1. Introduction

The objective of the federal government is the reduction of greenhouse gas emissions in Germany by 40 % as compared to 1990, by 2020 by the latest. An objective that can only be achieved through a sustainable economic system – saving energy, generating renewable energy and more efficient use of energy. Waste management and in particular that of organic waste can contribute significantly to the achievement of the set resource, energy and climate targets.

In recent decades much has changed in German waste management. A mere disposal contractor has become an expert for recycling and utilisation. With an excellent carbon footprint the German waste disposal industry is a pioneer in the implementation of climate protection objectives. This is documented in the study *Klimaschuttpotenziale der Abfallwirtschaft (Climate Protection Potentials in Waste Management)*[1]). The study looks at potential in recycling and the conversion into energy of the relevant waste fractions. The results prove that the German waste industry already contributes significantly towards the reduction of national greenhouse emissions. And it presents opportunities to reduce the emissions in Germany even further.

Against the background of rising prices for fossil fuels there is not just a substantial socio-economic pressure, but the economic evaluation of the use of waste for the generation of energy is also getting more and more important. For many years now residual waste has been used for the production of energy in waste incineration plants, which has contributed significantly to the conservation of resources.
A further possibility here is the use of separately collected organic waste not only for the production of compost or humus for the improvement of soil, but also for the production of biogas. The zymosis/fermentation of separately collected organic waste however is technically and biologically more complex and therefore also more cost-intensive as compared to mere composting. An economic adjustment of composting to fermentation has been observed over the past few years. In addition to the operating costs the proceeds of the net energy revenue of fermentation plants are gaining more and more significance. This becomes even clearer, as the total energy contained within biogas is used more efficiently and the energy concept associated with the fermentation plant is presented in a commercially more viable way.

The plant technology for dry fermentation of organic waste has been further developed over the past years and can be seen as largely well-engineered. If one focusses on this and considers the price increases of fossil fuels that can be expected in the future, the combination of recycling of organic waste and its conversion into energy is only a logical step. One opportunity that joins ecology and economy closer together and – considering the total potential of organic waste in Germany – contributes significantly to the reduction of greenhouse gases.

2. Initial Situation in Berlin

BSR (Berlin City Cleaning Services) is a state owned public-law institution and is responsible for the waste removal and town-cleaning of an area of 890 km² with 3.4 million inhabitants. The collection (400,000 provided waste bins) involves approx. 19 million emptyings per year. As a service to our citizens (approx. 2.8 million customer visits per year) we provide 15 recycling depots and 6 collection points for hazardous waste, which receive about 150,000 tons of waste. At the recycling depots the waste is separated into about 20 different recycling materials and 35 pollutant groups. Three of those are waste fractions of organic nature. These are the fractions waste wood, tree and shrub cuttings as well as fallen leaves. At the beginning of a year we collect almost 400,000 Christmas trees in Berlin. A special service is the collection of bulky waste directly from the citizens’ home. The cleaning of streets and pavements comprises approx. 1.5 million kilometres, about 4.9 waste bin emptyings as well as 260,000 gullies to be cleaned. The fallen leaves collected throughout the year amount to a volume of about 100,000 m³. Added to all this is the removal of illegal waste dumping and the extensive winter service (removal of ice and snow, gritting) that presented a particular challenge in the winter of 2009/10 in Berlin.

In the past the potential of these different waste fractions was not primarily considered for organic waste fermentation and gas utilisation. This has changed in the meantime. Based on the resolution of the Berlin House of Representatives of 6 December 2007 [2], the BSR is obliged to significantly increase the ecological value of the separately collected waste though conversion into energy. On 20 August 2010 this obligation to build a fermentation plant was substantiated in the waste management concept of the State of Berlin [3]).

In the sovereign area the BSR is funded by tariff-based fees that the BSR is levying directly from the citizens, or more exactly, from the property owner. The BSR is basically a guarantor for safe waste disposal and cleanliness in the federal capital. The company is regularly subjected to a benchmarking process. The comparison of fees with other German cities is essential in this process. In the past few years we succeeded to realise the most reasonable specific waste fees.
3. Biogenous Waste

The BSR can use the potential of biogenous waste from different fractions.

In total, the BSR has separately collected almost 120,000 tons of biogenous waste in 2009 – of which approx. 115,400 tons are fallen leaves and organic waste. The 120,000 tons equate to 35 kg per inhabitant.

![Figure 1: Development of Biogenous Waste Volume of the BSR](image)

4. Separately Collected Organic Waste

Since 1996 the BSR is collecting organic waste from private households. The so-called brown bin is obligatory to all households. The separate collection was increased again to almost 60,000 tons in 2010. Approx. 83 % of all households take part in this separate collection.

At the moment there are tests campaigns to find out if this volume can be further increased. In the political discussion about the further increase of the separate collection there was a demand for the introduction of fermentation and the complete stop of composting. During the discussion the BSR explained the difference between fermentable and non-fermentable waste. We have established the definition that waste has to produce at least 80 m³ crude gas during fermentation, otherwise the fermentation would require the use of energy and would not make sense economically.

In the light of these facts it was deduced that the first fermentation plant in Berlin has to have a capacity of 60,000 tons of waste on the input side and should generate an average amount of gas of 100 m³ per ton of waste.

While the commissioning for the larger one of the two inner city plants has been concluded, several measures are adopted simultaneously to increase the separately collected amounts of organic waste in Berlin. Once the volume has reached a sufficient level the second plant will also be built.
5. Plant and Process Engineering in the Biogas Plant West

In the 4th quarter of 2009, after an extensive Europe-wide tendering process the contract was awarded to the bidding consortium STRABAG Umweltanlagen GmbH, Dresden, and STRABAG AG, Berlin, for the first plant.

The project comprises the construction of a dry fermentation plant in Berlin-Spandau with the following areas:

- Vehicle weighbridge
- Delivery and preparation of the waste
- Fermentation plant with full flow drainage and fugat treatment
- Aeration of the hygienised and drained digestate
- Biogas collection, storage and conditioning to the quality of natural gas
- Collection of exhaust air and its purification via a two-line bio filter system

The access to the plant will be from the street *Freiheit* and leads via the access road to the weighbridge area.

After registration of the waste volume on the weighbridge the delivered waste will be stored in the designated storage area.

The delivery area is separated into three gates, equipped with air curtain and air wall respectively for atmospheric separation. The gates can be reached via a multi lane ramp. The delivery vehicles back up towards each open gate after turning around on a sufficiently big platform. The recessed flat bin has a depth of 2 meters from the ramp level and is on the same level as the rest of the reception and preparation hall. The bin management is carried out by mobile technology (wheel loader). The material is brought to the preparation area with wheel loaders. A flat bin system is envisaged for the waste reception, because this storage technology is simple, easy to maintain and easily accessible. During delivery the driver of the wheel loader can already start on the bin management – allocation, inspection, loading. The access for articulated trucks for unloading/delivery or outward transfer from the flat bin area takes place through a level access in a separate area of the delivery hall.

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**Figure 2:**

Prospective Utilisation of Biogenous Waste

**Diagram:**

- **Biogenous Waste**
  - non fermentable
  - fermentable
  - Organic Waste *(BIOGUT)*
  - Garden and Park Waste from Recycling Sites
  - Fallent Leaves
  - Composting
  - Wood: biomass power plant

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Figure 3: Process Flow of Biogas Plant

Figure 4: Floor Plan of Strabag Umweltanlagen GmbH
The preparation line that works like a sieving macerator will be loaded with the wheel loader via the dispenser with integrated bag opening function. The organic waste is then forwarded to the screening area on conveyor belts. The polygon construction of the drum screen makes the screen plates easily accessible and exchangeable. The polygon shape also enables a more efficient screening because of a better circulation of the material to be screened. The drum screen is attached to the waste air system of the hall. The screening separates the material flow into two fractions (the mesh size is 55 mm). The oversize material is now fed via a conveyor to the extraction of ferrous materials and an additional maceration process in a 2 wave shredder. This additional maceration can also be bypassed. Through this bypass which can also be opened for material flow discharge, the material is returned to the flat bin area. The waste amount to be transferred out of the sieving macerator cycle depends on the input characteristics (e.g. impurities, plastics sticking to damp material). The shredded material overflow is then moved back into the polygon drum screen. This screened material will also undergo a separation process from ferrous materials and is put into interim storage before fermentation.

![Diagram of interim storage](image)

**Figure 5:** Diagram of interim storage

The interim storage before the fermentation process is equipped with an aeration function following the principal of pre-rotting. Its primary function is the decoupling of the plant processes of preparation and fermentation, but also the correction and staggering of the hourly material flow, so that the daily waste volume can be fed gradually into the dry fermenter during the course of the day. In addition, this enables automatic feeding of the fermenters at weekends or on bank holidays. Each of the three bins has a capacity of approx. 135 m³ and is equipped with a hydraulic push floor system that enables an automatic discharge and therefore and automatic feeding of the reactor. Furthermore this storage also helps to pre-heat the reactor input and therefore reduces the heat requirements in the anaerobic area. Especially during the colder months of the year this is beneficial for the homogenising of the biogas production. The waste heat that develops from converting the biogas to natural gas quality is used and fed permanently into the concrete floor of the interim storage area through tubes, similar to under floor heating to support the self-heating of the material. Ventilators on each of the bins ensure the heat transport through the material through convection. The interim storage is encapsulated and connected to the waste air system. If necessary, it can be emptied into the reception area with the conveyor system.
Two LARAN – dry fermenters TF 2200 with a gross volume of 2,399 m³ are used. This process is a one-step, thermophile dry fermentation procedure. The fermenters work in a quasi-continuous plug flow. They are manufactured flat from special concrete as concrete chambers. Solid, laterally arranged agitators prevent the formation of swimming or sinking layers and facilitate the release of gas. Each fermenter also has all safety and gas-related components in accordance with the applicable statutory provisions. After discharge from the interim bin the fermenter input is weighed with a belt weigher and is then transferred on a distributor belt to one of the two plug screws which push it into the reactor. The material in the plug screw seals the reactor and prevents air flowing into the fermenter.

The material is passing through the reactor in a quasi-continuous plug flow and – depending on the dry matter content – ensures a long defined retention time within the reactor. To be able to meet the hygienisation requirements of the organic waste regulation, the fermenter is operated thermophilic (>55 degrees C). The thermophilic operation combined with the plug flow feature ensured the certification for the hygienisation of the reactor in accordance with the Bundesgütegemeinschaft Kompost e.V. (Federal compost association). The average hydraulic retention time lasts approx. 23 days. This results in a volume of organic dry matter of about 9 kg organic dry matter/m³/d. The fermenter has 8 laterally arranged agitators. The agitators consisting of solid stirring paddles dip very slowly and in intervals into the digestate suspension. This prevents the formation of swimming layers and splits up any layers that have formed already, which improves the release of gas. The agitators are controlled by a computer and are chronologically staggered. The right/left rotation of the agitators prevents an impact on the plug flow. The fermented substrate is discharged contact-free, and therefore with low wear and tear and low interference, at the end of the fermenter though generously sized siphons with a vacuum system. A vacuum pump creates a vacuum in the digestate extraction tank. By opening the reactor extractor valve the digestate is sucked into the tank. In the next step the compressor applies pressure to one of the two containers and the material is pushed though the tubing into the receiver containers of the screw presses.

The receiver containers are positioned directly above each of the screw presses so that the digestate flows directly from the container into the press. The dehydrated solid phase with a dry matter content in the press cake of approx. 35 – 40 % falls on the conveyor that is
arranged under the drainage aggregates. The entire dehydrated material will then be put into a box for further handling by a wheel loader for aerobisation. The fluid phase of the first dehydration step is led into a residual water tank. The residual water tank is equipped with agitators to prevent the segregation of solid materials and water in the suction area of the pump. The decanter loading pump sucks the residual water from the tank and loads the decanter for the fugat treatment. The fugat quality/process water quality is optimised without a flocculant to a dry matter residual value of < 15 %. To this end only a partial flow dehydration is undertaken in the form of a fugat treatment that ensures the necessary amount of process water for the fermenter recirculation and to adjust the dry matter value in the tanks. In this way only as much residual water is decanted as is needed for the recirculation into the fermentation and to reach the residual water quality necessary for agricultural utilisation. The residual process water is stored in two two-day-storage tanks that are emptied with a pump into tank trucks. Due to the storage time and the characteristics of the medium the storage tanks are fitted with the required safety equipment and heat insulation and are connected to the internal biogas network.

Because the solid digestate is only slightly interspersed with structured material and therefore has a smaller pore volume for normal ventilation – as it is usually the case during composting – the aeration is only conducted with a surface load of 1 ton/m², which is the equivalent to an expected density of just under 1 ton/m³ in a bulk height of about 1 metre. The retention time to reach an assured aeration/stabilisation is at least seven days. The objective of the aeration is a specific treatment of exhaust air and the guarantee of solid digestate removal with as little odour as possible. The six rotting boxes are loaded with a wheel loader. The aeration is guaranteed through the feed of large amounts of air and additional heat. The moisture saturated exhaust air passes through a blower into the exhaust air system.

The biogas escaping from the large substrate surface in the horizontal dry fermenters and from the fluid fermentation product storage flows – due to its inherent pressure – through the gas dome at the fermenter head and through the preliminary cleaning with integrated condensate separation. The biogas then flows through stainless steel pipes into a double membrane gas storage tank with a volume of approx. 2, 150 m³ positioned on an open air site. This size allows for a temporary storage of the raw biogas for about 2 hours. After desulphurisation the biogas is cooled or dried, as this is necessary for the further treatment of the biogas when it is converted to natural gas quality or used internally for the generation of process heat in a furnace. For further utilisation the biogas from the gas storage tank is forwarded via a booster fan to the consumers, the gas treatment and the heat furnace. The cleaned raw biogas is treated in a gas treatment plant to have a methane content of at least 96 % CH₄ and is then passed for pressurising, caloric value adjustment and odorising to the network operator Berlin-Brandenburg.

The fermentation plant has an extensive exhaust air treatment system with bio filter and an upstream acid washer. The bio filter is a closed, dual in-line filter. The exhaust air is then discharged through a chimney. The plant meets all statutory requirements and additionally the irrelevance criteria of GIRL (Geruchsimmisions-Richtline, odour emission directive).

6. Conversion of Waste into Energy at the Biogas Plant West

The ongoing gas dispute between Russia and Ukraine and the harsh winter of 2009/10 have shown once more how much Germany depends on energy imports. This is a further reason why the federal government supports renewable energy.

The framework conditions for the biogas feed were redefined through the implementation of the integrated energy and climate programme of the federal government. The change in the gas network access act (GasNZV, revised in September 2010) that came into effect on 12 April 2008 defined as an extension target the development of a potential of around
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6 billion m³ of biomethane until 2020 and about 10 billion m³ until 2030 to be fed into the gas network.

Partner of the BSR for the biomethane feed is the local distribution network provider Berlin-Brandenburg (NBB). It is a spin-off company of the net operator GASAG (Berliner Gaswerke Aktiengesellschaft) and EMB (Erdgas Mark Brandenburg GmbH) and was founded on 1 January 2006. As one of the largest local distribution network providers in Germany it is the task of NBB to guarantee the technical operation of the gas supply in the region of Berlin and Brandenburg. The main tasks are the maintenance and development of the necessary technological infrastructure and the implementation of the technically safe operation.

Figure 7: Biogas Utilisation at BSR

The gas network access act regulates the responsibilities and cost distribution between the feeder and the network operator and defines for the first time priority access for biomethane into the gas network. According to paragraph 41c of the gas network access act (GasNZV) the network operators are obliged on all levels to connect plants with priority to the gas network. The cost for the network connection is split between the network operator (75 % share) and the biogas feeder (25 % share). According to paragraph 41c GasNZV the network connection consists of the connecting pipeline (up to 10 km), the gas pressure control measurement unit, the compressor unit and the unit for the calibrated measurement of the biomethane to be fed into the network. The network operator is the owner of the network connection and bears the cost for maintenance and operation. According to paragraph 41d, section 1 GasNZV, the network operators have to conclude feeding and exit agreements primarily with transport customers of biomethane. At the same time the network operator is responsible for all economically reasonable expenditures to optimise the technical capacity of the network. For Biogas transport customers the GasNZV provides special provisions for an extended settlement of imbalances in biogas accounting. For the purpose of the settlement of imbalances the transport customer is assigned to a designated biogas accounting grid. Within this accounting grid the different amounts have to be balanced. This is done through a so-called balancing account. The network operator is obliged with regard to pure biogas accounting grids, to offer a flexible scale of 25 percent (in terms of the amount of gas fed into the network) that is calculated over an accounting period of 12 months. Here, the cumulative deviation between the energy amount of the biomethane fed into the network and the exited energy equivalents is balanced. Positive
When the biogas is used as fuel, the diesel consumption of the collection can be reduced by closing balances for the biogas feeder can be carried over into the next accounting year. If the flexible scale has actually been made use of, the feeder has to pay a flat fee of 0.1 €/kWh to the network operator. Additionally, subject to the gas network charge act (GasNEV), the network operator has to be reimbursed for the transport services within the gas network. On the other hand it has been stipulated that in case of a decentralised feeding of biogas into the network, the networks upstream to the feeder will not be utilised and therefore will avoid network charges. These avoided network charges are reimbursed to the biogas feeder at a rate of 0.7 €/kWh by the network operator, into whose network the gas is fed. With the above mentioned regulations the biogas transport customer is in a better position in the end than a natural gas transport customer, so that the biogas can be fed into the network at an economically competitive price. These regulations also take into account that biogas is produced by a microbial process around the clock, whereas the use of energy is generally subject to variations throughout the day and even more so throughout the different seasons of the year. The cost relief for the Biogas feed for connection, remuneration for avoided network costs, gas quality and the extended balance adjustment results in expenses for the network operator. These expenses can be compensated by specifying them as acknowledged network expenses and therefore can be transferred to the gas end user.

The essential quality requirements for gases within the public utility networks are stipulated in the white papers of the Deutsche Vereinigung des Gas- und Wasserfaches e. V. (DVGW, German association of gas and water authorities). The GasNZV refers to the white papers G 260 (gas quality) and G 262 (use of gases from regenerative sources in the public gas network). The feeder has to guarantee the gas quality stipulated in these white papers, whereas the network operator is responsible for odourising, fuel value, and the pressure level.

The energy is used as a substitute for fossil fuel for our own vehicle fleet. As the BSR is fuelling the vehicle fleet with the energy equivalent derived from the biomethane, the company will extend its vehicle fleet by more than 100 further natural gas-powered waste collection vehicles in the course of the investment for replacements. This will result in a CNG vehicle inventory of about 150 trucks. Additionally, two new high performance gas fuelling stations will be installed on our sites.

The amount of biogas provided to the BSR by the biogas plant equates to about 2,000 tons of natural gas and 2.5 million litres of diesel equivalents per year, according to conservative estimates and taking the operating energy into account. The BSR has ecologically and economically examined the various utilisation options for the generated biogas, with due consideration of the integrated site specific parameters. Therefore it was decided that the use as fuel for our own waste collection vehicles would be most beneficial.

The main reasons for that decision are:

- A marked reduction of noise from the gas powered engines combined with considerably improved emission values (see Euro VI), which is of major environmental benefit in the inner city of Berlin.

- The continuously rising costs for diesel and natural gas, which when substituted by biogas results in substantially reduced collection costs.

When the biogas is used as fuel, the diesel consumption of the collection can be reduced by close to 2/3 and the carbon dioxide-emissions of the vehicle fleet can be reduced by more than 6,000 tons of carbon dioxide per year. The generated amount of bio fuel is so large that not only the fuel requirements of the organic waste collection vehicles can be covered, but can in future also fuel other waste collection vehicles for household waste. Besides that the
gas fuelled vehicles are a lot quieter, and the actual noise reduction of about 2 dB equates to a perceived reduction of about 50%. The particulate emissions are also very low so that there will be a substantial improvement compared to the existing vehicles.

In other plants the biogas is converted into energy on site, as the generated biogas is used in an affiliated combined heat and power plant. Many such plants however have a low efficiency rate and utilise only a small part of the energy contained in the biogas, as the thermal energy generated by the cogeneration plant in addition to the power can often not be utilised due to missing heat sinks. The heat is emitted via coolers into the surrounding atmosphere. If a plant has no provisions for heat utilisation, the raw biogas can be cleaned and fed into the gas network, which increases the efficiency of the plant by about 80 percent. This is where the preparation of the raw biogas to a natural gas-like product and the feeding into the gas network comes in. The energy equivalent of the biomethane can then substitute the whole range of uses of fossil natural gas elsewhere. The advantages of the use of the gas network are clear. On the one hand, the bio methane production can be decoupled from the use and the network acts as a kind of storage, on the other hand the network constitutes a credit function through the rules of the flexible scale for the biogas accounting grid.

7. Climate Protection

Even after the climate summit in Copenhagen, Berlin's senator for the environment, Katrin Lompscher, advocates adhering to the climate targets. As part of the further development of the energy concept it is planned to reduce the carbon dioxide emissions in Berlin by at least 40% until 2020 as compared to 1990.

The BSR was the first company to conclude a cooperation agreement for the reduction of greenhouse gases with the State of Berlin. As part of this agreement the BSR has pledged to further reduce the emissions of gases that are damaging to the environment, and to create regenerative energy to reach this target. This is mainly achieved with the waste treatment plants and the landfill coverage. Therefore the BSR has updated its concept for the utilisation of organic waste and prepared the construction of two biogas plants. Additionally, we are also implementing climate protection potential for the vehicle fleet and properties.

A recent publication [4] of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU) in cooperation with the Federal Environment Agency (Umweltbundesamt, UBA) illustrates the benefits of fermentation for the climate. The conversion of organic waste into energy in combination with recycling of the plant nutrients contained within the organic waste can be described as, high-quality utilisation. This publication also depicts a pioneering illustration that compares the essential benefits and disadvantages of composting and fermentation with regard to the carbon dioxide equivalents.

This clearly shows the positive effect of fermentation compared to composting:

But even so, other environmental effects should not be forgotten. Many waste fractions make an important contribution to other environmental aspects, such as organic and biodegradable waste, which when collected separately, protect phosphor resources. The current discussion on climate change often only focusses on energetic potential. Specific benefits to the soil resulting from the use of treated organic waste are often marginalised or not discussed at all. This is because it is difficult to combine different concepts, such as the substitution of fossil fuels on the one hand and the impact of compost on the fertility of the soil on the other hand, in one coherent ecological evaluation scheme. Exactly that however was the task set by the Association of the Humus and Soil Industry (Verband der Humus- und Erdenwirtschaft, VHE) of EPEA (International Environmental Research Hamburg) [5].
The study also establishes the ecological benefits of composting and fermentation of organic waste and justifies the meaningfulness of the separate collection and recycling with the fertilisation effect of the generated products. The recirculation of the digestate into the ground for example leads to a credit regarding the dioxide sequestering of approx. 6,000 tons of carbon dioxide-equiv. per annum (gross).

8. Conclusion and Outlook

Communal waste removal services have to meet today’s environmental and social demand for reduction of greenhouse gases and the need for sustainable resource management. In the process, the transparency, continuity and reliability of the necessary political economical, environmental and technical conditions for the further development of biogas production are obviously significant. The cost of energy will rise steadily in the future, which is an essential factor for the decision-making process. The use of waste for generating energy is therefore gaining an increasing importance for the strategy of the BSR. With the updated plant concept of the BSR for organic waste, especially for the separately collected biodegradable waste (BIOGUT), it will be possible to minimise increases of charges, if fermentation can be achieved at a reasonable cost and therefore reduce transport and diesel procurement costs, while it will also enable us to extend the value chain and increase the BSR’s production of green energy.
Moreover, we can take advantage of the opportunity for reduction of carbon dioxide and methane emissions by recycling the digestate to contribute further to the circular economy and climate protection. With this plant concept we have successfully combined the logistics cycle with the organic material cycle in an ecologically sound way.

9. Bibliography


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