The transformation of blackwater, lawn cuttings and grease trap residues into biogas and fertilisers in neighbourhood of Hamburg – an integrated approach on the territorial scale

Körner Ina[1], Hertel Saskia[1], Deegener Stefan[1]
(1) TUHH, Hamburg University of Technology, 21073 Hamburg, GE

Abstract
In *Jenfelder Au*, a combination of renewable energy and innovative wastewater systems is being introduced. The blackwater will be supplied to a 900 m³ fermentation plant. The anaerobic treatment of blackwater is energetically advantageous compared to standard wastewater treatment, as the latter is very energy-intensive. Significant improvements of biogas yields can be expected through the addition of co-substrates since they contain a considerably higher content of easily fermentable substances. Another advantage is that lawn cuttings, which are a bioresource with a still unexplored potential, can be utilised. Furthermore, nitrogen and phosphorus contained in the bioresources are not lost, as would be the case in conventional treatment but can be transformed into mineral fertilizer. The strategy regarding the implementation of such an efficient bioresource utilisation in *Jenfelder Au* is presented hereinafter. It focuses on inventories, and briefly discusses issues of anaerobic fermentation and digestate utilisation.

Introduction
Fossil raw materials are becoming scarcer. This pushes a change towards an economy that is based on bioresources. Sources for secondary and tertiary bioresources in the urban area are households, gardens, public areas, industry, and commerce. Today, we only perceive them as a nuisance. We are only interested in their disposal without being aware of their benefit. In this manner, important bioresources are being wasted and our environment is being contaminated. The fullest possible and efficient utilisation of urban bioresources is an important step with regard to a bio-based economy.

This blind spot is where the KREIS project starts. The Hamburg *Jenfelder Au* neighbourhood, which is a new residential area of 35 ha for 1,800 inhabitants, is currently under development. In the *Jenfelder Au*, a combination of renewable energy and innovative wastewater systems is being introduced. The buildings will be connected to an innovative system for the separate collection of greywater and rainwater, and to a separate collection of blackwater through vacuum toilets. The blackwater will be supplied to a 900 m³ fermentation plant. Biogas will provide for heat and electricity via gas turbines [1]. The anaerobic fermentation of blackwater alone would lead to a rather small biogas production, and the amounts of blackwater accumulating in the district are not sufficient to fill the entire reactor. This is why co-substrates are required. An inventory was drawn up in order to determine the potential of bioresources that are suitable for the fermentation plant. The inventory constitutes the focus of this article. Blackwater and co-substrates were also investigated with regard to their biogas formation potential. Subsequent to fermentation, fermentation residues remain, out of which usable products will be produced. This article will also provide an overview of the options that appear to be suitable.

Material and methods
A basic inventory study determined the potential of various secondary and tertiary bioresources in *Jenfelder Au* or in the surroundings of *Jenfelder Au*, which is the *Wandsbek* district:
- Blackwater: calculated via the number of inhabitants of *Jenfelder Au*, and the blackwater generation rate via the data of [2].
- Lawn cuttings: calculated via area-specific generation rates given by [3], and public and private lawn areas in the *Wandsbek* district determined by [4]; using GIS, distances of 5, 10, 15, and 20 km from *Jenfelder Au* were evaluated.
- Kitchen waste: calculated via the number of inhabitants of *Jenfelder Au*, and kitchen waste generation rate based on [5].

- Grease residues: calculated via the amounts generated in a similar district with data given by [6], and the number of inhabitants of both districts.

Biogas potentials were determined in mesophilic anaerobic batch tests for both single substrates and mixtures of blackwater with grease trap residues and with lawn cutting preparations (press juice, maceration of fresh and silage lawn). Various chemical parameters of the bioresources were analysed or determined by means of literature research too. The values from both internal investigations and literature showed, as was expected, a wide range of fluctuation. Particularly probable values were chosen in order to be able to carry out further-leading calculations in connection with the planning for the construction of the biogas plant, for the energy supply of the area, and for the economic and ecological evaluations of the entire system. The data base documented here is to be considered as provisional and will continuously be updated. Methods that are suitable on principle for the post-treatment of fermentation residues were determined by means of a literature study, taking into account the conditions in Jenfelder Au.

Results

Table 1 provides a survey of the bioresource inventory results, including important chemical parameters. Subsequently, the individual bioresources are characterised with regard to their suitability for the biogas plant of *Jenfelder Au.*

Table 1. Inventory results for suitable bioresources including selected properties; values rounded

Bioresource	**Bioresource potential** Mg/a	**Biogas potential** l/kg oDM	**Dry Matter** %	**Organic Dry Matter** % oDM	**Nitrogen** % DM	**Phosphorous** % DM
Blackwater	5,000[1]	500	0.7	60	23.0	2.7
Kitchen waste	150[1]	600	40	50	2.6	0.3
Private lawn cuttings	12,000[2]	500	20	90	2.5	0.3
Public lawn cuttings	70,000[2]	500	20	90	2.7	0.3
Grease trap residues	1,500[3]	1000	5	90	1.2	0.6

[1] *Jenfelder Au*; [2] *Jenfelder Au* 5 km surounding within *Wandsbek*; [3] whole *Wandsbek*

Blackwater: a human being produces 500 l of urine and 50 l of excrement per annum [1]. In addition, blackwater from vacuum toilets is composed of 15 kg toilet paper per annum and human being [7] and 1 l flush water per flush [1]. The organic material deriving from excrement and toilet paper shows an energetic potential. Although the fermentation of blackwater does not result in very high biogas yields, it is energetically advantageous compared to the conventional, very energy-intensive wastewater treatment. The nitrogen and phosphorus potential is of special interest for material recycling. These components can be found mainly in urine and can be used for the production of fertilisers.

Greasy water: grease separators are employed, for example, in restaurants and hotels for the pre-treatment of wastewater containing high amounts of fat. They should be emptied once a month. In practice, however, the intervals are longer. This results in the fact that a major part of the greasy waters disappears in the sewerage system. Greasy water consists mainly of water. It is very inhomogeneous and contains, in addition to fats and oils, for example food leftovers, detergents, and cleaning agents. The exclusive fermentation of greasy water is problematic as, during the fat degradation, substances are formed which can decelerate or even stop the fermentation process. However, as a co-substrate, it can exert a very positive influence on the biogas yield.

Lawn cuttings: approximately 1-2 kg lawn cuttings per m^2 and annum accrue in private gardens and on public green space from March to October. The amount and quality depend mainly on the season and on the type and care of the lawn. Fresh lawn cuttings are humid and contain high shares of easily fermentable organic material. Lawn cuttings are actually either left on the lawn or on a heap, composted in the garden, supplied to the collection station, collected by gardeners or landscapers, or collected in the biowaste and residual-waste bin. For wet fermentation, a juice that is pressed out of the grass or aqueous grass sludge can be used. The grass juice and also the sludge are well fermentable, and they also have a nitrogen and phosphorus potential.

Kitchen waste: due to their proximity of generation and the material properties, kitchen waste would be an ideal co-substrate for fermentation. Currently, these are collected in *Wandsbek* via the biowaste and residual-waste bin. As a result of mixings with other waste types, the contents of these bins are not suitable for the wet fermentation in *Jenfelder Au*. Kitchen waste grinders installed in the sink offer a new collection possibility. These promise a nearly absolutely full, homogeneous and, in addition, very user-friendly possibility of kitchen wastes collection. In *Jenfelder Au,* 10 kitchen waste grinders will be installed for the test operation.

Other bioresources: in gardens and public areas, large amounts of green waste such as weeds, branches, and boughs from bushes and trees accumulate. These fractions are not suitable for fermentation, as they either contain too high soil shares or woody components. In contrast, leaves are, on principle, fermentable. The biogas yields significantly depend on the type and age. The residues from a fruit-processing industry that accumulate in the proximity of 7 km are very well fermentable. These residues occur as fruity water composed from shredded fruit peeling residues, mixed with process water, that accrue during the industrial fruit processing.

The daily quantity of blackwater will amount to approximately 12 m³. Considering a retention time of 25 d in the reactor it will fill the fermenter to approximately one third. Greasy waters from canteens and restaurants, and lawn cuttings from public areas were considered as suitable co-substrates, which could made available on short or medium term. The greasy water from *Wandsbek* is currently fermented in another Hamburg district. Redirection appears possible at short notice. The public-lawn inventory study showed that enough lawn cuttings accrue within a 5 km radius. In a next step, their exploitation needs to be planned, starting with the selection of particularly suitable areas. Since lawn cuttings are available only from March to October, storage will be required to provide input for the other months as well. The storage is possible by means of silage. Fresh grass and silage suspension was favoured over grass juice, because this allows for higher biogas yields, and the integration of the necessary technology into the fermentation site is easier. Kitchen waste and lawn cuttings from private areas are also very well suitable with regard to their chemical properties. However, they were excluded here, as their exploitation at short notice for employment in the *Jenfelder Au* biogas plant is impossible. On long term this may change.

The biogas potential of all co-substrates is significantly higher than the potential of the blackwater. Approximately 45 l of biogas could be obtained from greasy water, 35 l of biogas per litre of co-substrate from grass juice and fruit water approximately, and from blackwater only 2 l. Out of fresh grass, it would even be possible to produce 100 l of biogas, due to the significantly lower water content. However, if the grass shares are too high, the mixture would no longer be able to be pumped. The blackwater /co-substrate mixture should not exceed a dry matter content of approximately 10%. A suitable mixture of blackwater and greasy water, fresh grass, and grass silage (3:3:2:1) could electrically supply approximately 165 kW, and thermally 260 kW.

During the fermentation, the volume of the substrate mixture changes only insignificantly, as it contains at least 90% water. Subsequent to fermentation, a digestate remains. It also shows a high water content. To generate usable products, the digestate will first be separated into a liquid phase rich in nutrients and into a sludgy phase rich in organic material through solid-liquid separation. In addition to the input, the exact composition of these two substance flows strongly depends on the selected process. The solid fraction of the fermentation residue contains organic substances and part of the nutrients. The prioritised utilisation option for the latter is composting. As the solid fermentation residue will be too humid and too poor in structure for composting alone, it could be composted along with woody waste substances in a composting plant nearby, and could simultaneously also be sanitised. In the liquid phase, the main part of the nutrients N and P is contained. If these were introduced into the sewage network, they would be lost for further utilisation. In addition, in the sewage treatment plant, the digestate-N would be converted into atmospheric nitrogen requiring lots of energy, in order to avoid water contaminations; 3 kWh alone are required for 1 kg N [8]. Since N is an important plant nutrients with worldwide increasing demand, on the other hand, the extremely energy-intensive Haber-Bosch process is used in order to produce N fertiliser from atmospheric nitrogen. More than 1% of the global energy requirements are attributed to this process [9]. Therefore, it suggests itself to obtain N fertilizer directly from digestates. Different methods will be investigated, from ammonia stripping – which is coupled with gas washing – to evaporation. Additionally, the recovery of phosphorus could take place in a stirred loop reactor through the addition of lime and subsequent sedimentation of phosphates, as well as through the addition of magnesium oxide or hydroxide for the crystallisation of magnesium ammonium phosphate (struvite) [1].

Conclusion and perspectives

In order to utilise urban bioresources as efficiently as possible, the regional bioresource potential, as well as the actual disposal and utilisation pathways need to be known. To select the suitable bioresources for a process, e.g. the fermentation plant in *Jenfelder Au*, their availability in the short, medium and long term shall be assessed. Furthermore, the technical usability for the process needs to be evaluated. For the *Jenfelder Au* fermentation plant, important parameters are the biogas potential and the consistency (ability to be pumped) of the bioresources. Moreover, the provision must be ensured throughout the year . Since the major part of the bioresources do not directly fulfil all demands, the preparation of these bioresources must be considered; e.g. grass cuttings for the *Jenfelder Au* fermentation plant need to be macerated and should partly be stored as silage in order to provide materials for the winter months. In addition, utilisation of the product and also the residual streams of the processes need to be considered. From biogas, electricity and heat can directly be produced for utilisation in *Jenfelder Au*. Fertilizers must be marketed. Therefore, transportable products should be produced.

The evaluations for *Jenfelder Au* are not finished yet. The next step is to create and evaluate several scenarios in order to finally choose the best option.

References

[1] KREIS, 2012. Versorgung durch Entsorgung **-** Koppelung von regenerativer Energiegewinnung mit innovativer Stadtentwässerung. Hamburg Wasser (Ed.), www.kreis-jenfeld.de, accessed 03/2013

[2] Wendland C, 2008. Anaerobic digestion of black water and kitchen refuse. Dissertation. Hamburg University of Technology, Hamburg, Germany

[3] Adwiraah H, Oldenburg S, Körner I, Stegmann R, 2012. Bioresource inventory – GIS-based identification, quantification and characterization methods. In: ORBIT- 8th International Conference, Tremier et al. (Eds.); Proceedings topic 2, 80-87, France

[4] Flerlage JM, 2012. GIS-basierte Analyse des Biogaspotentials im Hamburger Osten. Eine Biomassestudie im Rahmen des Projekts "Jenfelder Au". Bachelorarbeit. Hamburg University of Technology, Hamburg, Germany

[5] Körner I, Hertel S, Adwiraah H, 2012. The civilisation biorefinery – Inventories for efficient utilization of local waste and waste water based bioresources for material and energy generation. In: ORBIT- 8th International Conference, Tremier et al. (Eds.); Proceedings topic 3, 1-8, France

[6] Meinzinger F, 2010. BERBION – Ergebnisse der Abwasserinventur. Unpublished results from Hamburger Stadtentwässerung, presented at the project meeting, Leipzig, Germany

[7] Statista, 2010. Der Pro-Kopf-Verbrauch von Toilettenpapier in Deutschland und der EU in Kilogramm pro Jahr. http://de.statista.com/statistik/daten/studie/157665/umfrage/pro-kopf-verbrauch-von-toilettenpapier-in-deutschland-und-der-eu/, accessed 03/2013.

[8] Meinzinger F, 2010. Resource Efficiency of Urban Sanitation Systems: A Comparative Assessment Using Material and Energy Flow Analysis, Hamburg University of Technology, Hamburg, Germany

[9] Process Chemie Lexikon, Vogel Business Media, 2013. http://www.process.vogel.de/index.cfm?pid=2995&title=Haber-Bosch-Verfahren, accessed 03/2013