The Biobattery
– Integrated Heat and Power Generation from Biomass Residues and Waste –

Matthias Franke, Fabian Stenzel, Samir Binder and Andreas Hornung

In the light of rising energy costs and ongoing discussions concerning climate and resource protection, the use of bio-waste can no longer solely be focused on the production of compost. Modern emerging technologies show the capability to make use of these resources as feedstock, both for material and energy production. Recent years have already seen the integration of anaerobic digestion units at multiple existing compost plants to exploit this potential [6]. A further benefit of the on-site production of energy is that it largely increases the self-sustainability of the whole facility in terms of heat and power, thereby lowering costs.

In comparison to the food competitive energy crops, energy production from bio-waste is not only widely accepted, but also seen as an opportunity to deal with partially problematic waste streams. It is estimated that in Germany alone 4 million tons of bio waste arise per year – excluding cuttings. About half of this amount is collected as a dedicated and separated waste fraction. The about one hundred German bio-waste digestion plants (Figure 1), produce approximately 1.3 million tons of digestate from this feedstock, producing a power output of around 85 MW [13].

However the large spread in dedicated bio-waste fraction amounts collected per capita in Germany varies dependent on the region between 32 kilograms per person per year to 152 kilograms per person per year [12]. This is largely due to the fact that only half of Germany's population is connected to a dedicated compost collection system [12]. There is therefore significant opportunity to increase the overall collected amount nationwide. In accordance with the German law on life-cycle management to connect all households to such a bio-waste collection system by 2015, it is estimated that the bio-waste amounts collected could increase by about two million tons per year to a total of four million tons per year [1, 2]. Digestate is mainly used agriculturally and will increase significantly in the wake of these regulatory changes. The number of bio-waste digestion plants are predicted to increase by 220 plants to a total amount of more than 300 plants to deal with the amounts [2].

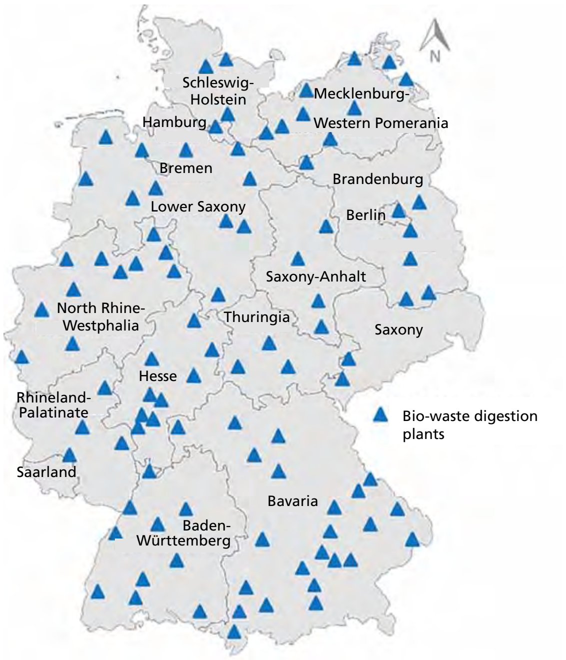


Figure 1:

Bio-waste digestion plants in Germany

1. Marketing structure of bio-waste digestion plants

Agricultural use is the sole and exclusive sales market for bio-waste digestates to date. Post-rotting and compost production is only carried out by five to ten percent of the plants [9]. An increase in the number of bio-waste digestion plants can lead to increasing competition with agricultural anaerobic digestion plants for the agricultural use of digestate. Kern et al. [11] assume that in areas where large quantities of liquid manure are already agriculturally used, additional use of digestate will be difficult. As part of the revision of the bio-waste ordinance extending testing requirements of bio-waste digestates were established. In addition, green cuttings are now also subject to the testing requirements.

2. Climate relevance of digestates

Digestate has on the one hand a great potential for the substitution of mineral fertilizers, thus contributing to resource conservation and reduction of greenhouse gas emissions. On the other hand, digestate sets free the climate-relevant gases ammonia, nitrous oxide and methane after completion of the fermentation process due to the open storage and spreading. Indeed, resulting emissions from open storage are estimated at up to ten percent of the amount of biogas produced [4, 19]. Mainly the liquid fraction of digestate contributes to relevant emissions of nitrous oxide and ammonia, while methane is classified as less relevant [3]. Although in many cases improper preparation and application of the digestate is considered the main cause of emissions [19], they cannot be completely avoided without further treatment steps.

3. Further use of digestates

The production of biochar is an alternative production approach to substitute the direct application of digestate and compost. Application of biochar can avoid the release of climate-relevant emissions. Carbon is stabilized through the carbonization process and can be stored in soil for an extended period. Due to the high adsorption capacity of produced biochar it can be used as water and nutrient store at the same time, thus increasing the nutrient use efficiency [14, 18]. Biochar can be produced by hydrothermal and pyrolytic processes.

Processes, based on gasification lead to a solid, coke-like residue. This, however, is characterized by increase amounts of poly-cyclic hydrocarbons and is therefore unsuitable as a soil improver or for fertilization purposes [16, 17].

Hydrothermal carbonization (HTC) is in principle suitable for the treatment of wet and limited biodegradable biomass, therefore also applicable for the further treatment of digestate. The substrates are treated in the aqueous phase at temperatures from 180 °C to 250 °C and pressures up to twenty bars. An overview of process variations and process parameters are documented by Quicker [16].

In pyrolytic processes the digestate is first dewatered, dried and finally fed to the pyrolysis unit. The process is carried out at temperatures ranging from 400 °C to 800 °C under oxygen free conditions. Due to the very different settings of both process variants, the produced biochars have different characteristics. Thus HTC coals produced at relatively low temperatures have a reduced degradation stability. Compared with composts these biochars can have an increased bioavailability and a conversion in the soil is enabled [8].

In contrast, biochars produced with pyrolysis show an increased degradation stability due to significantly increased carbon contents compared to the HTC-coal, and can therefore be used for a long-term carbon fixation in the soil. A technically already realized concept by the company PYREG is based on the drying and pyrolysis of various material flows at compost plants. Another Austrian concept realizes 450 EUR/Mg for biochar [5].

The Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT works at its premises in Sulzbach-Rosenberg on the biobattery concept. This concept makes it possible to store energy from renewable sources over different periods. A key component of the biobattery is the thermocatalytic reforming unit, which combines

CHP usable gas and oil as products with high quality biochar. It is therefore an ideal supplement for existing bio-waste digestion plants. The thermocatalytic reforming unit is based on intermediate pyrolysis principal, which uses temperatures between 350 °C to 450 °C [15]. Its uniqueness comes from an integrated reforming step with an in-situ produced catalyst (Figure 2). In this step the biomass is converted into a solid and a gaseous phase. In a following step, the gaseous phase is reformed for a second time to improve the product quality. Herein, the char is used as a catalyst to crack the long-chained hydrocarbons into smaller molecules. Finally a product separation takes place, yielding char, a separated oil and aqueous liquid phase, and gas.

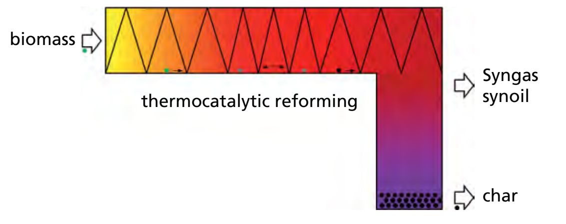


Figure 2:

Concept of thermocatalytic reforming

The RME-scrubber in the gas separation unit ensures that the gas is nearly free of particles. The main components of the gas are hydrogen – up to forty volume percent – carbon dioxide, carbon monoxide, nitrogen, methane and small fraction of higher hydrocarbons.

The oil shows average high lower heating values between 28 and 35 MJ/kg and a low acid numbers.

Both, the gas and the oil can be used in modified CHP engines. The company NEK GmbH in Kaiserslautern has modified such dual fuel CHP engines for the use of oil and gas from the intermediate pyrolysis.

In another application scenario, the produced oil and gas can further be applied in a bio activated fuel (BAF) reactor. This is a reactor, which is prefilled with waste plastics or glycerin where the hot gas and oil – still in gaseous phase – is directed through the reactor and interacts with the feedstock in such a way, that both the resulting gas and the produced liquid oil can be used on a dual fuel CHP. This has some advantages compared to the sole use of the thermocatalytic reforming unit. Firstly, the gas from the thermocatalytic reforming is cleaned when passing the BAF-feedstock. Secondly, the gas cracks the BAF-feedstock at much lower temperatures than would be possible without the activated gas from the thermocatalytic reforming unit.

As a result, a stable and storable fuel with high energy content is produced. Depending on the feedstock in the BAF-reactor and the chosen temperature profile either more gas or more oil can be produced.

The feedstock can vary from plastic waste (PE/PP) over waste oils to bio-oils.

With the stable and storable oil it is also possible to use it in decentralized power production plants for dealing with peak loads.

Figure 3: Pilot plant with BAF reactor

In the particular case of bio-waste digestion plants this application scenario is indeed of high relevance, as the received biowaste fractions are commonly contaminated with larger amounts of plastics. Currently these plastics are separated and have to be disposed of for a fee. By using the BAF technology, the plastics can be converted into a ready usable high-energy content fuel on site. A first demonstration plant was tested at Harper Adams University/UK in the years 2012-2013. Currently the plant is located at the Fraunhofer UMSICHT premises in Sulzbach-Rosenberg for further testing. This unit (Figure 3) has a throughput of thirty kilogram per hour biomass.

4. Integration of thermocatalytic reforming – BAF into bio-waste digestion plants

As already stated, the combination of thermocatalytic reforming and the bio activated fuel technology is ideal for the integration in bio-waste digestion plants (Figure 4).

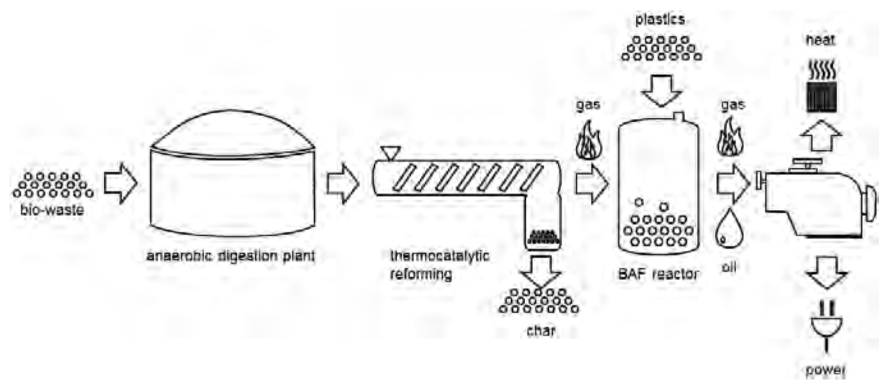


Figure 4: Integration of thermocatalytic reforming / BAF into bio-waste digestion plants

The dewatered and dried digestate from bio-waste digestion plants is fed into the thermocatalytic reforming stage, wherein the biopolymers are cracked. Subsequently, the gaseous phase from the thermocatalytic reforming is led through the BAF reactor which is filled with the plastic fraction. The generated gaseous and especially the liquid products can be stored or directly used in an adapted CHP engine to generate power and heat. The heat from the CHP can be used for the entire biogas system, for example for drying the digestate or for fermenter heating.

The produced char can be utilized both for energetic or material purposes, e.g. as a soil improver.

Overall, the efficiency of bio-waste anaerobic digestion systems is increased by the integration of the described concept and enables the on-site production of energy from renewables and the option to also store liquids and chars for on-demand use.

5. Outlook

The use of biochar as a soil improver does not lead to a release of methane, ammonia or nitrous oxide, in contrast to the direct use of digestate on farming land. The carbon fixation in the char and the long-term storage of CO_2 contributes to the further development of climate protection goals [10].

The interest in using biochar as a structural and soil additive is currently growing. Depending on the soil, biochar can contribute to a positive balance of nutrients and humus development and reduce the leaching of substances such as nitrate. Furthermore, the soil respiration can be improved [7].

Prof. Andreas Hornung is a member of the board of the International Biochar Initiative (IBI) which is committed to the sustainable use of biochar under social, economic and ecological aspects. The initiative supports the exchange and dissemination of information and facts concerning biochar.

The Sulzbach-Rosenberg branch of Fraunhofer UMSICHT is working on the realization of a demonstration plant for coupling an existing bio-waste digestion plant with described technology. A thirty kilogram per hour biomass feedstock plant is already available in Sulzbach-Rosenberg. A 300 kilogram per hour plant is planned to be operational at a customer site in early 2015.

6. Literature

[1] Alwast, H.: Auswirkung des Kreislaufwirtschaftsgesetzes auf Stoffströme und Behandlungskapazitäten in Deutschland, Wasser und Abfall, 13. Jahrgang, Heft 10, ISSN 1436-9095, 2010, S. 10-14

[2] Bergs, C.-G.: KrWG und Bioabfallverordnung – Konsequenzen für die Bioabfallerfassung und -behandlung. In: Wiemer, K., Kern, M., Raussen, T. (Hrsg.): Bio- und Sekundärrohstoffverwertung VIII, stofflich-energetisch, Witzenhausen-Institut, ISBN 3-928673-64-5, Witzenhausen, 2013, S. 107-120

[3] Cuhls, C.; Mähl, B.: Methan-, Ammoniak- und Lachgasemissionen aus der Kompostierung und Vergärung – technische Maßnahmen zur Emissionsminderung. In: Wiemer, K.; Kern, M. (Hrsg.): Bio- und Sekundärrohstoffverwertung III, stofflich-energetisch, Witzenhausen-Institut, ISBN 3-928673-52-1, Witzenhausen, 2008, S. 471-489

[4] Cuhls, C.; Mähl, B.; Clemens, J.: Emissionen aus Biogasanlagen und technische Maßnahmen zu ihrer Minderung. In: Thomé-Kozmiensky, K. J.; Beckmann, M. (Hrsg.): Erneuerbare Energien, Band 4, Biomasse und Biogas, Ersatzbrennstoffe, Solar- und Windenergie, Neuruppin, 2010, S. 147-160

[5] Dunst, G.: Die erste abfallrechtlich bewilligte Pflanzenkohle-Produktionsanlage Europas. In: Wiemer, K.; Kern, M.; Raussen, T.: Bio- und Sekundärrohstoffverwertung VIII, stofflich-energetisch, Witzenhausen-Institut, ISBN 3-928673-64-5, Witzenhausen, 2013, S. 349-354

[6] Franke, M.; Rühl, O.; Faulstich, M.: Integration von Vergärungsstufen in Kompostieranlagen. In: Bilitewski, B.; Schnurer, H.; Zeschmar-Lahl, B. (Hrsg): Müllhandbuch 4/09, ISBN: 978-3-503-09778-4, Berlin, 2009, S. 5420/1-5420/1

[7] Gerber, H.: Biomassepyrolyse mit Pyregreaktor, Ithaka-Journal, ISSN 1663-0521, 2009

[8] Humuswirtschaft & Kompost aktuell, Biokohle – Klimaretter oder Mogelpackung, Ausgabe 11/2011, Bundesgütegemeinschaft Kompost e.V., Köln, S. 3-6

[9] Humuswirtschaft & Kompost aktuell, Aktualisierte Statistik für Kompost und Gärprodukt, Ausgabe 4/2013, Bundesgütegemeinschaft Kompost e.V., Köln, S. 8-9

[10] Holweg, C.: Abschlussbericht zur Studie Biomasse-Pyrolyse, Machbarkeitsstudie zum Einsatz einer innovativen Technologie zur Bioenergieerzeugung mittels Pyrolyse mit niedrigen Staubemissionen und hohem CO_2-Reduktionspotential, Innovationsfonds Klima- und Wasserschutz badenova AG & Co. KG, Dezember 2010, S. 32

[11] Kern, M.; Raussen, T.; Funda, K.; Lootsma, A.; Hofmann, H.: Aufwand und Nutzen einer optimierten Bioabfallverwertung hinsichtlich Energieeffizienz, Klima- und Ressourcenschutz. In: UBA Texte 43/2010, FKZ: 370733304, ISSN 1862-4804, Dessau-Roßlau, 196 S.

[12] Kern, M.; Raussen, T.: Potenzieller Beitrag der Abfallwirtschaft zur Energieversorgung. In: Wiemer, K.; Kern, M. (Hrsg.): Bio- und Sekundärrohstoffverwertung V, stofflich-energetisch, Witzenhausen-Institut, ISBN 3-928673-56-4, Witzenhausen, 2010, S. 461-475

[13] Kern, M.; Raussen, T.: Biogas-Atlas 2011/12, Anlagenhandbuch der Vergärung biogener Abfälle in Deutschland, Witzenhausen-Institut, ISBN 3-928673-59-9, Witzenhausen, 2011, S. 283

[14] Libra, J. A. et al.: Hydrothermal carbonization of biomass residuals: a comparative review of chemistry, processes and applications of wet and dry pyrolysis, Biofuels 2(1), ISSN 1759-7269, 2011, S. 89-124

[15] Mahmood, A. S. N. et al.: The intermediate pyrolysis and catalytic steam reforming of brewer spent grain, J. Anal. Appl. Pyrol., 2012

[16] Quicker, P.: Thermochemische Verfahren zur Erzeugung von Biokohle. In: Wiemer, K.; Kern, M.; Raussen, T. (Hrsg.): Bio- und Sekundärrohstoffverwertung VIII, stofflich-energetisch, Witzenhausen-Institut, ISBN 3-928673-64-5, Witzenhausen, 2013, S. 325-336

[17] Reichle, E.; Schmoeckel, G.; Schmid, M.; Körner, W.: Rückstände aus Holzvergasunganlagen, Müll und Abfall, Jahrgang 42, Heft 3/2010, ISSN 0027-2957, S. 118-126

[18] Steiner, C.; Glaser, B.; Teixeira, W. G.: Nitrogen retention and plant uptake on a highly wethered central Amazonian Ferrasol amended with compost and charcoal, Journal of Plant Nutrition and Soil Science, 171, Band 6, 2008, S. 893-899

[19] Umweltbundesamt: Präsentation Workshop zum Projektabschluss der Projekte *Ermittlung der Emissionssituation bei der Verwertung von Bioabfällen* (FKZ 20633326) und *Ermittlung der Emissionssituation bei der Vergärung von Bioabfällen* (FKZ 370944320), Dessau-Roßlau, 2011

Erneuerbare Energien

Erneuerbare Energien, Band 1

Herausgeber:	Karl J. Thomé-Kozmiensky
ISBN:	978-3-935317-44-3
Erscheinung:	2009
Gebundene Ausgabe:	329 Seiten mit farbigen Abbildungen
Preis:	30.00 EUR

Erneuerbare Energien, Band 2

Herausgeber:	Karl J. Thomé-Kozmiensky Michael Beckmann
ISBN:	978-3-935317-43-6
Erscheinung:	2009
Gebundene Ausgabe:	713 Seiten mit farbigen Abbildungen
Preis:	40.00 EUR

Erneuerbare Energien, Band 3

Herausgeber:	Karl J. Thomé-Kozmiensky
ISBN:	978-3-935317-54-2
Erscheinung:	2010
Gebundene Ausgabe:	366 Seiten mit farbigen Abbildungen
Preis:	40.00 EUR

Erneuerbare Energien, Band 4

Herausgeber:	Karl J. Thomé-Kozmiensky Michael Beckmann
ISBN:	978-3-935317-55-9
Erscheinung:	2010
Gebundene Ausgabe:	393 Seiten mit farbigen Abbildungen
Preis:	40.00 EUR

Erneuerbare Energien, Band 5

Herausgeber:	Karl J. Thomé-Kozmiensky
ISBN:	978-3-935317-64-1
Erscheinung:	2011
Gebundene Ausgabe:	353 Seiten mit farbigen Abbildungen
Preis:	40.00 EUR

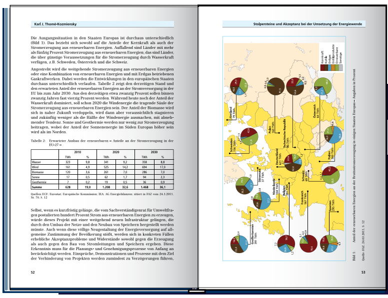
Erneuerbare Energien, Band 6

Herausgeber:	Karl J. Thomé-Kozmiensky Michael Beckmann
ISBN:	978-3-935317-65-8
Erscheinung:	2011
Gebundene Ausgabe:	417 Seiten mit farbigen Abbildungen
Preis:	40.00 EUR

115.00 EUR
statt 230.00 EUR

Paketpreis

Erneuerbare Energien, Band 1 • Erneuerbare Energien, Band 2 • Erneuerbare Energien, Band 3
Erneuerbare Energien, Band 4 • Erneuerbare Energien, Band 5 • Erneuerbare Energien, Band 6



Bestellungen unter www.vivis.de
oder

Dorfstraße 51
D-16816 Nietwerder-Neuruppin
Tel. +49.3391-45.45-0 • Fax +49.3391-45.45-10
E-Mail: tkverlag@vivis.de

vivis
TK Verlag Karl Thomé-Kozmiensky