 with pretreated organic feedstock. This assures that the biological process always avails of sufficient degradable material without the risk of partial acidification and high loading rates and biogas yields can be achieved.

Due to the high dry matter content of >30% material does not mix in the digester. The material slowly moves like a ‘plug’ from one end of the horizontal cylinder to the other, which assures a guaranteed minimum residence time of all feed material. The low-speed agitator has no mixing or conveying effect. Its main purpose is to enable the gas bubbles to separate from the substrate and to avoid sedimentation of heavier particles. The biological process steps of hydrolysis, acidification and methanation occur sequentially along the reactor. These features form the principles of a ‘plug flow digester’.

At the digester outlet the extracted digestate still contains highly active microorganisms. Around one third of the digestate is recirculated to the inlet of the digester where it is internally mixed with the feed. This is called ‘internal inoculation’ and allows the biological processes to start immediately. The digester is operated at thermophilic temperature which results in higher biogas yields and a shorter residence times compared to mesophilic digesters. A typical average residence time in a Kompogas® digester is 18-21 days. Various safety devices protect the system against overpressure, overfilling and other unfavorable process conditions. Kompogas® fermenters are extremely reliable, and can be automatically controlled and operated even with changing feedstock conditions.

3 The challenges with liquid digestate

The plug flow digestion is a highly efficient process to generate biogas from organic wastes. The digestate typically has a water content between 70 and 75%. For ideal aeration in the subsequent composting stage the water content should however be below 60%. In the standard AD process digestate is dewatered with a screw press. In this case, 1000kg digestate results in approximately 400kg press water. Due to its high nutrient content press water is generally used as natural liquid fertilizer in agriculture without any further treatment. However, in many regions in Europe, intensive livestock farming has already lead to an oversupply of nutrients. As a result, application of the liquid digestate in agriculture is becoming increasingly difficult or is even forbidden. Where allowed, restrictions regarding application seasons and associated storage requirements for press water increase the cost of press water handling. Due to the high content of water, organics and sand in the press water, alternative treatments such as drying or filtration are very costly.

Now there is a proven alternative to avoid dewatering and handling of press water at all.

4 Press water free Anaerobic Digestion Concept

The required conditions for composting can also be obtained by mixing the digestate with dry structured material. Ideal structure material is e.g. green waste or the coarse fraction of the solid digestate after maturing and after screening off the fine compost. The aim of mixing of digestate with structure material is to produce a loose mixture with optimum aeration properties. The dry matter content of the mixture should be minimum 40%. Practical experience shows that 50% digestate and 50% of structure material is a good ratio. A lower fraction of structure material increases the risk that the mixture can not or only poorly be aerated in the composting section.

Picture 1: Liquid digestate storage tank

Picture 2: Mixer for structure material

4.1 Digestate mix with structure material

The mixing of digestate with the structural material can be done in different ways:

1. Manually, with a Wheel Loader

   This type of mixing requires the lowest amount of installed equipment. The digestate is pumped directly into a box and mixed with the structure material by wheel loader bucket. However, it requires an experienced wheel loader driver to correctly assess the material characteristics and to achieve a very homogeneous mixture.

2. Automatic Batch Mixer

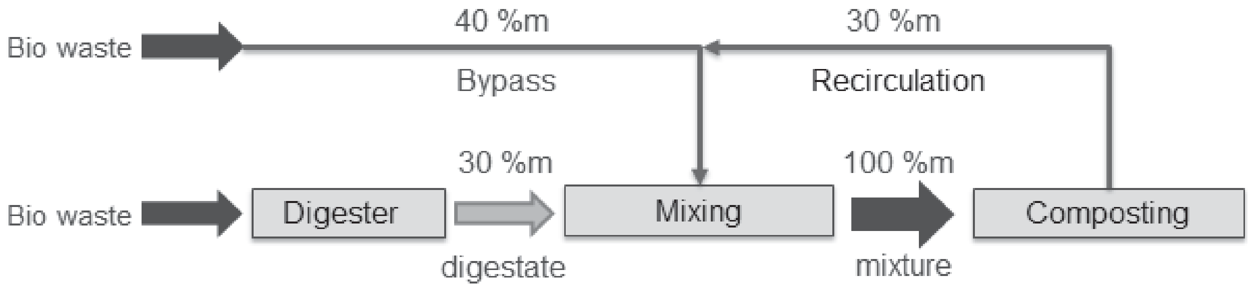
   The digestate is pumped into a batch mixer and structure material is added by wheel loader. Over a defined period of time the digestate and the structure material is intensively mixed. After the mixing cycle, the material is discharged from the mixer. If the mixer is equipped with a weighing system, the mixture can be produced according to a specific recipe. However, this system is limited in throughput capacity due to equipment sizes and required mixing times.

3. Automatic Continuous Mixer

When mixing in a continuous process, the digestate and the structure material are fed to the mixer at the same time. The structure material is fed automatically from an intermediate storage while the digestate is pumped into the mixer. This allows to make best use of available plant space and to operate the plant in fully automatic mode.

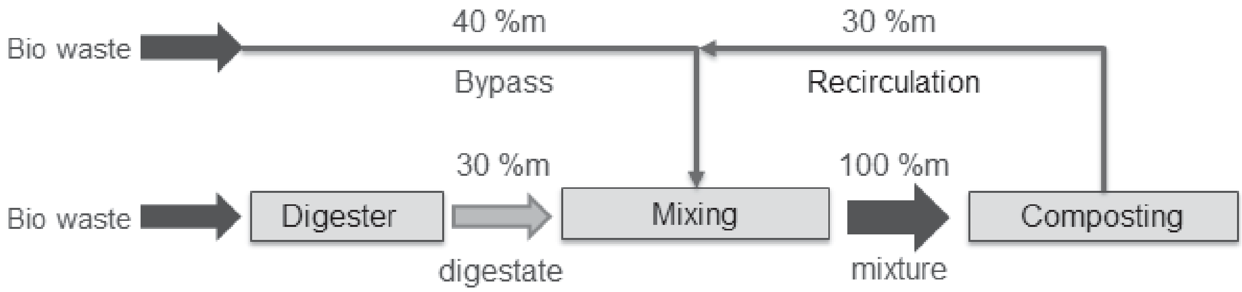
4.2 Structure material and Process Management

The reference cases reveal that the composition of the available structure material varies from case to case. In some plants, a very high partial flow is bypassing the digester; sometimes up to more than half of the total organic feedstock. An advantage of bypassing a high amount of feedstock as a structure material is the high biological activity of the mixture. Therefore, very high temperatures and excellent evaporation rates can be achieved in the composting section. The high temperatures usually also assure sanitation of the mixture. Although the digestate from a Kompogas® fermenter is already sanitized, a second sanitation may be required because the bypass feedstock.



Picture 3: Digestate free concept with high bypass rate of waste (%m = Masse-Prozent)

Other AD-plant-concepts work with a much smaller amount of bypass material, but with a higher recirculation rate of the coarse fraction from compost screening.



Picture 4: Digestate free concept with high recirculation rate

4.3 Cost of composting

The aerobic treatment of the mixed material is usually done in enclosed composting tunnels with forced aeration. A large bypass and/or recirculation rate increases the amount of material to be composted. Compared to the classic AD concept with digestate dewatering, the press water free concept producing the same amount of biogas may require a higher overall plant throughput and a corresponding composting capacity up to 2-3 times in size. In addition, more labor is needed for material movement by wheel loader and the facility will have a higher parasitic load due to the intensive ventilation required to ensure a high aerobic activity and a good water evaporation rate.

5 Comparison standard with press water free AD concept

5.1 Investment cost

Additional systems used in the Standard AD concept are screw presses and press water storage. On the other hand, the press water free concept includes a mixer and requires a larger composting section. To move the larger amounts of material also an additional wheel loader may be required. In comparison, the capex of the two variants are comparable.

5.2 Operating cost

The application of the liquid digestate as a fertilizer in agriculture is usually associated with payment of at least the transport cost to the farmers. Depending on the level of contamination of the feedstock, wear of the dewatering screw press may cause significant maintenance costs.

On the other hand, the press water-free AD concept has a higher electrical consumption for the aeration fans and higher fuel cost for wheel loaders.

While the standard AD concept generally has lower cost to operate, the main driver towards the press water free concept is usually the cost of the liquid digestate management. These vary between a few Euro per m^3 if only transport has to be paid to over 30 €/m^3 in the Netherlands, where liquid digestate land application is not permitted and digestate has to be disposed.

5.3 Conclusion of costs comparsion

There is no apparent advantage for one or the other plant concept from a Capex point of view alone. The key factor for either concept is usually the liquid digestate management cost. With the currently in the most regions of Germany prevailing costs associated with agricultural use of press water of around 10-15 € per m3, both concepts also have comparable Opex. The main advantage of the press water-free AD concept in that case is clearly the long-term solution for digestate management, regardless of the price development for land application and regardless of potential changes of legal requirements. Due to their large feedstock variability and operation at high solids content Kompogas plug flow fermenters are ideally suited and have been used several times in both AD plant concepts. HZI has the experience to provide an optimized AD concept for all possible feedstock and digestate management situations described.

6 References

KOMPOGAS® has built more more than 75 waste fermentation plants are worldwide. Find here a selection of plants, that are operating digestate free in different variations.

Table 1: Selected KOMPOGAS® reference plants – liquid digestate free

Plant	Country	Digester	Plant size	Mixer-typ	Input material
AD added to composting plant	NL 1	2x PF1300	40’000	continuous	Bio waste
New plant	NL 2	2x PF1300	40’000	Wheel loader	Bio waste
AD added to composting plant	DE	PF1300	18’000	Wheel loader	Bio/green waste
New plant	IT	2x PF1300	32’000	batch	FORSU (wet bio waste) green waste

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Dry fermentation of organic waste by BEKON technology

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Abstract

Das BEKON-Verfahren ermöglicht es aus organischen Abfällen Biogas und Kompost herzustellen. Einsatzstoffe sind dabei die organische Fraktion aus dem Restabfall (OFMSW), getrennt gesammelter Bioabfall, Grünabfall oder andere organische Abfälle aus Landwirtschaft oder Industrie. Die robuste und vielfach erprobte Technologie erzielt dabei bis zu 90% des Biogasertrages im Vergleich zum Labortest (VDI 4630). Durch die Möglichkeit des thermophilen Betriebs von BEKON-Anlagen wird der Abfall zudem hygienisiert und die Kapazität erhöht.

Keywords

Biogas, dry fermentation, batch fermenter, thermophilic, sanitation, OFMSW, biowaste, organic waste

1 BEKON batch dry fermentation

Die Trockenfermentation nach dem BEKON-Verfahren eignet sich für unterschiedliche organische Abfälle. Es können sowohl die organische Fraktion aus dem Restabfall (OFMSW), separat gesammelter Bioabfall, Grünabfall als auch verschiedenste landwirtschaftliche oder industrielle organische Abfälle verwertet werden. Grundvoraussetzung für den Einsatz der Abfälle ist ein TS-Gehalt zwischen 20% und 50%.

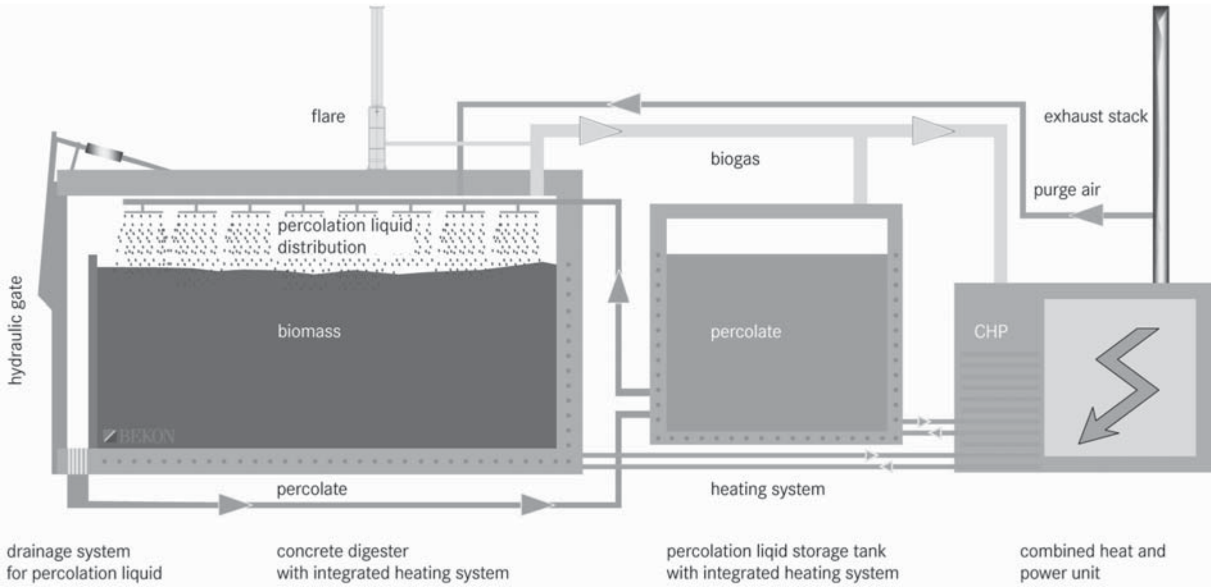

Figure 1: Das BEKON Verfahrensschema

Das Bekon-Verfahren benötigt keine Rührwerke oder Pumpen, die mit dem Abfall in Kontakt stehen, daher ist das Verfahren komplett unabhängig gegenüber Störstoffen (Steine, Sand, Glas, Holz etc.). Aus diesem Grund ist eine Vorbehandlung des Bioabfalles verfahrenstechnisch nicht notwendig. Enthält der Abfall viele geschlossene Tüten, ist ein Sackaufreißer zu empfehlen, um den Inhalt der Tüten der Biogaserzeugung zugänglich zu machen. Der Fermenter besteht aus widerstandsfähigem Beton und hat von Innen keinerlei störende oder wartungsanfällige Einbauten installiert.

Die BEKON-Trockenfermentation ist modular aufgebaut und besteht aus mindestens 3 unabhängigen Fermentern. Die Kapazität eines Fermentes liegt, abhängig von dessen Größe und der Verweilzeit des Materials, zwischen 3.000 und 5.000 t/a. Eine typische Anlage besteht aus 10 bis 12 Fermentern und hat eine Kapazität von 30.000 bis 50.000 Jahrestonnen. Auf einer solchen Anlage werden pro Woche 2 bis 3 Fermenter mit Abfall befüllt.

Die garagenförmigen Fermenter sind aus beheizbarem Stahlbeton gefertigt. Im Boden und in den Wänden der Fermenter sind mehrere Warmwasser-Heizkreise in den Beton integriert, die das Gärgut im Fermenter durch die hohen Kontaktflächen sehr schnell und gleichmäßig auf die gewünschte Temperatur bringen. Das patentierte Heizsystem erlaubt die schnelle Beheizung des frischen Substrates und dadurch optimale Abbaubedingungen und hohe Gaserträge.

Figure 2: Fermenterbefüllung auf der BEKON-Anlage Iffezheim

Die Befüllung der Fermenter erfolgt mit einem Radlader, der Radlader ist das einzige Aggregat das direkt mit dem Abfall in Kontakt kommt. Die Anlagenverfügbarkeit ist aufgrund des konsequenten Radladerbetriebs außerordentlich hoch. Der Fermenter wird mit Abfall und mit einem Teil des Gärrestes der vorherigen Befüllung befüllt. Diese Inokulation mit Gärrest sorgt für einen sofortigen Start der Biogasproduktion. Während der Verweilzeit von 3 bis 4 Wochen verbleit das Gemisch aus Abfall und Gärrest im Fermenter und wird in dieser Zeit perkoliert, um die Befeuchtung und den Stofftransport sicher zu stellen. Durch die Rückmischung von Gärrest und die Beheizung über Wand und Boden sind für den Prozess minimale Perkolationsraten ausreichend, dies führt zu einem trockenen Gärrest und einer problemlosen Kompostierung.

Das Biogas der einzelnen Fermenter wird zusammen der Gasverwertung (BHKW oder Gasaufbereitung) zugeführt. Für eine gleichmäßige Biogasproduktion sind mindestens 3 parallel betriebene Fermenter notwendig. Die zeitversetzte Befüllung der einzelnen Fermenter sorgt für eine Vergleichmäßigung der Qualität und Quantität des erzeugten Biogases.

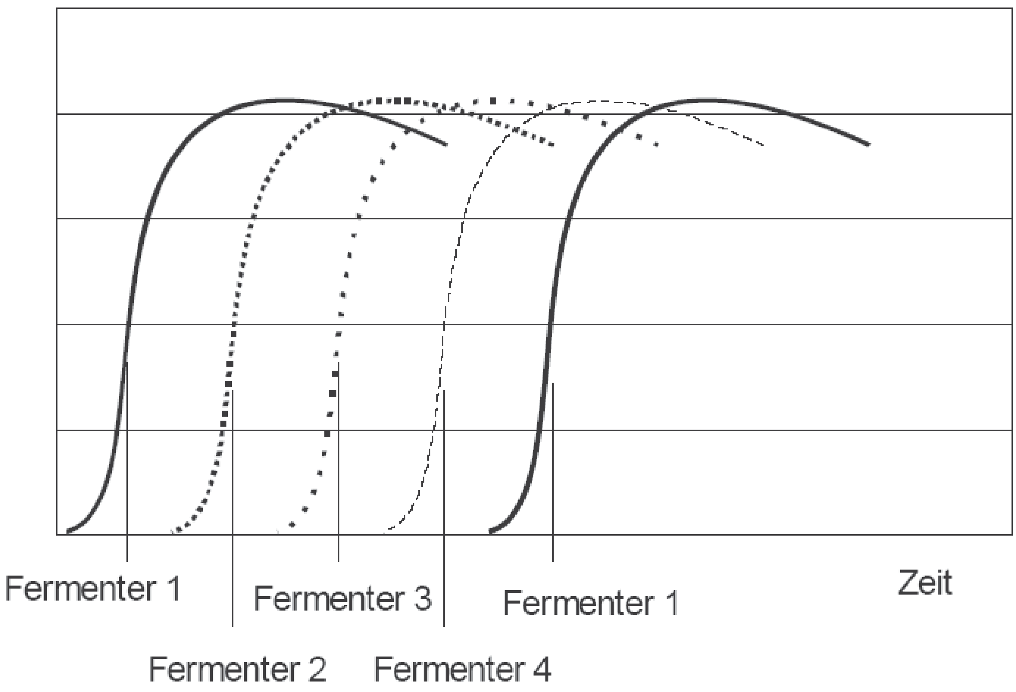

Figure 3: Gleichmäßige Biogasproduktion durch modularen Aufbau

Um explosive Gasgemische beim Betrieb auszuschließen setzt BEKON ein patentiertes Verfahren zur Inertisierung der Fermenter ein. Nach der Befüllung des Fermenters wird im Kopfraum befindliche Umgebungsluft mit dem Abgas des BHKW bzw. der Biogasverwertung verdrängt und so eine Vermischung von Sauerstoff und Methan verfahrenstechnisch verhindert. Am Ende der Verweilzeit wird das im Kopfraum befindliche Restbiogas wiederum mittels Abgas verdrängt und im ersten Schritt der Gasverwertung zugeführt, im zweiten Schritt erfolgt die Verbrennung über eine Fackel. Erst wenn der Fermenter komplett mit Abgas gefüllt ist startet die Spülung mit Umgebungsluft. So werden explosive Gasgemische zu jedem Zeitpunkt sicher verhindert.

Für die der Trockenfermentation nachgeschaltete Kompostierung hat BEKON spezielle geschlossen Kompostierungsboxen entwickelt. Mit diesen Kompostierungsboxen erfolgt die effiziente Umstellung von anaeroben auf aerobe Verhältnisse. Die Kompostierungstechnologie ermöglicht, abhängig vom verwendeten Abfall, die Erzeugung von qualitativ hochwertigen Komposten. Die Abluft der Kompostierungsboxen wird mittels Wäscher und Biofilter gereinigt und desodoriert.

Die erste BEKON-Anlage ist seit 2003 in Betrieb, seitdem wurden insgesamt 20 Anlagen in Deutschland, Italien und der Schweiz errichtet und sind erfolgreich in Betrieb. Insgesamt wurden bisher in BEKON-Anlagen über 2.000.000 t Abfall verwertet und entsprechende Mengen an Biogas und Kompost erzeugt. Durch zielgerichtete Internationalisierung konnten BEKON erste Aufträge in den USA und Mexiko gewinnen.

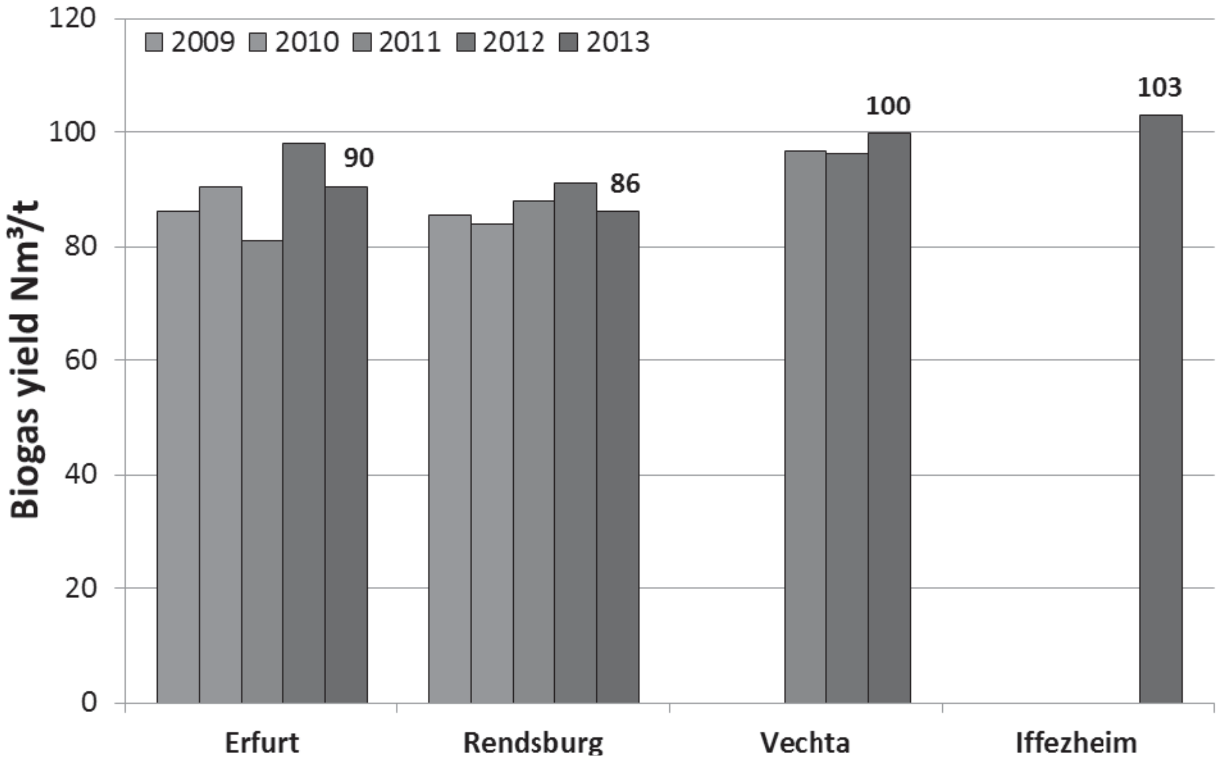

Figure 4: Biogaserträge aus getrennt gesammeltem Bioabfall in BEKON-Anlagen

2 Biogaserträge mit der BEKON dry fermentation

Die patentierte Fußboden- und Wandheizung, die Rückführung von Gärresten und die optimale Prozesssteuerung führen beim BEKON-Verfahren zu Gaserträgen von bis zu 90% vom Laborwert (VDI 3640). Beim Biogasertrag ist zu beachten, dass dieser sich auf den Abfall wie angeliefert bezieht, eine Störstoffabscheidung vor der Vergärung ist nicht erforderlich.

Für getrennt gesammelten Bioabfall aus Deutschland liegt der jährliche Mittelwert des spezifischen Biogasertrages bei ca. 90 – 100 Nm³/t Bioabfall. In Figure 4 sind Praxisdaten aus BEKON-Anlagen in Deutschland dargestellt. Für die organische Fraktion aus Restabfall liegt der Biogasertrag mit ca 120 bis 150 Nm³/t höher.

Der spezifische Biogasertrag ist in erster Line von den Inhaltsstoffen der Bioabfälle abhängig und variiert daher im Jahresverlauf. Hohe Laub- und Grünabfallanteile führen besonders im Herbst zu geringeren Biogaserträgen. Außerhalb der Vegetationsperiode steigt der prozentuale Anteil an Küchenabfällen und dadurch der Biogasertrag. In Figure 5 ist der Verlauf der spezifischen Biogasproduktion der BEKON-Anlage in Vechta im Jahresverlauf dargestellt.

Jahreszeitliche Mengenschwankungen können durch Variation der Verweilzeit und der Rückmischrate abgefangen werden. Kurzfristig sind Übermengen von ca. 20 % durch die Anlagen zu verarbeiten.

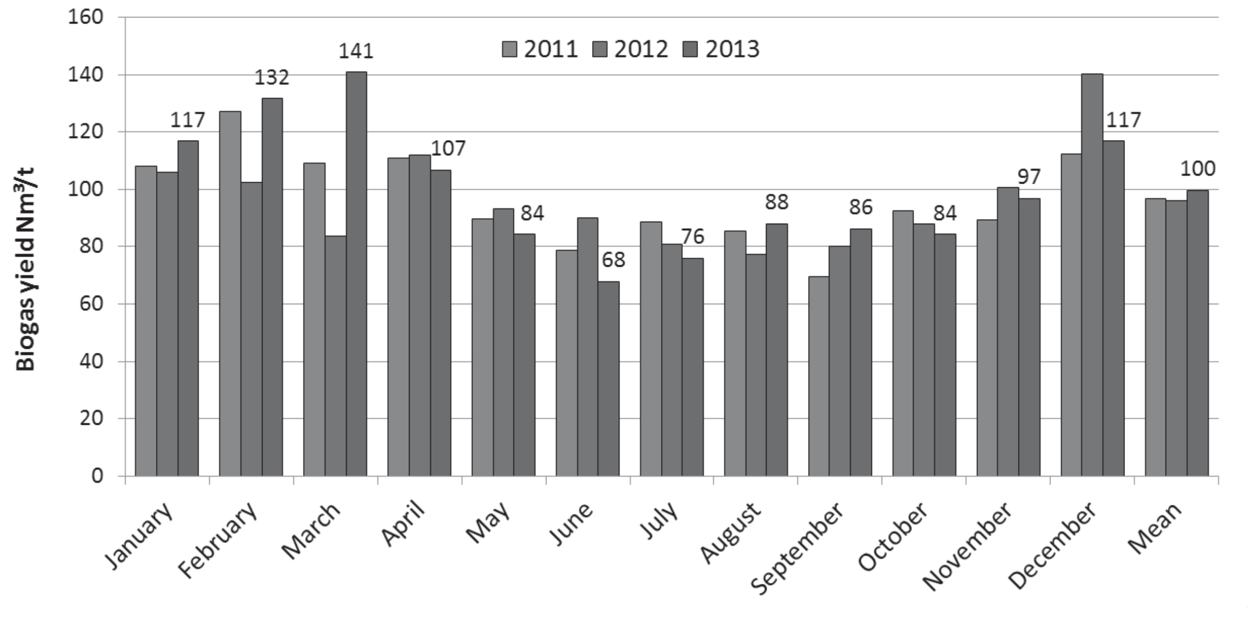

Figure 5: Biogaserträge in Abhängigkeit der Jahreszeit (BEKON-Anlage in Vechta)

3 Thermophiler Prozess

Das BEKON-Verfahren kann aufgrund der patentierten Fußboden- und Wandheizung sowohl mesophil als auch thermophil betrieben werden. Die erste thermophile BEKON-Anlage verfügt inzwischen über mehr als 4 Jahre Betriebserfahrung und belegt die Vorteile des thermophilen Betriebs.

Die Vorteile des thermophilen Prozesses liegen in einem deutlich schnelleren Abbau und dem dadurch höheren Biogasertrag. Im Vergleich mit der mesophilen Vergärung zeichnet sich die thermophile Vergärung durch einen, abhängig vom Abfall, um ca. 20-25% höheren Biogasertrag aus (Figure 6). Durch den schnelleren Abbau kann, bei gleichem Gasertrag im Vergleich zum mesophilen Prozess, die Verweilzeit im Fermenter verkürzt und damit die Kapazität erhöht werden. Dies führt zu einem entscheidenden Wettbewerbsvorteil.

Der zweite Vorteil des thermophilen Prozesses liegt in der Hygienisierung des Fermenterinhaltes. Im Gegensatz zu kontinuierlichen Verfahren findet im Batchfermenter keine Rekontaminierung mit frischem Abfall statt, der Inhalt eines Fermenters verbleibt bis zum Ende der Verweilzeit unvermischt. Im BEKON-Fermenter reicht eine thermophile Behandlung (> 50°C) über 3 Wochen aus, um sowohl die Anforderungen der deutsche Bioabfallverordnung (BioAbfV), die englischen Animal By-Products Regulations (ABPR) und die Schweizer Verordnung über die Entsorgung von tierischen Nebenprodukten (VTNP) sicher einzuhalten.

Im Gegensatz zu einer nachgeschalteten Hygienisierung erfolgt bei BEKON dieser Schritt bereits am Anfang, die Gefahr durch unhygienisiertes Material und die Gefahr der Rekontamination wird dadurch minimiert.

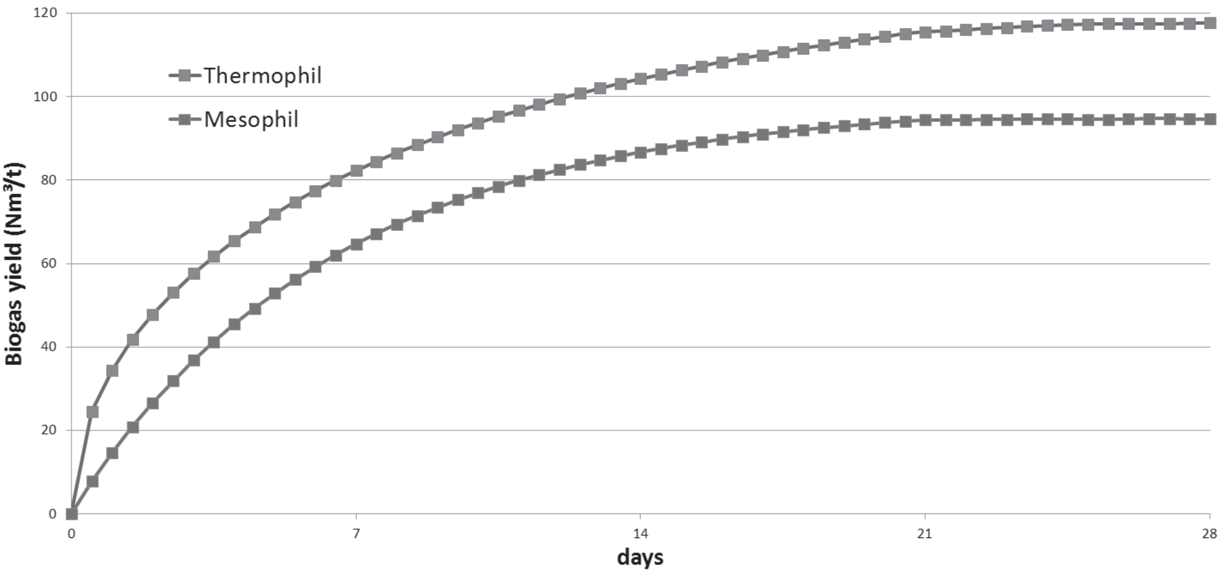

Figure 6: Biogas yield thermophilic vs. mesophilic

4 EPC oder Technologielieferant

BEKON bietet den Bau von Trockenfermentationsanlagen als Generalunternehmer oder als Technologielieferant an. Nach Kundenwunsch kann der Lieferumfang abgestimmt werden.

BEKON ist in Deutschland, Italien und der Schweiz hauptsächlich als Generalunternehmer tätig, die im Zuge der Internationalisierung gewonnen Projekte in den USA und Mexiko werden dagegen als Technologielieferant bearbeitet.

Als Technologielieferant übernimmt BEKON die Planung, die Lieferung von Kernkomponenten, die Überwachung von kritischen Bauphasen, die Inbetriebnahme sowie den Nachweis der vereinbarten Leistungsparameter.

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Recovery of value from MSW and SSO by press extrusion and waste cleaning

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Abstract

Municipal solid waste (MSW) or source separated organics contain a large amount of energy and can be treated into sellable products. Through press extrusion waste is physically separated into two fundamental fractions, a biogenic wet fraction with hardly any non-organics and a solid dry fraction with almost total absence of organic biodegradable substances. This wet biogenic fraction can be further cleaned and subsequently used in anaerobic digestion plants to produce fertilizer, heat & electricity and gas. Through an additional separation process the dry non-organic fraction is prepared into RDF and recyclables. Within the SEPARATE project several waste streams and the two outgoing fractions are tested with a long-term test in Germany and several short-term tests in different European countries.

Keywords

Bio-degradable waste municipal waste waste cleaning organic fraction wet fraction dry fraction refuse derived fuel recyclables energy from waste

1 Introduction

Municipal waste has always been considered a problem, something that no one wants to see, something to be removed and hidden as soon as possible. However, the mixed fraction of municipal solid waste (MSW), the materials that remain after separate collection of the recyclable components of urban waste, still contains large quantities of energy. MSW are mainly composed of:

- materials ("dry") such as wood, plastic, paper and cardboard and (if not previously removed) metals and glass;
- damp and fermentable organic substances ("humid").

The function of the so-called OREX (ORganic EXtruder) is to treat solid urban waste "dry" and "humid" parts by way of high-pressure extrusion into two valuable streams of material that are each more valuable with the absence of the other.

2 Enabling high quality recycling of MSW and SSO

2.1 Current situation in Europe

Europe's largest waste stream is municipal solid waste (MSW): the daily waste from our households. It consists of 6 main product groups: biological waste, paper & cardboard, plastics, glass & rubble, metals and other rest waste.

Rather than importing these valuable raw materials and resources from other parts of the world, it makes sense to re-use and recycle them efficiently.

Bio-waste represents the largest fraction of MSW, yet the recycling of bio-waste is still in its infancy. If treated properly, bio-waste can result in high-quality fertilizer and biogas thus avoiding the emission of greenhouse gases and the loss of high-value material.

Today, Europe loses 60% of its 3 billion tons of solid waste through landfilling and incineration each year. EU Directives such as the Waste Framework Directive (2008/98/EC) and the Landfill Directive (1999/31/EC) are slowly changing this situation towards a circular economy.

Moreover, in July 2014, the European Commission has released the Communication "Towards a Circular Economy" and a new Legislative Proposal for Amending the Waste Directives putting forward ambitious recycling targets for 2030.

2.2 The challenge: efficient separation

In our waste, the valuable material streams are all entangled, mixed together, contaminated. To sort dry recyclables is easy, but the real challenge is to get the organics separated from the rest of the waste. Two options exist:

- separation at source or so-called "kerbside collection". The households are asked to sort their organic waste in specific bins. While source separation is theoretically the best means to achieve clean organic waste, the reality look different. Mentality and culture influence the participation rate and the separation efficiency, but regardless of these, experience has shown that it is hard to implement organic kerbside collection in densely populated urban areas;

- centralized separation happens at waste treatment facilities. Due to problematic hygiene conditions and high personnel cost, manual separation of bio-waste is not an option. Mechanical separation through shredding and sieving is the most widespread method today, but its efficiency is not optimal and the high remainder of organics in the non-organic fraction causes problems for both streams.

The innovative OREX, overcomes these problems with an unprecedented separation efficiency: it removes up to 98-99% of total soluble organics from contaminated waste streams, leaving the organic fraction pure, and the non-organic fraction dried and clean. The OREX (Organic Extruder) is a waste pressurizing machine designed to physically separate waste into two fundamental fractions, a biogenic wet fraction with hardly any non-organics and a solid dry fraction with almost total absence of organic substances. The process involves the treatment of the solid municipal waste “as it is collected” and the use of a very simple form of refuse-disposal technology, which is considered compatible with the situation of practically any territorial or local administration department.

2.3 European eco-innovation project SEPARATE

The European eco-innovation project SEPARATE supports the market entry of this innovative separation and cleaning technology. The SEPARATE project involves four organisations from Belgium, Germany, the Netherlands and the UK. With the help of a testing unit of the hydraulic press OREX and cleaning system called Cyclone, SEPARATE will carry out on-the-spot tests of different waste streams (MSW, separately collected bio-waste and mono-streams) in five European countries.

SEPARATE will analyse the quality and characteristics of the waste streams that have been separated with the new technology with regard to quality of the organic feedstock, substances contained and eventual suitability for fertilisation. The results of the analysis will be certified by renowned institutes and laboratories in the test countries.

3 Solution for the treatment of MSW and SSO

3.1 Waste separation with hydraulic press

The OREX is a hydraulic press that achieves highest separation efficiency MSW or SSO of up to 98%. Under high pressure, the soluble organic matter behaves like a liquid and is separated from the dry fraction.

The OREX PRESS has a modular construction. It consists of the “active part” which is the press ram, the guiding and all the functional parts are located in a self-supporting structure in an electro-welded construction, and the central “passive” part of the structure containing the main cylinder and the extrusion chamber. **The extrusion process** is carried out in three phases:

1. Feeding phase;
2. Compression phase;
3. Expulsion phase.

The feed cylinder feeds the incoming organic waste via a pre-press ram from the feeding hopper into the extrusion chamber then the main cylinder compresses the material via the main ram to extrude the material that turns into a liquid under this extreme high pressure. When the compression phase is finished, the ram retracts, a side door opens and the feed cylinder brings out the structural dry material that remained in the compression chamber. The feed ram retracts and the door closes for the next cycle.

3.2 Result of the extrusion process

The municipal solid waste or source separated organics is split into a dry non-organic and a wet biogenic fraction, the physical and biological characteristics of which allow for advantageous disposal systems.

3.2.1 The dry fraction

The dry fraction is formed by materials which are mechanically more stable and strong such as plastic, wood, paper and cardboard, various minerals and metal with the following significant physical properties:

- upstream density 0,7/0,8 t/m^3 approximately
- residual humidity about 18%-20%
- average calorific level > 14/16,000 kj/kg
- organic (except wood) < 4-5 %

. The dry fraction can be used as a raw material for refuse-derived fuel (RDF). RDF is a fuel producing thermal or electrical energy. Part of it can be further separated in special sorting plants extracting recyclables. The dry fraction that cannot be put into recyclables or RDF can be advantageously disposed of in landfills or storage areas, because of the considerable reduction in volume (up to 1/3 of the volume), with considerable savings in terms of the duration of the landfill or waste-disposal unit (e.g. a 2-year old landfill or disposal area could be used for a further 5-6 years). Its volume reduction also gives reduction in logistics or transportation costs. Finally, the minimal amount of organic substances and moisture result in minimization of damping and gas forming, resulting in less odours and insects.

3.1.1 The wet fraction

The wet phase is essentially formed by organic substances (foodstuff refuse) with low quantities of various fibers, plastic materials and minerals. The physical appearance is that of a semi-fluid, fine-grain paste (depending on the moisture). In particular, the low quantities of glass and ceramics have a granulometric shape. The characteristics of the wet fraction are:

- the level of humidity is about 60-65% and there is no floatation of material from the paste-like mass;
- the upstream density is approximately 0.8-0.9 t/m^3;
- in case of anaerobic digestion:
  - biogas yield >180m3/h;
  - CH4 approximately 60%;
- extrusion efficiency of digestible organics approximately 95%.

(All numbers depend on the input material.)

3.1.2 Products from MSW

The process described above allows the user to obtain the following products from municipal solid waste (mass % depends on the input):

- wet fraction 30-40 % approx
- dry fraction 60-70 % approx
  Off which:
  - metals 1-3 % approx
  - sand and minerals 10-15% approx
  - remaining plastics, wood, cardboard, textiles and leather and whatever is in the solid waste.
  - the remaining organics 5% approx

All of the above products are almost biologically inert and therefore do not generate the negative effects typical for a landfill for municipal solid waste such as leakages, pollutants, biogas, and noxious odour.

3.2 Usage of products coming from the extrusion process

3.2.1 The dry fraction

The dry fraction The dry fraction, characterized by a degree of humidity lower than 20 %, can be used in incinerator plants, gasification, pyrolytic or cement factories systems as RDF. This contributes significantly towards the reduction of the mass of waste transferred to landfill areas and disposal sites in general and the equally significant advantage owing to a recovery of energy. If the mineral and metal fraction are separated from the dry waste the calorific value will increase accordingly, also the amount of slag will reduce significantly since the inert fraction that is taken out is the main part of the slag. The RDF can be formed into bales or briquettes for later use. To facilitate transportation the blocks can be wrapped in (recycled) plastic.

If incineration for the conversion to energy is not an option, nor is any other thermal conversion, then the remaining option is disposal of the material to a landfill. It should be noted that the size of the mass is reduced five or six times with respect to the size of the original waste treated, this because the organic wet fraction is removed from it and the dry fraction is compacted. The immediate advantage, besides the considerable saving due to the reduction in transportation costs is that of a significant increase in the life of the landfill area and simplification of the operation cost of the disposal unit itself because of the fact that the processed waste material is highly biological inert.

3.2.2 The wet organic fraction

The organic fraction that is produced by the OREX is very suitable as raw material in digestion or composting processes. The mechanical effect, to which the material is submitted in the compression and extrusion phase, causes a breaking-up of the solid material forming the wet phase, which allows for a rapid fermentation process, the initiation of which is also facilitated by a raise in temperature of the extruded mass when it comes out of the extruder compactor. Because the material is pressed through small holes in the extruder, this functions as a screen allowing only small material to reach the wet fraction. During the compression, the solid material in the compression chamber holds itself, allowing only minor movement. In this way less solid material and no mechanically hazardous material will end up in the wet fraction. Stainless steel knives, for instance, could ruin pump linings potentially resulting in downtime of the later fermentation process. Depending on the input material and end products needed, the biogenic fraction is further cleaned to limit the remaining impurities.

4 Waste cleaning with CYCLONE

4.1 Description of the process

The system to further clean the biogenic fraction is the Cyclone. It operates in two phases. In the first phase, the material is rotated in the Cyclone at high speed pushing the organic material through a perforation and separating it from the material that is bigger than the perforation – typically plastic film. Whilst the organic fraction is pressed through the holes of the cyclone, the remaining plastic falls over the top and is transported away by a screw conveyor.

In a second phase, inert material and contaminants such as very small pieces of stone, glass and sand are removed from the fraction. During this second phase, the biodegradable organic material is moved into a sink tank in which the material sets to rest. Heavy material such as small stones and glass has the time to sink down in this tank. At the bottom, there is a scraper bar that slowly brings the sunken fraction out of the tank, above water level.

4.2 Result of the waste cleaning

Through the Cyclone, the biogenic fraction is cleaned to limit the remaining impurities, such as plastics and inert materials to less than 0.5% of the total organic matter. The result is a homogenous paste that is perfectly suitable for anaerobic digestion and ensures low maintenance costs of the digesters. The cell structures of this organic material are broken up whereby a high gas yield with sorter retention times can be achieved. Short retention times are of economic importance as they reduce the investment costs for digesters. As a result of the very clean separation, a number of high quality products can be obtained.

5 Testing the solution

5.1 Description of the test

The test hydraulic press and cleaning system are installed at Entsorgungs-Gesellschaft Westmünsterland (EGW) at Gescher in Germany and will be integrated in their existing waste treatment systems. The test unit separates the incoming waste fraction into two fractions: a wet organic fraction with a separation efficiency of 95% and is further cleaned in the cyclone. The fraction will then be optimally prepared as homogeneous feedstock for the biogas plant and subsequent fertilizer production. The dry non-organic fraction can be further sorted for recyclables and prepared into high quality RDF.

The long term test will be split into three tests:

- test 1: input material- organic mono-stream waste
- test 2: input material- separately collected bio- waste
- test 3: input material- unsorted municipal solid waste

The incoming materials as well as the two outgoing fractions will be analyzed. Furthermore, several short term test will be carried out in several EU countries.

6 Conclusion

By using the extrusion procedure it is possible to separate municipal solid waste and source separated organics into two streams of material, a dry mainly non-organic fraction and a wet biogenic fraction, that each are more valuable with the absence of the other.

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MBT Ljubljana: In Slovenia arises one of the largest and most modern plants in Europe

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Abstract

The new MBT in Slovenia's capital gets ready to become one of the largest and most modern waste treatment plants in Europe. It will produce biogas, recover heat and power as well as SRF and other recyclable products while avoiding landfilling. The new facility is implemented into the existing waste management centre of Ljubljana.

Keywords

mechanical-biological waste treatment (MBT), anaerobic digestion (AD), solid recovered fuel (SRF), biogas, stabilisation, composting, sorting, landfill

1 Introduction and scope of work

Already in 2012 the Municipality of Ljubljana has awarded the contract for the new Regional Centre for Waste Management RCERO Ljubljana (Regijskega centra za ravnanje z odpadki Ljubljana) to produce biogas from organic waste with the patented STRABAG LARAN® plug-flow technology, for production of SRF and recovery of valuable materials. Since then this waste treatment and biogas plant is constructed for € 112,2 million and thereby one of the largest and most modern MBT plants arises in Europe.

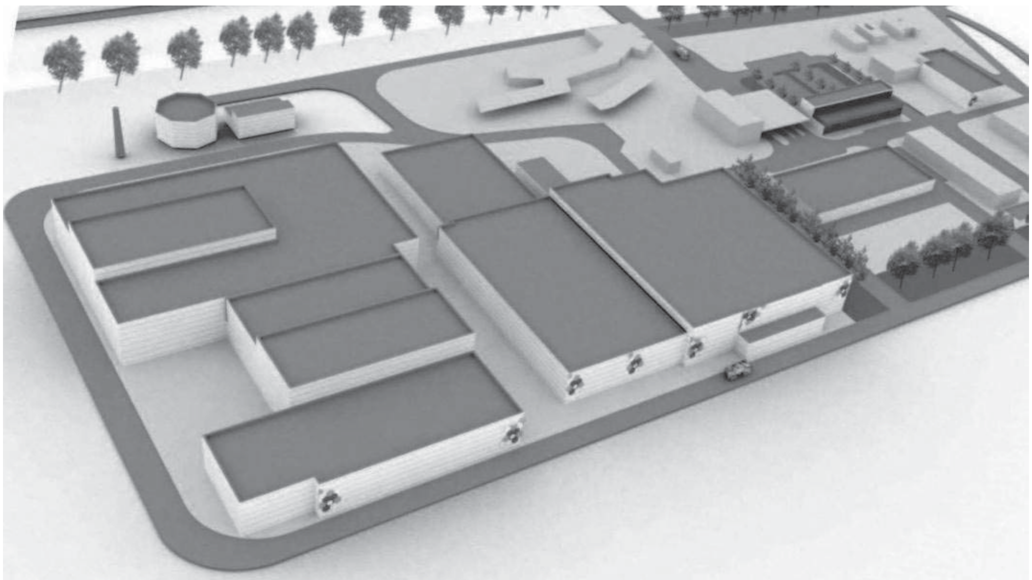

Figure 1 Model of RCERO Ljubljana at Barje landfill site (2012)

On the one hand the project comprises the construction of replacement buildings for objects that had to be removed at the construction site near the landfill Barje. On the other hand all building permits had to be obtained so that the new turnkey mechanical-biological waste treatment plant (MBT) can be handed over in 2016. The integrated plant concept will enable an efficient processing of approx. 171.000 Mg/a (Phase 1).

Due to intensive activities in accordance with Slovenian legislation resulting from the current European Union Directives, significant changes in quantities and waste structure are expected. Major changes are expected until 2020 when certain collection/recycling goals need to be reached. Considering these facts, the plant will be constructed in a way that the highest flexibility will be provided and all collected waste types are going to be treated also in Phase 2.

2 Technical concepts and planned process steps

2.1 Technical concepts

Prime target of the project is to avoid landfilling at the existing landfill site Barje and to recover as much as reasonable waste products which are reusable and to obtain biogas resp. to produce heat and power from organic waste fractions. The residuals from waste treatment are utilised as SRF, on the one hand as high calorific fuel applicable in industrial thermal processes (SRF A) and on the other hand as low calorific fuel (SRF B).

Table 1 Waste input data (2012)

Type of waste	Quantity (Mg/year)	European Waste Code
Household waste MHW	108.200	20 03 01
Commercial waste PTSS	25.500	20 03 01
Bulky waste BW	9.300	20 03 07
Biowaste BHW	21.000	20 01 08
Yard waste	1.948	20 02 01
Treated wood	2.508	20 01 38, 17 02 01, 02 01 07
Untreated wood	2.185	20 02 01, 20 01 38
Waste from market halls	600	20 03 02

Depending on specific waste types and waste input characteristics, obtained from field surveys carried out by the Municipality of Ljubljana, the technical concepts have been generated.

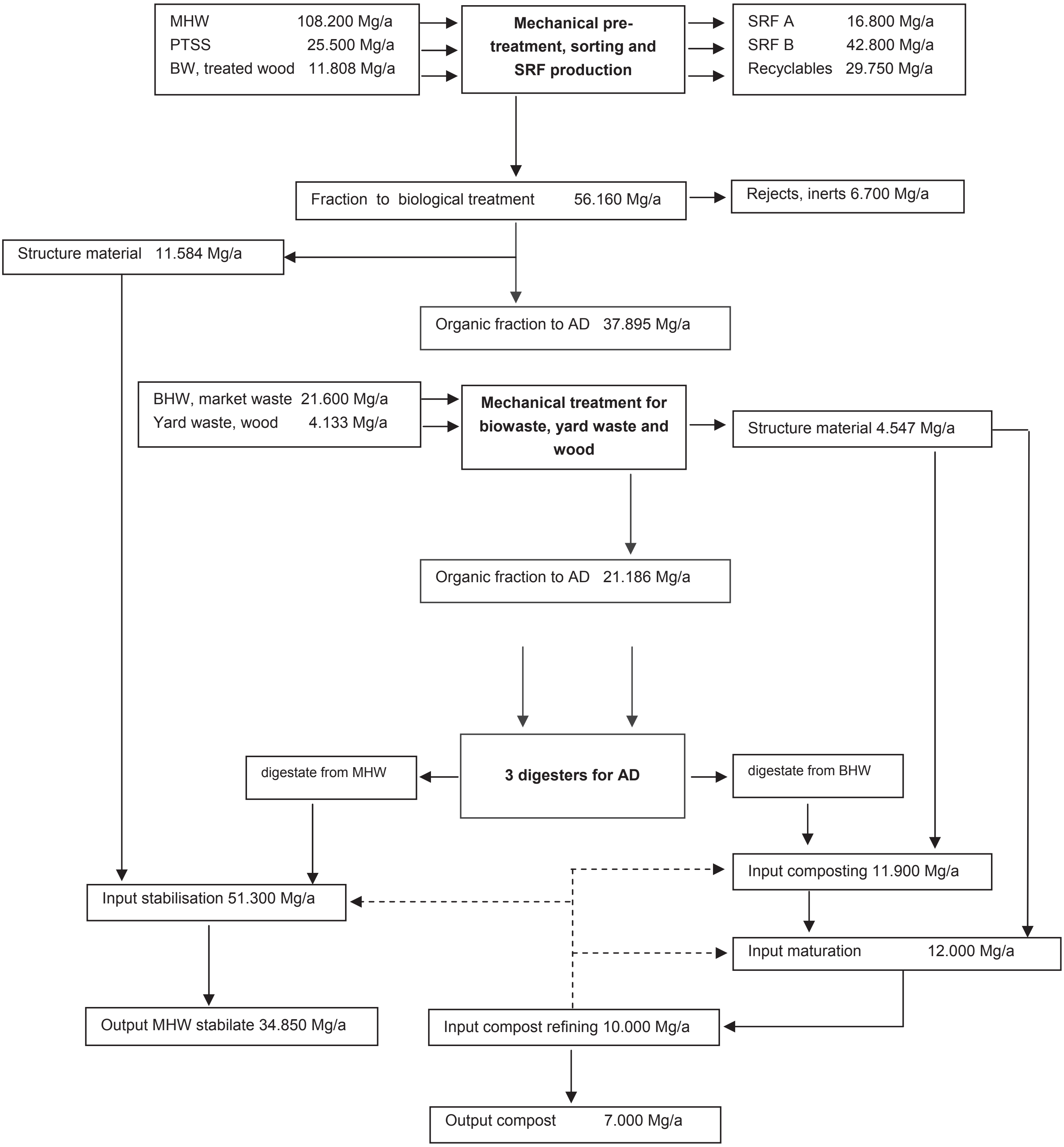

Figure 2 Block diagram of MBT Ljubljana (2012)

The MBT is designed for two phases of expansion, whereas the initial stage includes already a complete and fully functional treatment facility for approx. 171.000 Mg/a. Possible future extensions are for extending the capacity, e.g. up to 60.000 Mg/a biogenic waste, including space for an additional digester for AD.

2.2 Planned process steps

2.2.1 Mechanical pre-treatment, sorting and SRF production

The delivered municipal waste (MHW), commercial waste (PTSS), bulky waste (BW) and packaging material are first split in the mechanical pre-treatment in several lines by means of shredding or just bag splitting, screening and ballistic separation in 2D, 3D and fine fraction. Also classical methods are applied for the recovery of scrap iron and non-ferrous metals.

Then, the particular mass flows are further processed in order to recover valuable materials and for the production of solid recovered fuels (SRF). For this purpose innovative sorting methods are implemented by using optical sorters (NIR). This sensor-based sorting technology with an additional manual follow-up check allows to produce high-quality, almost pure product streams of HDPE and PET bottles for recycling. The recyclables are pressed into bales finally. By means of compressing the volume and the storage space are decreasing and the logistics significantly simplify.

However MHW, PTSS, BW or packaging material are not processed together, meaning that the different waste types are not fed simultaneously, but in different shifts with the particular material, to optimise the product quality of recyclables.

Special applications, e.g. for sorting PET bottles by colour, may be carried out by feeding a mixed PET fraction once again and appropriate adjustment of the NIR sorter.

In order to improve the quality of refuse derived fuels optical sorters (NIR) are also used to separate PVC. Depending on the fuel specification different shredding aggregates are applied, too. The alternative fuels (SRF) can be transported for recycling either loose or baled. The baling enables a substantial reduction in volume and is in compliance with the requirements for storability of the SRF.

2.2.2 Biological treatment

In the mechanical pre-treatment is recovered also an organic fraction from the delivered municipal waste (MHW), which is utilised in the biological treatment to produce biogas in two STRABAG LARAN® plug flow digesters and finally in the biological stabilisation with drying of the digestate.

The delivered biogenic waste (BHW) and yard waste are prepared for biological treatment depending on the type of waste in the mechanical processing, on the one hand to produce biogas in a STRABAG LARAN® plug flow digester and secondly for composting of the digestate (intensive composting and curing phase) and compost refining.

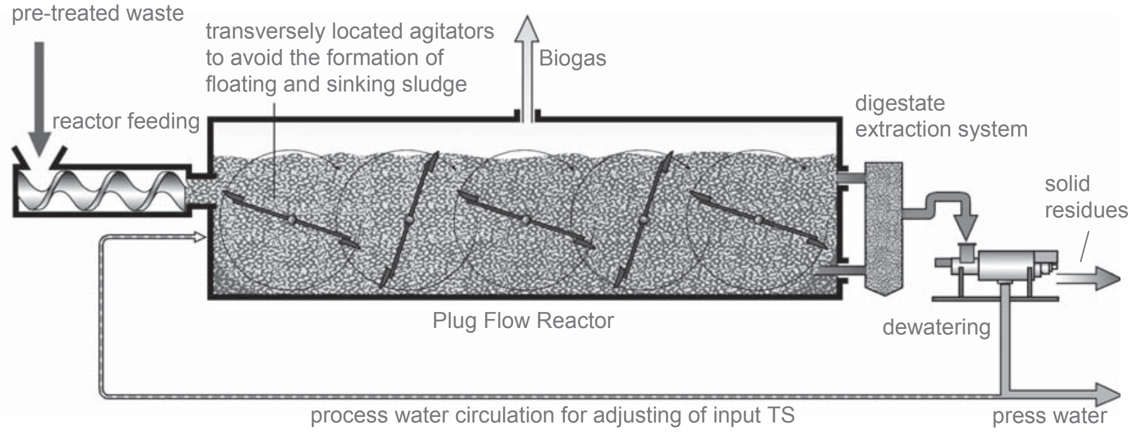

Figure 3 Process scheme of a STRABAG LARAN® Dry Digester

The two horizontal plug flow reactors for organic fraction of MHW (mesophilic operation) and the one for BHW (thermophilic operation) are of identical design and type TF 2200. Therefore a second plug flow reactor can be made available for BHW easily substituting one plug flow reactor from MHW digestion (Phase 2).

Dry anaerobic digestion has proven its capability for drier waste types with higher structure content, like organic fractions from municipal solid waste and residual household waste as well as for typically wet food waste and biowaste. According to the experience dry anaerobic digestion provides a less complicated operation as it avoids the higher water volumes and additional reject streams typically for wet anaerobic processes.

The main characteristics of the STRABAG LARAN® plug-flow technology are:
- horizontal, rectangular plug flow digester providing large surface for biogas release
- plug-flow – providing a controlled residence time within digester and
- this reduces mixing and movements inside the digester
- possibility of product and centrate recirculation giving a stable biological process
- reduced space requirements, modular system making the units very service-friendly
- operation either in meso- (≈37ºC) or thermophilic (≈57ºC) temperature ranges whilst
- using the same heating circuit for both temperature ranges
- flexibility in treatment capacity due to
- digester filling level and residence time can be varied according to necessary capacity
- flexibility in operation according to waste quality – even dry waste can be treated

The digesters are fed one after another with organic fraction from MHW or BHW from the intermediate storage buffer (continuous operation mode on 7 days per week and 24 hours per day in contrast to the mechanical pre-treatment which is feeding the intermediate storage buffer on 260 working days per year and 16 operational hours per day) which ensures continuous and even anaerobic digestion and biogas production.

Additionally, the waste is inoculated with centrate from the downstream dewatering units. The centrate is “anaerobically active” water re-circulated to activate the fresh material and to adjust the dry substance moisture content at the digester inlet. At the required design throughput, the retention time in the anaerobic digesters would be approx. 25 days. After the AD the material is taken out with vacuum system to dewatering.

The three-stage dewatering of digestate from BHW and MHW will be done consecutively to avoid a mixture of the different press cakes for ongoing stabilisation/maturation and the different centrates. To avoid contamination of each waste stream, the entire dewatering sequence cascade is flushed with fugate from biowaste fugate tank which will then (after the flushing) be returned into the MHW processing. This assures “biowaste fugate” quality level throughout the entire dewatering sequence cascade at the beginning of both dewatering cycles. Three screw presses, two vibrating screens and two decanter machines are available and used parallel for dewatering either BHW digestate or MHW digestate. No surplus water will remain from MHW and from BHW line besides emergency overflow.

The press cake-/screen-overflow (screw press, vibrating screen, decanter) from MHW is transported to a mixing device where it is unified with structure material from MHW and then the stabilisation boxes are filled by means of an automatic feeding system to the stabilisation boxes. The solids from dewatering of BHW are conveyed straight to the composting boxes whereas structure material (e.g. shredded green waste or coarse fraction from compost refining and shredded untreated wood, if adequate) is dosed from an intermediate storage conveyor directly onto the conveyor system transporting the digestion residues.

The boxes for stabilisation and composting are of same type and provide redundancy and also the biological process for MHW and BHW is similar. The plant is equipped with process ventilators and heat exchangers for the intermittent aeration of the boxes.

2.2.3 Biogas and energy recovery

The energy recovery of the biogas takes place in a common plant technology. The biogas produced from the three STRABAG LARAN® plug flow digesters is buffered after desulphurisation and siloxane-cleaning in a biogas storage and then passed for energy recovery in three cogeneration units (CHP). The supply of electrical energy (about 2 MW) takes place into the public network. The waste heat - both from the existing CHP (landfill gas) and the new gas engines - is fed into a common central heating system and utilised in the plant (e.g. for heating the digesters or drying the digestates).

2.3 Accessories and infrastructure

2.3.1 General

Also included in the scope of work are the soil preparation, construction of an administration building and the setting up of the entire infrastructure, including roads and supporting structures, and the renewal of the bridge on the access road.

To the infrastructure belong amongst others the demolition of the existing car wash plant and the erection of the new car wash plant, washing area for heavy mobile equipment and installations for the workshop facilities and laboratory. A visitor gallery throughout the entire mechanical pre-treatment and sorting plant is also included.

High performance requirements are to be fulfilled for ventilation respectively exhaust air treatment as well as fire protection and firefighting, too.

2.3.2 Fire protection and firefighting

Various installations are provided to achieve utmost fire protection and highest efficiency for firefighting to prevent spreading of the fire inside the building and on neighboring objects, e.g.:

- subterranean water tank for fire-fighting and hydrant system with diesel pumps
- several fire zones with internal firewalls and de-smoking openings
- statics of roof constructions and emergency ladders considering thermal loads
- manual alarm buttons at the doors of halls
- fire access paths and safety lighting

- ventilation piping and
- conveyors passing fire zones equipped with fire retarding devices

- CO-detection for early detection of hidden fires in waste bunker
- fire detection, alarm system and sprinkler system in treatment halls

- independent fire extinguishing with foam for shredders
- detection of sparks and separate fire extinguishing units and
- standard ex-protection measures on specific equipment

2.3.3 Ventilation and exhaust air treatment

The ventilation management and exhaust air treatment concerns to the whole MBT plant consisting of the mechanical pre-treatment and the biological treatment. Amounts of waste air from the buildings and single equipment are partly providing the process air flow into the aeration system of stabilisation and composting. The principle of ventilation of the MBT is to provide for negative pressure in the processing halls to avoid uncontrolled emissions.

Ventilation is carried out for the processing halls as well as storage halls and locally at specific equipment. For reduction of the dust load in the ventilation system a dust filter is installed prior the air is reused again. The final treatment of exhaust air from stabilisation and composting is an enclosed biofilter system. Before the exhaust air enters this final treatment stage it is pre-cleaned and conditioned by means of a chemical acid scrubber stage. The latest Slovenian legislation for exhaust air from biological waste treatment is limiting emissions on the stack, e.g. 50 mg non-methane TOC/m³.

2.3.4 Car wash

The new car wash is a four-track plant whereas two tracks are designed for manually washing, especially for the interior surfaces of inlet openings of vehicles for the transport of municipal waste, one track for the combined manually-washing-machine-washing and one track for exclusive automatic machine wash consisting of a travelling frame mounted with nozzles and brushes, which are arranged laterally and transversely to clean the sides and roof of the vehicle. This modern car wash comprises all the facilities, which include cleaning the washing water to such a degree that it can be re-used for the purpose of washing or for discharge into public sewers.

Figure 4 New car wash of RCERO Ljubljana (start-up 2013)

3 Economic characteristic data

In Phase 1 the treatment capacity of the MBT is approx. 171.000 Mg/a consisting of household waste (MHW), commercial waste (PTSS), bulky waste (BW) and packaging material. The efficiency of the system is greatly influenced on the one hand by the recovered energy and the other by products. Thus, approximately 30.000 Mg/a recyclable material and 60.000 Mg/a SRF, approximately 41.500 Mg/a stabilised digestate and landfill material and around 7.000 Mg/a compost will be produced. Due to the biological treatment of waste a mass loss of about 32.500 Mg/a contributes a positive impact, too.The supply of electrical energy will be about 2 MW which are fed to the public network. Working places for operation in 2 shifts will be approx. 60 (without management).

In Phase 2 the treatment capacity will be increased to a maximum with extension of operational time for approx. 256.000 Mg/a, with the focus on growth of capacity of bio-waste and additionally the maturation area for compost production will be extended accordingly.

4 Current status of implementation

Actually in early March 2015 the technological civil construction works of the three digesters are finished, of the mechanical pre-treatment halls are under finalisation and of stabilisation/composting as well as maturation are ongoing.

Figure 5 STRABAG LARAN® plug-flow digester under construction (September 2014)

Figure 6 Waste treatment hall under construction (December 2014)

In December 2014 the mounting of the two drum screens in the mechanical pre-treatment hall and also of the bridge cranes in the waste bunker hall has been carried out.

Starting with January 2015 the assembly of ventilation piping works as well as equipment in the mechanical pre-treatment is ongoing.

Figure 7 Drum screen for mechanical pre-treatment (January 2015)

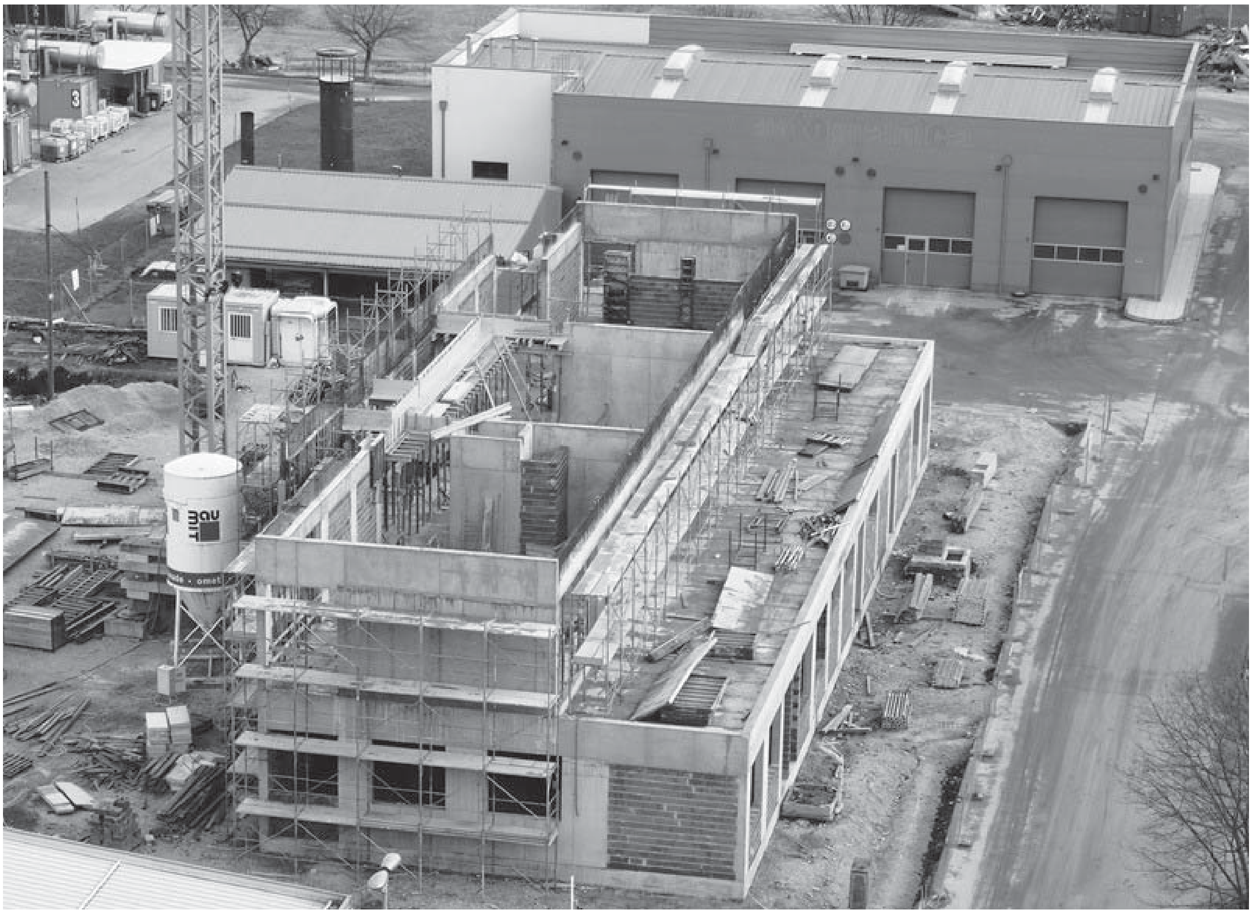

Figure 8 View on the administration building under construction (January 2015)

Figure 9 Scenic view on the hibernal construction site (February 2015)

In figure 9 the whole MBT area can be seen whereas on the left side the SRF storage hall is in the foreground with the bales storage for recyclables far left and the elevated mechanical treatment hall. In the middle the three digesters are in the background, the biological treatment hall and the intermediate storage buffer for AD is still missing in the foreground. Far right the stabilisation and composting building is under construction.

The following time schedule is tough as start-up is planned for November 1st, 2015.

5 Literature

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The relevance of the context for greenhouse gas emissions from residual municipal solid waste management

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Abstract

Given the current EU legislation, the assessment of greenhouse gas emissions related to the treatment of residual municipal solid waste is relevant. As to a lack of models that allow for comparing the climate impact of different treatment options (incineration, mechanical biological treatment, landfilling), a model adequate for such comparisons is developed. Due to the impact of background conditions on the climate performance of waste treatment, the model is adaptable to different EU context situations. Exemplary calculations conducted with the developed model reveal, that the context of residual municipal solid waste management is of such importance that it even impacts the order of treatment technologies when assigning them according to increasing climate impact.

Keywords

Residual municipal solid waste treatment, mechanical biological treatment, incineration, landfilling, context, framework conditions, greenhouse gas emissions, climate impact, EU legislation

1 Introduction

The reduction of greenhouse gas (GHG) emissions from municipal solid waste (MSW) management in general and methane emissions that yield from landfilling of biodegradable substances in particular is a demand that is expressed by various legislative texts showing relevance within an European Union (EU) context [UNFCCC, 1998], [EU WFD, 2008], [EU LFD, 1999]. Measures that are available in order to reducing GHG emissions from residual (r) MSW management are the application of one of the state-of-the-art treatment technologies for rMSW, which are incineration (MSWI) and mechanical biological treatment (MBT) [BOGNER ET AL., 2008], [MANFREDI AND PANT, 2011]. In order to quantify the climate impact of these technologies, life cycle thinking and life cycle assessment (LCA) is the approach that is called for e.g. by the EU Waste Framework Directive [EU WFD, 2008]. While there is wide agreement with regard to the general advantage of applying one of said technologies prior to landfilling [LAURENT ET AL., 2014], [CLEARY, 2009], a statement in terms of the climatic superiority of either of the technologies over the other requires specific consideration. This is due not only to the impact of the chosen methodological approach on the results of an LCA, but also due to the fact that the environmental performance of MSW management can be assumed to strongly depend on the context that it takes place in [KLÖPFFER AND GRAHL, 2012], [EU WFD, 2008], [JOINT RESEARCH CENTER, 2010], [MANFREDI AND PANT, 2011]. Reviews of LCA studies that are available in the field of MSW management however reveal a lack of studies of MBT technologies and especially of direct comparisons of the technologies MBT and MSWI [LAURENT ET AL., 2014], [CLEARY, 2009]. As to the relevance of both technologies [BREF WI, 2006], [BREF WT, 2006], [STEINER, 2006] and the legal requirement in numerous EU member states to establish integrated MSW management in the near future [EUROSTAT, 2012], [EU WFD, 2008], [EU LFD, 1999], a model was developed within a dissertation [CLAUSEN, 2015] that allows to compare the GHG emissions related to MSWI and MBT and that is adaptable to varying context situations as they may occur in EU. In the following, the modelling approach is presented including first calculations that demonstrate the relevance of varying framework conditions on the climate performance of different rMSW management approaches.

2 Methodology

2.1 LCA framework

As far as possible, ISO 14040 [ISO 14040, 2006] and the ILCD Handbook [JOINT RESEARCH CENTER, 2010], serve as a methodological basis for defining the goal, the scope and life cycle incentory (LCI) modelling rules for the Model. Due to the potential medium/large scale impact of rMSW management activities, consequential modelling is applied. The system boundary is represented by the ecosphere and the reference flow of 1t of rMSW (20 03 01 of European waste codes [EU LIST OF WASTES, 2000]). Thereby, emissions that may be related to infrastructure and transportation are neglected. The functional unit includes the treatment of the reference flow conform to current EU legislation with the foreground system being represented by MBT (see Figure 1). The time horizon correspondently is set to the near future, namely 2050. As to the focus on GHG emissions, climate change is the only impact category considered. In addition to fossil carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions, biogenic CO_2 emissions are modelled. However, the results presented within this paper are derived applying the IPCC 2007 LCIA method, which implies that biogenic CO_2 emissions are neglected.

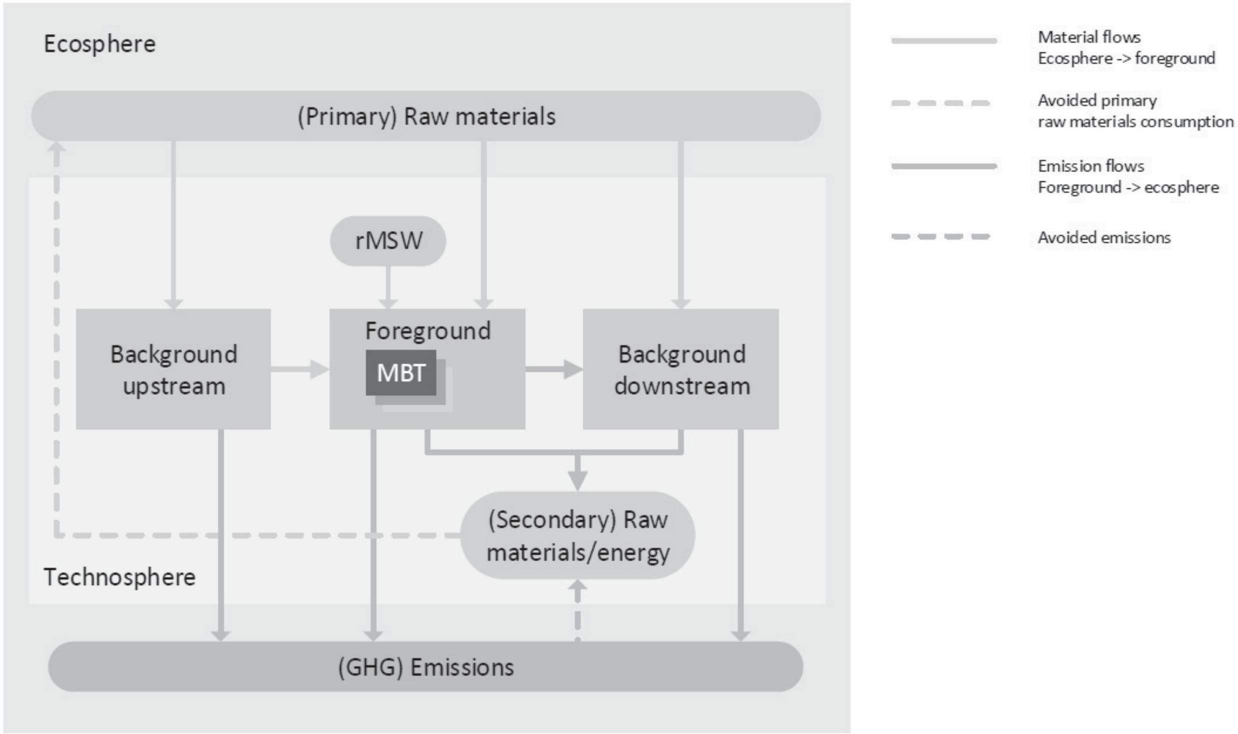

Figure 1 Schematic system boundary diagramme of the Model

2.2 The reference flow rMSW

rMSW shows heterogeneous and fluctuating characteristics [CLAUSEN, 2011], which – due to the high number of stakeholders that are involved in generating it – can be controlled to a limited extend only. Therefore, most principles that can be applied when modelling the LCI of a well-defined product, e.g. the law of stoichiometry [KLÖPFFER AND GRAHL, 2012], are not applicable in relation to modelling the LCI of rMSW and its treatment. However, the quality of the reference flow is crucial for the modelling results and thus needs special consideration.

MSW in general is a result of a population's consumption patterns. The quality of rMSW is influenced by the disposal pathways available for different material flows that are part of MSW and by the decision of a consumer to supply the waste to one of the pathways that the consumer has access to. Due to the fact that the efficiency of separate collection always is less than 100%, each MSW management system involves a residual MSW material flow containing all materials that are not directed to a route for separately collected materials (see Figure 2).

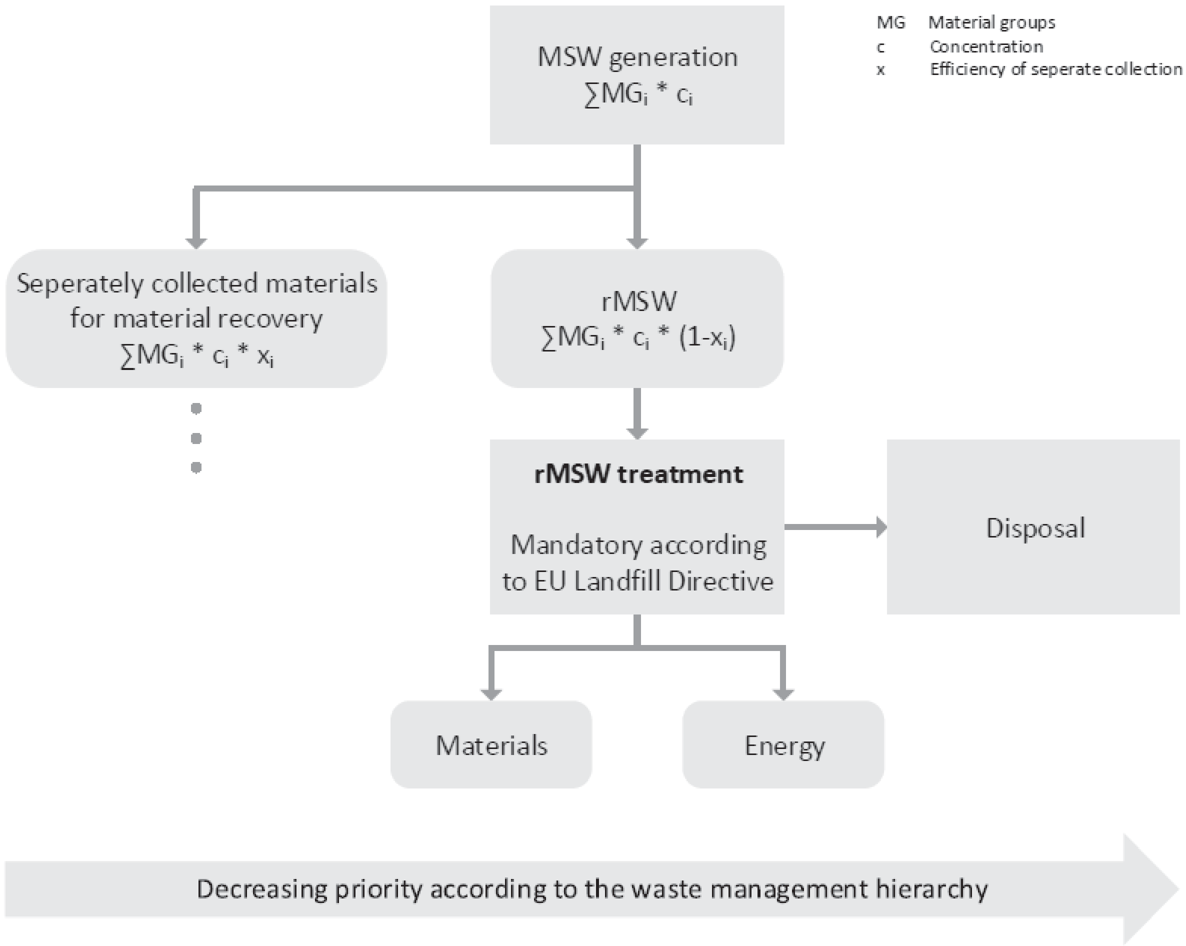

Figure 2 EU framework of rMSW management

2.3 Background Conditions

The pathways that are available for both separately collected MSW material flows and rMSW are influenced by:

- Legal demands on the ecological performance of MSW management that arise from a society's individual claim for a save and healthy environment in a democracy
- The demand for cost efficiency that goes together with market-based economies
- The demand for secondary raw materials that is driven by legal demands for resource efficiency and the current market situation
- The geographical background as a static framework

The interaction of stakeholders in the field of waste management is demonstrated in Figure 3.

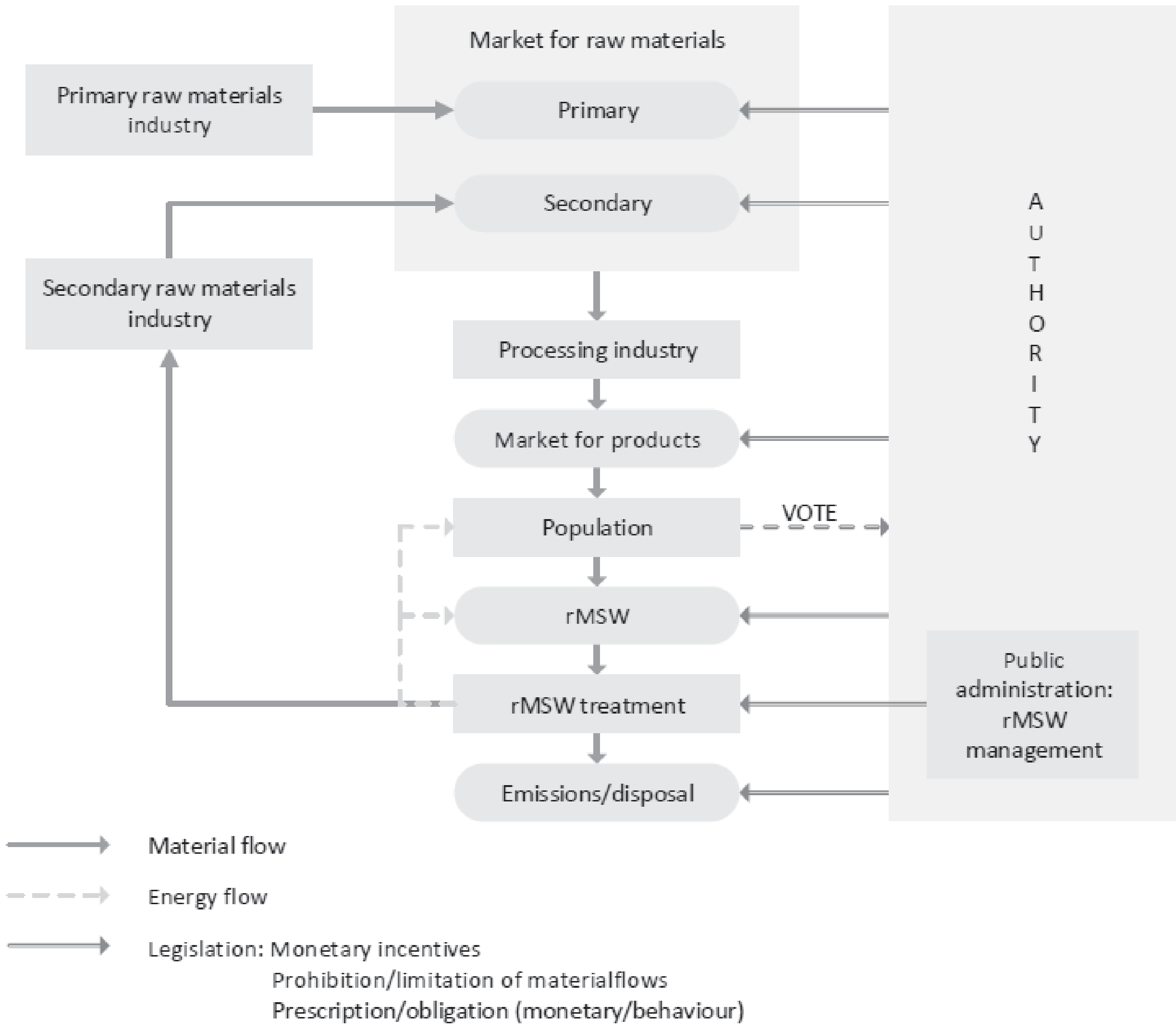

Figure 3 Interactions of stakeholders in the field of waste management

Sensitivity regarding geographic boundary

Time related sensitivity	No (valid EU-wide)	Yes (valid on local level)
No (static)	Natural law	Climate Geology
Yes (dynamic)	EU legislation	National/local legislation Markets rMSW generation rMSW handling

Figure 4 Classification of background conditions

The background conditions can be classified according to their sensitivity in terms of time and geography. Figure 4 shows an overview of the background conditions that influence rMSW generation and management and thus must be considered in the Model.

As a result of these manifold impacts, current rMSW management in EU ranges from landfilling activities that are not in line with EU legislation yet over incineration with and without energy and metals recovery up to systems that integrate MBT and advanced material recovery (metals, plastics, refused derived fuels (RDF)) from rMSW and that already fulfil the targets that are defined by current EU legislation.

2.4 Modelling

Basically, all mentioned process chains can be investigated by the Model so that both current baseline scenarios as well as future waste management systems can be reproduced. The process chains included in the Model are shown in Figure 5, whereby single processes can be chosen to be not considered for calculation (efficiency = 0) in order to model those systems that include only part of the processes.

Due to the considered time horizon and scope of application, the rMSW treatment technologies that are covered by the Model - MBT and MSWI - have to comply with current EU legislation. EU legislation prescribes that rMSW treatment has to be in line with the related EU BREF documents. Certain efficiencies with regard to energy recovery are demanded and emission limit values are stipulated that require e.g. closed systems and flue gas treatment with a limited flue gas volume flow to be met [BREF WI (2006)], [BREF WT (2006)].

There is a high number of specific implementations of MBT technology. In terms of developing the Model, two options of biological treatment are selected to be included. Given their robustness with regard to a varying quality of the feed material, these are biological stabilisation by rotting and biological drying. As a data basis for modelling of the processes that are part of the foreground system, operating plants that apply state-of-the-art technologies are addressed. Data describing the process of biological stabilisation and related flue gas cleaning by biofilter or reverse thermal oxidation (RTO) originate from the MBT plant `MBA Großefehn' (Aurich, Germany); data describing the process of biological drying as well as mechanical treatment for metals separation are gathered from the MBT plant `MBT Mertesdorf' (Trier, Germany), which operates according to the HerHof® Stabilate technology. Modelling of plastics separation and RDF refinery are based on data collected from a pilot and demonstration plants that were/are implemented at the `MBT Mertesdorf' plant.

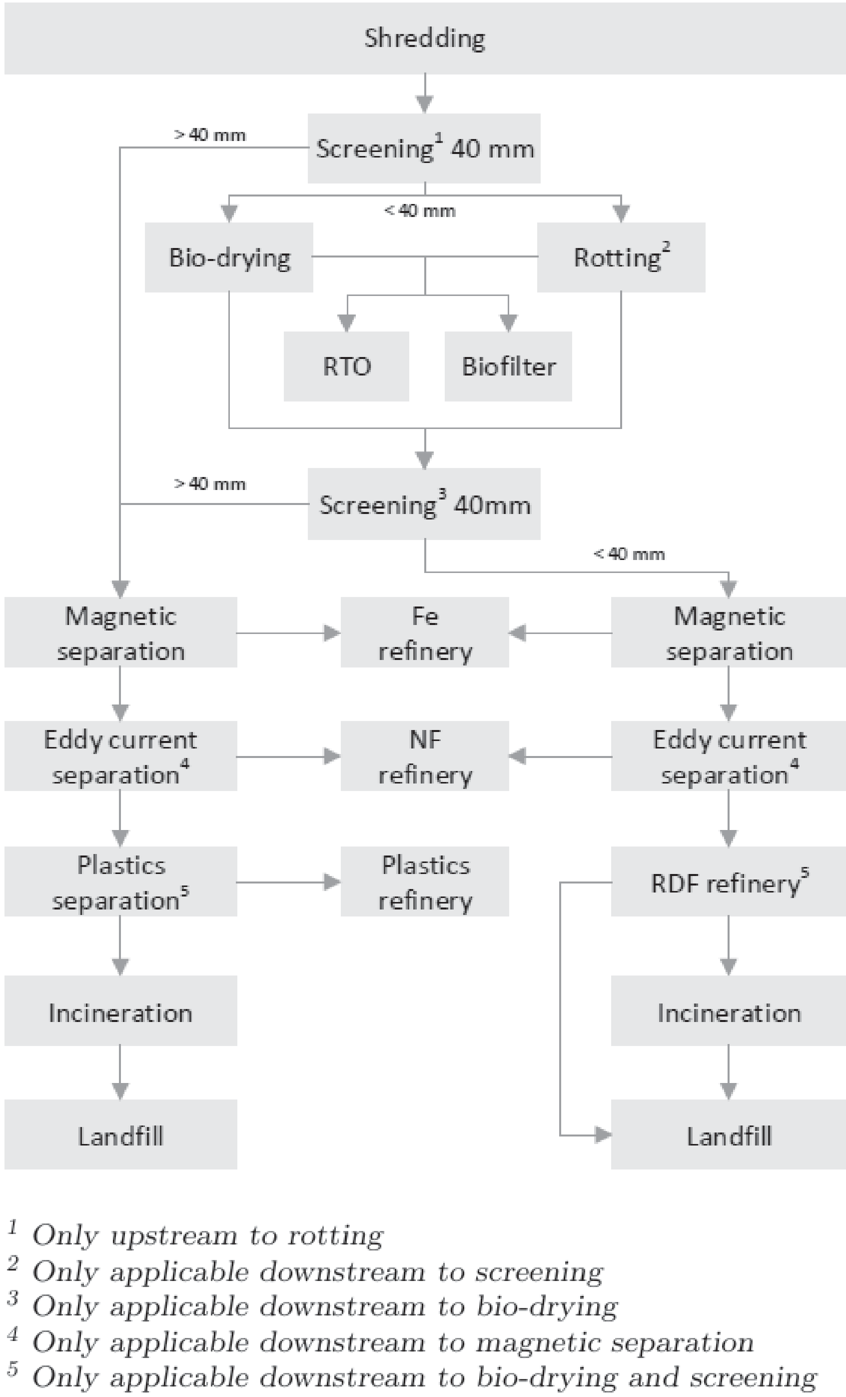

Figure 5 Generic flow chart of the process chains implemented in the Model

Modelling requirements are defined by investigating all processes that are part of the Model in terms of potentially related GHG emissions. While mechanical processes (including recycling activities) are considered to be related to indirect GHG emissions due to energy consumption only, modelling of biological treatment requires consideration of biogenic CO_2, CH_4 and N_2O emissions. In terms of incineration, fossil and biogenic CO_2 emissions are to be modelled. For the sake of simplicity, N_2O emissions related to incineration are neglected. Emissions considered within modelling of landfilling are biogenic CO_2 and CH_4 emissions.

In order to model the emissions that are related to energy consumption or energy substitution, consequential result processes from the ecoinvent data bank are addressed. Thereby, the role of markets, legislation and the geographical background on the energy background must be taken into account, as they influence the emission factor related to electricity and heat consumption. ecoinvent data sets are also applied to model the avoided burdens that must be accounted for when including metals and plastics recovery into a scenario.

In order to keep the model flexible so that it can be adapted to varying background conditions, each process shown in Figure 5 was investigated with regard to its dependency on the background conditions shown in Figure 4. As a result, the parameters related to the feed material shown in Table 1 as well as the process parameters shown in Table 2

Table 1 rMSW related parameters that are relevant for modelling the GHG emissions

Physical properties	Bio-chemical properties	Type of material
PSD	TOC	HDPE
Metallic properties	Origin of organic carbon	PP
Magnetisability	Biodegradability	PET
	W	Fe
	NCV	Al
		Cu

Table 2 Parameters that are relevant for modelling the GHG emissions and that are potentially impacted by either markets and legislation or climate and geology

Process	Impact market/legislation	Impact climate/geology
Landfill	- $Type\ of\ landfill$ - η $LFG\ catchment$ - η $Energy\ recovery$	- $T\ air$ - $\phi\ air$
Energy sypply	- $EF\ Marginal\ energy$	- $EF\ Marginal\ energy$
Bio-stabilisation	- η $Oxidisation$ - η $Energy\ consumption$ - η $GHG\ transformation$	- $T\ air$
Bio-drying	- η $Oxidisation$ - η $Energy\ consumption$ - η $GHG\ transformation$	
Separation	- η $Product$ - η $Impurities$ - η $Energy\ consumption$	
Screening	- η $Overflow$ - η $Energy\ consumption$	
Shredding	- η $Energy\ consumption$	

were identified to be (1) relevant for the GHG emissions and (2) potentially influenced by the context. Correspondently, these are the parameters adaptable in the Model.

The Model is implemented using the software Umberto®. The parameters listed in Table 1 are modelled in a streamlined way. For mechanical processes, the Model applies transfer coefficients that are to be set individually for each modelled material group. Energy consumption is modelled specific to the throughput of mass. For plastics recovery, the transfer coefficients are further specified so that they address different properties of the target materials.

Modelling of biological treatment is more complex. As the moisture content of all material groups and the content of organic substances of some material groups change during biological treatment, these must be addressed by transfer coefficients instead of the total material groups. Biological stabilisation is modelled by assuming a fix duration and aeration rate, setting a specific degradation rate for different types of organic content and by setting a moisture content for the output material, which yields from water that is added during operation. Related to the degradation of organic carbon, emission factors are applied to calculate the CH_4 and N_2O emissions. The CO_2 emissions yield from the degradation of organic carbon and the CH_4 emissions.

Bio-drying is modelled by setting a moisture content that inhibits biological drying. Applying this moisture content, the duration of the drying process is calculated considering different modes of operation (e.g. temperature) as they are implemented in the plant according to which the process is modelled. The amount of carbon that is degraded and the related CO_2 emissions are derived from the amount of heat that is released by the biological activity, which again is determined from the difference in temperature of inlet and outlet air, the related amount of water that is evaporated and the aeration rate. Thereby, the impact of the atmospheric temperature on the drying process is taken into account. In addition to the mass balances of the biological treatment processes, the change in energy that the waste carries is calculated as well as the energy that is consumed by the processes. For flue gas cleaning the consumed energy is determined and the CH_4, which is transformed into CO_2, if supplied to an RTO unit.

Thermal treatment of both rMSW and RDF is modelled assuming that all organic substance is released with the flue gas and the organic carbon is transformed into CO_2. The efficiency of energy recovery (heat and/or electricity) is subject to settings by the user.

Landfilling is modelled applying the first order decay model. Thereby the approach as suggested by the United Nation Framework Convention on Climate Change [UNFCCC, 2012] is extended so that also the CO_2 emissions related to landfill gas emissions and, if applied, energy recovery thereof are determined.

For detailed information with regard to the modelling rules that were followed in the Model and related assumptions, e.g. concerning process efficiencies, reference is made to [CLAUSEN, 2015].

3 Results

Figure 6 shows an overview of the Model as implemented in Umberto®.

After developing the Model, exemplary calculations are conducted for selected scenarios and background conditions. The results are assessed applying the IPCC 2007 LCIA method. A fossil and a renewable energy background, a hot and dry and a cold wet climatic background and two qualities of rMSW (see Figure 7) are combined with scenarios that consider landfilling, incineration, mechanical biological stabilisation and mechanical biological drying as main treatment technologies. The settings of the scenarios are shown in Table 3.

Table 3 Settings of the investigated scenarios

	LF		MSWI	MBS				MBD		
	1.0	1.1	2.0	3.0	3.1	3.2	3.3	4.1	4.2	4.2
Biological stabilisation	-	-	-	×	×	×	×	-	-	-
Biological drying	-	-	-	-	-	-	-	×	×	×
Screen II	-	-	-	-	-	-	-	-	×	×
MSWI I	-	-	×	-	-	-	-	×	×	×
Fluidised bed furnace	-	-	-	-	-	-	-	-	×	×
MSWI II	-	-	-	-	-	×	×	-	-	-
Metal separation* I	-	-	×	×	×	×	×	×	×	×
Metal separation* II	-	-	-	×	×	×	×	-	×	×
Plastics separation	-	-	-	-	-	-	-	-	×	×
RDF refinery	-	-	-	-	-	-	-	-	×	×
RTO	-	-	-	-	-	×	×	-	-	-
LFG catchment**	-	×	-	-	×	-	×	-	-	×

* Includes Fe metals and NF metals separation

** 0% if landfill gas (LFG) catchment is not applied, 50% if LFG catchment is applied

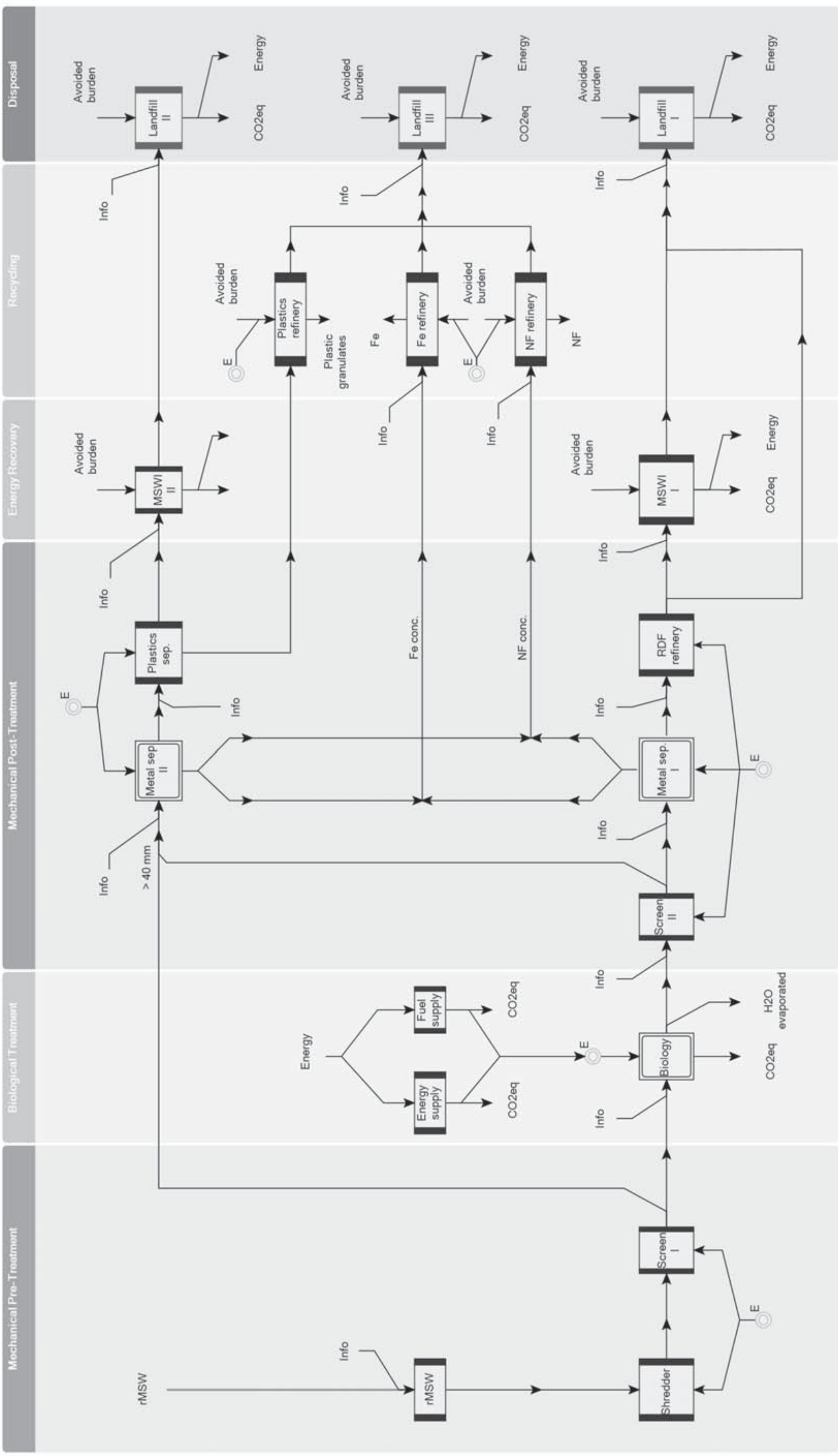

Figure 6 Generic flow chart of the Model implemented in Umberto®

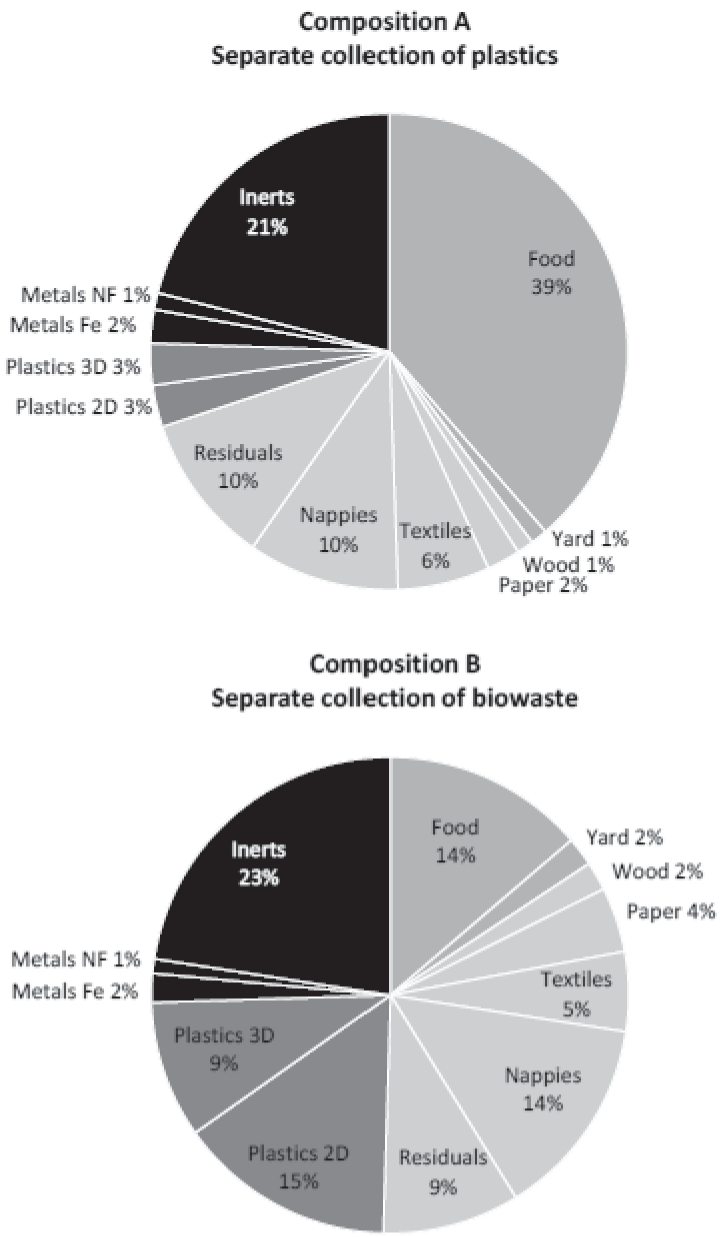

Figure 7 Composition of Material A and Material B applied for exemplary modelling

4 Discussion

The results of the exemplary calculations (see Figure 8) confirm that it depends on the background conditions, which of the technologies shows the best or worst climate performance. Thus, within a fossil energy background incineration and MBT combined with extended energy recovery are - from a climate perspective - favourable technologies, while MBT with landfilling of stabilised materials and, if applicable, energy recovery from biogenic carbon is to prefer in a renewable background. Given that the input material contains a low content of biodegradable substances, landfilling combined with energy recovery from landfill gas performs even better than incineration or MBT with fossil-rich RDF recovery. Notwithstanding its link to the energy background, the climatic background can be considered to be of minor importance with regard to its impact on the climate performance of rMSW treatment.

				Landfill		MSWI	MBS				MBD			
				no LFG catchment	LFG catchment & Energy recovery	Electricity & heat recovery	No energy recovery		Energy recovery from RDF		Energy recovery from RDF	Plastics recovery & energy recovery from refined RDF (fluidised bed furnace)		
				f=0	f=0.5	f=0	f=0	f=0.5	f=0	f=0.5	f=0	f=0	f=0.5	
Composition A	Fossil energy background	Dry	30°C	761	201	-575	291	-3	-228	-313	-538	-6	-256	a
		Wet	5°C	779	205	-575	296	-1	-225	-312	-541	-9	-259	b
Separate collection plastics	Renewable energy background	Dry	30°C	761	375	45	278	75	142	83	42	211	38	c
		Wet	5°C	779	383	45	282	77	145	84	41	212	39	d
Composition B	Fossil energy background	Dry	30°C	592	156	-716	355	18	-462	-545	-702	62	-222	e
		Wet	5°C	619	164	-716	362	21	-462	-544	-704	67	-223	f
Separate collection biowaste	Renewable energy background	Dry	30°C	592	292	460	338	109	461	396	455	312	116	g
		Wet	5°C	619	305	460	351	116	461	404	455	320	120	h
				1.0	**1.1**	**2.0**	**3.0**	**3.1**	**3.2**	**3.3**	**4.0**	**4.1**	**4.2**	

Figure 8 Net GHG emissions determined by the Model for the exemplary scenarios

Note: All contents of this paper are extracted from [CLAUSEN, 2015]. Direct quotations are not marked.

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Percolate anaerobic digestion plant as component of MBT Erfurt Ost

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Abstract

The GICON® Process, a two-phase, two-stage high solids anaerobic digestion process, has proven highly suitable for the processing of structurally-complex and often impurity-laden feedstocks such as organic wastes of municipal or commercial origin for the generation of biogas. Recently, this process was integrated into an existing mechanical and biological waste treatment facility in Erfurt, Germany, by modifying intensive composting boxes to produce percolate for fermentation in a GICON® Process fixed-bed methane digester. The application of the GICON Process enabled the exploitation of an energy source (the organic fraction of the feedstock) and the reduction of the residence time for the material in the composting boxes. GICON's experiences with the development and realization of this project, as well as observations on the performance of the plant will be discussed.

Keywords

Biogas, GICON Process, percolate, fermentation, scalability, organic waste, tunnel composting, control power

1 The GICON® Process

1.1 Origin and developmental path

Since applying for the basic patent for the GICON® Process in 2004, extensive developmental work arising from collaboration between GICON and BTU Cottbus and other partners has been carried out to prepare the process for market introduction. In 2007, the large-scale research facility in Cottbus commenced operation. It was built by GICON with financial support from the EU, the federal government and the State of Brandenburg. It was initially used for large-scale verification (up-scaling) of the functionality of the overall process. Since then, numerous client- or project-oriented trials have been carried out with original feedstock in order to be able to design future industrial projects with the greatest possible process certainty. Operated by GICON, the research facility is unique worldwide and the knowledge gained from its tests forms the basis of the process optimization which is carried out.

The range of feedstocks tested to date in the large-scale research facility stretches from energy crops and agricultural residuals to organic wastes and organic fractions from mechanical treatment of municipal solid waste (MSW).

With the establishment of the Biogas Production and Service Center in Cottbus, Germany, the first commercial plant using the second generation design was realized. The integrated biogas plant in this center produces approx. 900 kW biogas (total firing capacity), which is utilized off site. The plant is currently processing various energy crops and landscaping residuals; however, the plant has also been designed for the processing of source-separated organic waste.

Internationally, GICON established this type of biogas plant as a commercial-scale plant in North America for the treatment of organic wastes, including food wastes and yard wastes.

For the treatment of MSW, GICON, in cooperation with TUT Thüringer Umwelttechnik GmbH, erected an industrial pilot plant. For this application, existing intensive composting boxes at a mechanical and biological waste treatment facility (MBA) were modified and their range of application expanded to produce bioenergy in the form of biogas.

For all the applications described above, GICON was able to successfully prove the functional suitability and capability of the technology.

1.2 Technical approach

The approach of the GICON Process as a two-phase two-stage dry fermentation is the physical separation of the hydrolysis and methanogenesis in two different types of reactors (see Figure 1). The solid material, as with all batch systems, is loaded into large tunnel reactors. Within these tunnel reactors the feedstock is then irrigated with process water. The arising acidic rich process water is then removed from the reactor, filtered and pumped into a high-yield methane reactor, also called a digester.

An inert, fixed-bed host material is used for the methane bacteria in the methane digester, which provides for a large surface area in order to facilitate the best possible rate of reaction. This limits the acidity of the environment in both the discontinuously percolated "dry fermentation reactor" (percolator) and in the continuously-functional methane digester. This ensures that the methane bacteria are able to flourish in a functioning environment at all times. Furthermore, the requirement of renewing the biocenosis through the use of digestate from the previous batch is not needed with this process.

The water which leaves the methane digester has been neutralized through the production of biogas, and is pumped into a storage tank which, in combination with another buffer tank for percolate, supplies the percolation system of the percolators. In these buffer tanks two different fluids are stored, a neutralized and an acidic fluid that can be utilized when necessary in order to regulate the pH of either the percolator or the methane digester.

The regulation of temperature within the system is provided through heat exchangers on the piping that delivers the process water either to the methane digester or the percolators. If needed for either the hydrolysis or the methanogenesis, heating is available to each separately.

Virtually all methane bacteria in this process are stored in the methane digester. Furthermore, the amount of methane bacteria that is transferred to the actual feedstock is minimized, as it would interfere with the removal of the CO_2-rich hydrolysis gases. Also, the gas produced in the methane digester has high methane content. The optimal condition preferred in this system is one where the gases produced by hydrolysis and by the methane digester do not come into contact and do not mix, whereby ensuring the purity of one, and the complete removal of the other. However, as it is impossible to ensure that no methane production within the percolators during the entire cycle occurs, the GICON® Process percolators are designed as gas-tight containers.

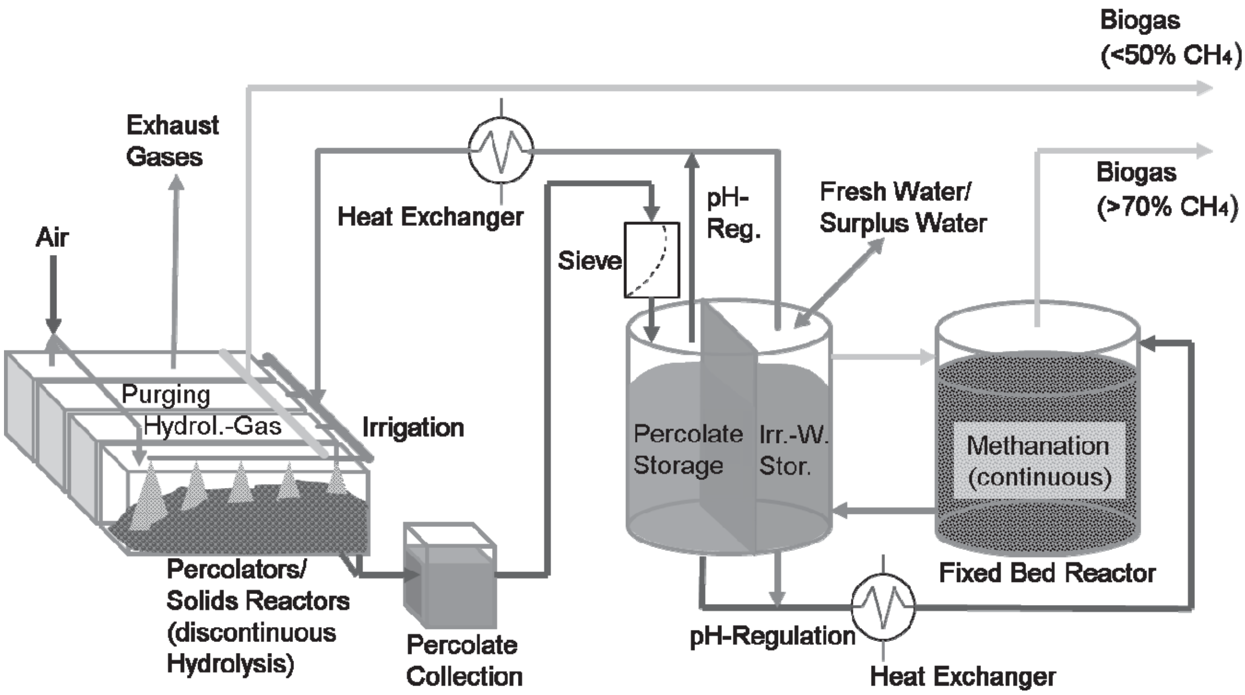

Figure 1 Schematic depiction of the GICON® Process.

1.3 Process suitability and benefits

The GICON® Process is most suitable for anaerobic treatment of structure-rich organic waste with high dissolved solids content and is comparably robust against impurities (plastic, glass, metal, etc.). The solid residuals are removed from the percolators after the hydrolysis in stackable condition allowing for post-treatment by composting without high effort required for interim preparation of the digestate.

The engineering design of the GICON Process allows for several additional benefits to the operator/owner. These include:

- Highly efficient yet stable process management, since the residence time of the feedstock in the system is decoupled from the methane formation process
- High system availability
- Safe handling of the most diverse of feedstocks through individually controlled percolators - simultaneous application of different feedstocks is therefore possible
- High flexibility regarding varying feedstock quality (seasonal adaptation to feedstock availability possible)
- Due to the decoupling of the two process steps, a integration of methanisation as a modification to an existing compost plant is possible

1.4 International expansion at industrial scale

The Harvest Energy Garden in Richmond, BC, Canada is the first industrial-scale high-solids anaerobic digestion (HSAD) plant in Canada and is also one of the largest HSAD plants in North America. The plant utilizes the GICON® Process. The plant processes up to 40,000 t/a of combined food wastes from residential and commercial sources and yard (lawn/garden) waste and generates approx. 1 MW of electrical energy (see Figure 2). Approx. 12,000 tons of compost is then after completion of subsequent aerobic composting.

GICON provided complete core process design, supervision of construction, supervision of mechanical and electrical installation and commissioning, and provides operational technical support.

Figure 2 The Harvest Energy Garden in Richmond (British Columbia), Canada.

The design of the plant was recognized by KPMG as one of the Top 100 infrastructure projects worldwide in 2012 and received the Award of Excellence from the Canadian Consulting and Engineering Awards in 2013.

2 Application of the GICON® Process at RABA Erfurt-Ost MBT

2.1 Initial on-site situation in 2008 at RABA Erfurt Ost

At the Erfurt Ost facility, a comprehensive waste treatment plant consisting of the following components was commissioned:

- Reception area with mechanical waste recycling and waste stream separation utilizing a trommel sieve (screen size 40 mm)
- Energy recovery plant based on a grate furnace for thermal treatment of the high calorific value fraction (> 40 mm)

- Biological treatment plant with intensive tunnel composting and enclosed post-composting for the fine fraction, which tends to be wetter and more organic-laden

The innovative overall concept of the system is characterized, among other things, by the fact that that the odorous and germ-contaminated exhaust air from the intensive tunnel composting is supplied as combustion air to the grate furnace in the energy recovery plant, which significantly reduces the costs for treatment of the exhaust air.

Figure 2 View of the RABA Erfurt Ost plant from the initial situation in 2008 (a photo montage of the percolate fermentation plant, then in the design stage, is included in the lower right portion of the photo).

2.2 Concept for integration of the GICON® Process into existing MBT waste treatment operations

The approach to developing the concept of percolate fermentation plant (PFP) came from the empirical fact that the intensive composting process in the RABA is, on the one hand, very energy intensive (especially for the supply of appropriate composting air), and on the other hand high temperatures were reached for several days during the intensive composting process which suggested the presence of a significant proportion of relatively easily degradable organic components. This seemingly available energy resource cannot be exploited from a pure composting process.

Essentially, the existing tunnel composting system in Erfurt is already equipped with similar components, such as appropriate boxes for a batch high solids anaerobic digestion plant, namely a sprinkling system utilizing process water (here originally intended for moistening of the material to be composted), a perforated floor and underlying basement for removing seeping liquid (percolate) and a percolate buffer tank.

As part of a cooperation between the operator, TUS, and GICON as a technology developer, the extent to which the energy contained in the organic components of the fine fraction could be utilized by the production of biogas was examined. To achieve this, it was intended that the existing tunnel composting system was to operate for a given period with minimal technical changes as a percolation system. While undergoing composting operation, the existing degradable organic matter is broken down by intensive contact with atmospheric oxygen to CO2 in the presence of increasing heat; a percolation process essentially operates without the addition of air but with increased application of water. Under these conditions, hydrolytic microorganisms provide for rapid degradation and removal of the organic portions into the aqueous solution.

As before, the percolate is then led to the percolate buffer tank, but instead of simply being recycled for the repeated moistening of the material bed in the composting tunnel, it is fed to a methane digester corresponding to the second stage of the GICON® Process. In the digester, the fixed-bed is inoculated with methanogenic microorganisms that almost completely convert the incoming organically-laden percolate into biogas. The clear separation process between hydrolysis and methane formation - one of the key features of the GICON® Process – is thus also strictly implemented in the case of percolate fermentation.

It was already known from previous operating experience with the two-stage biogas process that the "washout" of organic matter from the applied feedstock is very high, above all, during the first 4 - 6 days. During this time, the acidification by the hydrolytic microorganisms is still very intensive, which simultaneously suppresses the formation of methane in the percolation stage. Therefore, in order to "siphon off" the bulk of the energy from the organic fraction, the process conversion to percolation mode only requires a portion of the total residence time in the “composting” boxes. Thereafter, the intensive composting process will continue as before.

Through the process conversion, two positive aspects are envisaged:

1. Extraction of useful energy in the form of biogas and thus improvement of the overall energy balance of the MBA components in the RABA

2. Shortening of the overall process duration (percolation + intensive composting phase) in the composting boxes due to the faster removal of the organic component in the initial days compared to pure composting process

Since implementation of this concept required encroachment into an existing plant, a multi-stage inspection program of the realization phase was inserted to verify the conceptual approaches and minimize risks.

2.3 Experimental development of the concept

The concept for the PFP was experimentally tested at GICON's large-scale testing facility, beginning with analysis of the proposed feedstocks and then by performing test-fermentations at increasing scale.

Before starting the testing, an experimental methodology was developed and applied. Starting with “Level A” laboratory testing, the products to be fermented were analyzed with regards to their physical, chemical and biological properties. Thereafter, “Level B” testing was carried out utilizing standard digestion tests. The reactor size for the testing was adapted to the product to be fermented based on the homogeneity of the product. As a result, the biogas yields, which were obtained under standardized conditions for different fermentable products / product mixtures were compared and comprehensively evaluated. The second aim of the standard digestion tests was the identification of processes or substances which act as inhibitors to the fermentation and which may be reduced or eliminated.

Figure 3 The Level C testing system at GICON's large-scale testing facility in Cottbus.

As a result of the Level C barrel-testing, optimization of hydrolysis and methane reactor sizing and the associated achievable, predictable biogas yield was obtained on the basis of balancing of material flows (see Figure 3).

With level D pilot- scale container testing, a higher and final scale of functional capability was obtained. For this, a batch of approx. 15 tons of original residual waste (particle size <40 mm) was applied weekly over a trial period of 6 weeks at GICON's large-scale testing facility in Cottbus. As percolation boxes, the facility uses four 20-foot containers with appropriate technical equipment, which in scale virtually corresponds to the commercial scale plant.

With these results in hand, the design and engineering of a full industrial scale PFP as a demonstration plant could take place.

3 Realization of the Erfurt Percolate Fermentation Plant

Execution of the project took place in line with GICON-produced permit planning / application and detailed planning. After receiving official environmental approval, the percolate fermentation plant was constructed with GICON Bioenergie GmbH acting as general contractor (see Figure 4).

Figure 4 The GICON percolate fermentation plant at the RABA Erfurt Ost mechanical and biological waste treatment facility.

This plant was designed for electric power production of 250 kW via a combined heat and power generator (CHP). The produced electricity is fed to the power grid. The heat produced by the CHP is connected to the comprehensive district heating system for the RABA site.

4 Experiences and Insights from Operation of the Erfurt Percolate Fermentation Plant

The Erfurt PFP was commissioned in late 2011 with the first regular feed-in of electricity to the grid. Since that time, this expansion to the existing facility has been supplied with process water / percolate.

During the operating period from commission to the present, the quality and quantity of input materials was subject to significant fluctuations due to external constraints. As a general trend, it could be observed that the proportion of usable organic load decreased. This can be explained by an increased introduction of the "organic (brown) bin" in the collection area of RABA. This source separated organic waste is collected and supplied to other treatment facilities. Furthermore, material with above-average portions of construction and demolition (C&D) wastes or very fine, undersized inorganic and dissolvable sulfur compounds (such as plasterboard) was occasionally introduced. These facts naturally have an impact on plant operations - both technically and economically.

Firstly, the lower organic load led to lower biogas yields per unit of waste introduced. A permanent full-load operation of the CHP was thus no longer possible.

Secondly, a significant increase in H_2S formation was occasionally observed in the methane digester. This is due to the presence of additional sulfur sources in the feedstock, which, as a result of process-related acidic operation of the percolation stage, led to a carryover of dissolved sulfur compounds into the methanization stage. It could be positively noted that despite above average H_2S concentrations, no toxic impairment of methane formation was observed. However, the downstream gas recovery facility (CHP) had to be protected by a higher-quality, more efficient desulphurization unit.

Therefore, together with the TUT, it was determined to adapt the gas system to the changing conditions. For the initial expansion phase, a redundant and on-site renewable desulfurization unit was installed; for the second expansion phase, adjustment to a control power operational mode in response to the lower amounts of produced gas was achieved by installing an additional clean gas storage unit. The clean gas storage is connected downstream of the desulfurization unit, so that the biogas produced can be safely utilized by the installed CHP, and the installed CHP can be provided with biogas with a correspondingly high efficiency (optimal nominal load operation) during times of peak load.

5 Demonstrated Functional Capability / Advantages of the Percolate Fermentation Plant Concept

The Erfurt PFP demonstrates the accessibility of energy, which is still to be found even in low-calorific, sorted residuals which are present in residual waste processed in this mechanical treatment plant (i.e. originating from a collection area in which organic waste are collected separately). With this demonstration system, it has been shown that existing composting tunnels can be re-designed with only minor adjustments to the existing system for humidity control of decomposing material in order to obtain acid-rich percolate and to ferment it in subsequently-erected methane digester.

6 Summary and Areas of Application

This type of plant (PFP) is suitable for all composting facilities with solid and defined composting boxes that allow for modifications to the liquid circuit. Here, the degradable organic matter can be converted into usable energy that would otherwise be inaccessible for energy utilization. The advantage is that the complete construction of a biogas plant can be avoided and the existing locational advantages of a MBA, especially regarding the mechanical treatment and post-composting facilities, can still be utilized.

For optimal design of the required additional plant components, the efficacy of applying a multi-scale research program described in Section 2.3 has been proven. The individual scaling steps allow a high degree of planning security, especially for an intervention in an existing plant regime, without having to shut down the existing plant.

Furthermore, the PFP model can be adapted to many applications for which low-solid but organic-rich liquid streams are available or are produced.

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