Implementing Advanced Concepts for Biological Utilization of Waste

Report no: O 4.5

MIDTERM OUTPUT REPORT – PILOT B IN SWEDEN

Tim Freidank, Silvia Drescher-Hartung, Andreas Behnsen, Johan Lindmark, Eva Thorin, Patrik Klintenberg, Thorsten Ahrens

August 2014

Baltic Sea Region
Programme 2007-2013

Part-financed by the European Union (European Regional Development Fund)

Ostfalia University of Applied Sciences
Institute for Biotechnology and Environmental Engineering
Wolfenbüttel, Germany

Index

Tables

Figures

1. Technical report

The technical report will deal with all aspects of on-site testing and the research on biogas potential of the different substrates used in the corresponding testing period. For detailed information on Pilot B operation see output report O.4.2.

1.1 Introduction, description of roadmap for report

First of all a short description will be given concerning the developed scenarios for Swedish case. Afterwards the issues of location, transportation and plant setup of Pilot B will be described (see 1.1.3 1.1.6).

1.1.1 Basic background information

The strategy of the operating period in Sweden differs a lot from the previous ones in Lithuania and Estonia. In these countries the main issue was to spread knowledge about biogas technology. Another point was to show the possibilities, different organic waste materials offer as a possible substrate for anaerobic biogas production.
In Sweden there are already plenty of operating biogas plants. The main problem here is the lack of suitable substrates in the region Västerås, because the ones that are used right know are almost completely being processed.

1.1.2 Technical information

The Swedish partners have been able to acquire the local waste treatment company *VafabMiljö AB* as host for the pilot plant. The company is owned by 12 municipalities. Situated in the outskirts of Västerås, a city in the southeast of Sweden, approx. 100 km west of Stockholm. The population of the region is approx. 300.000 people and more than 10.000 businesses which generate waste. [1]
Svensk Växtkraft AB is a wholly owned subsidiary company of *VafabMiljö AB*. A wet digestion biogas plant was built in the year 2005 and has been taken into operation in 2006. The plant uses pre-sorted biowaste from households and restaurants, fatty waste from grease traps and grass silage. The biogas being produced is than upgraded and used as a fuel for the local public transport (approx. 130 vehicles at the moment). There is also the possibility to fill private cars at some special gas stations.
As mentioned in 1.1.1 the main problem is the lack of suitable substrates.

The pilot plant has been set up at the composting area of the *VafabMiljö* site (Figure 1). The plant site was fully supplied with electricity and freshwater.

Figure 1: Location of Pilot B in Sweden. VafabMiljö site in Västerås, Sweden. The local wet digestion biogas plant in the background.

1.1.3 Transportation

The lesson learned from the previous transport to Lithuania was to use a trailer without truck superstructure. This made the loading procedure much easier (see Figure 2).

Figure 2: Loading of the container in Estonia for the transportation to Sweden.

Sanitation of the equipment was performed in Estonia by heating the cleaned fermenter with water at a temperature of 60°C for at least 24 h. Inner surfaces have also been sanitized with a surface disinfectant before transportation to Sweden started.

Figure 3: Unloading of Pilot B at the VafabMiljö site.

1.1.4 Positioning

Square timber has been positioned under the corners of the container in order to level it. As a positive side effect, the higher floor level prevent water from entering the container. A big puddle forming in front of it could otherwise have caused damage.

Figure 4: Levelling of the container with square timber.

The team of VafabMiljö provided an additional small container as a material storage. Containers (IBC) have been placed to dispose the potentially contaminated digestate.

1.1.5 Electrical connection

Via one 30 m cables, the container had to be connected to the local electricity grid.

Figure 5: Connecting the pilot plant to the local electric grid.

1.1.6 Check-up

After setting up the equipment, an inventory check has been performed to make sure everything (lab equipment, additional tools, etc.) was in its place (see also output report O.4.3.).

There was only minor damage after the Estonian operating period. One paddle of the first stirrer was broken (see Figure 6). In the absence of equipment to weld stainless steel and because no major difficulties for the process have been expected, this has not been fixed.

Figure 6: Broken paddle of the first stirrer.

During start-up it turned out, that a relay for one of the three heating circuits was broken as well. The broken relay was then replaced. Otherwise there would have been a loss of approx. 1/3 of the overall heating power.

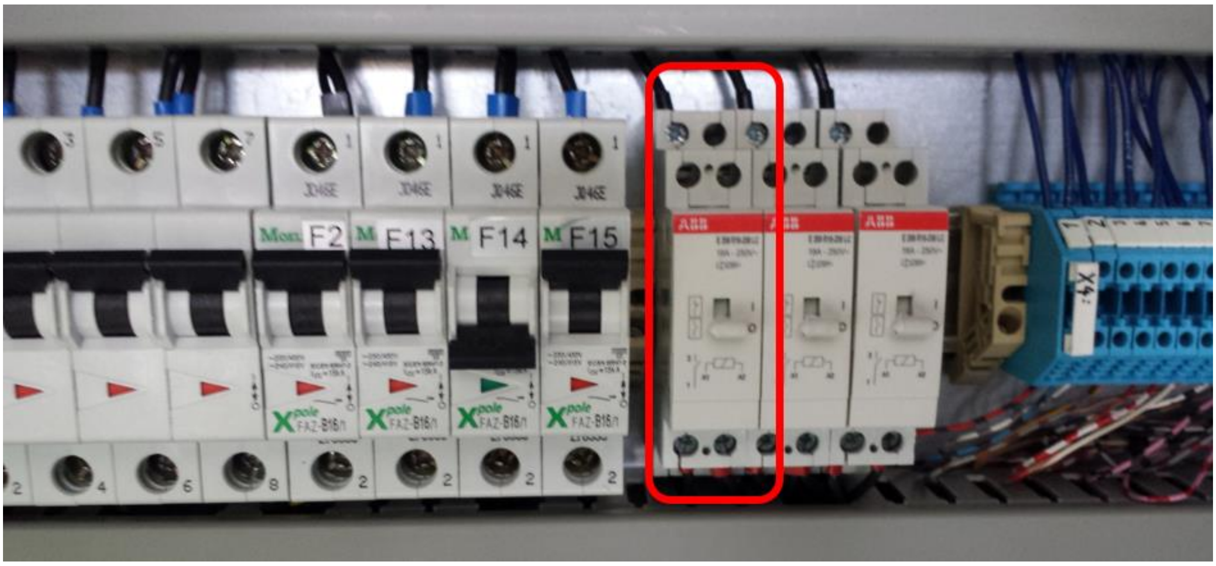


Figure 7: Broken relay for one of three heating circuits.

1.1.7 Pilot B process technology

The operators' manual for Pilot B is part of output report O.4.2. It contains:

- General plant description
- Equipment description
- Program description
- Work instructions for Pilot B
- Troubleshooting advices

See also previous reports O.4.3 and O.4.4 for more information.

1.2 Definition of general regional challenges regarding technical implementation of biogas technology

The biogas technology is well known in Sweden, where biogas plays an important role in public transport. The challenge for pilot B was more to show, that the dry digestion technology is able to handle MSW and biowaste in a stable and reliable way. The biogas plant that is in operation in Västerås is a wet digester, though the operation of this plant is complex and the maintenance expenses are high it has proven that it can manage biowaste and produce biogas on a long term perspective.

The local population has a high demand for biomethane. This is mainly being used for mobility purposes. As there is a constant increase in the demand for biomethane, the actual biomethane production needs to be tripled until the year 2016. For example the number of public transport vehicles, powered with biomethane, shall increase from 130 to 220 until 2016. [2]
The mayor problem, as mentioned before, is the availability of substrates. As the biowaste is already nearly completely utilized, new substrates have to be found. The use of pre-sorted municipal solid waste (MSW) has been taken into account. The examination of MSW as single substrate for anaerobic biogas production has been the main issue of the Swedish operating period.

As there are several technical solutions for anaerobic biogas production a suitable solution for the use of MSW as single substrate had to be examined. While wet digestion did not seem a satisfying application for this kind of substrate, dry digestion was considered to be more suitable. As the MSW is pretty inhomogeneous and full of material that is highly potential to harm the fermenter equipment (please see chapter 1.3.1 for an impression of the materials complexity), a reliable process technology has to be used. Another important point to consider is the amount of digestate, which arises from the digestion process. When using MSW, the risk of contamination of the digestate with, for example, high heavy metal concentrations is given. So the aim of process design should be, to keep the amount of liquid digestate leaving the process a low as possible. For this reason the wet digestion technology is unfavourable.
The disturbing material that can be found in the MSW may also be harmful for the equipment of dry digestion biogas plant. Pilot tests in Sweden were meant to be a proof of technology regarding this issue.
To compare different types of dry digestion and in order to even more minimize the amount of liquid digestate an additional dry fermentation system has been tested.
A lab scale garage fermentation system, available in the Ostfalia laboratory, has been used in addition to the pilot plant in Sweden. This system can handle non pre-treated MSW. This would make the handling of the raw material much easier. Also the liquid digestate can be recirculated.
The experimental garage fermentation system will be described in detail in chapter 1.3.4 .

1.3 On-site and additional testing strategies

The substrate used during the Swedish operating period was municipal solid waste (MSW). Due to a lack of other biodegradable substrates to be used for the demanded biogas production, this was the substrate of choice (see also chapter 1.2). The determination of the biogas potential and the suitability of plug flow dry digestion technology was the main focus of the Swedish operating period (see 1.1).
In the following a detailed report of the raw material (MSW) and its characteristics will be given. The resulting consequences for on-site testing will be explained afterwards. Followed by a description of the tests that have been performed.

1.3.1 Municipal solid waste (MSW)

The team of VafabMiljö provided several batches of MSW samples. The MSW has been shredded to a particle size ≥30 – 40 mm. Figure 8 gives an impression on the different sample batches for the pilot plant.

Figure 8: Impression of different MSW batches. The material has been shredded and sieved to a particle size ≤ 30 - 40 mm.

Table 1 gives an overview on the variation of the dry matter and organic dry matter contents of the different waste batches. The variation is quite big. It must be said, that for the determination of the organic dry matter content, the contained plastics falsify the amount of biodegradable substances.

Table 1: Dry matter (TS) and organic dry matter (VS) contents of the different waste batches.

Date	TS (%)	VS (%TS)	pH
23.05.2014	49.5	66.5	6.4
28.05.2014	55	65.6	6
10.06.2014	66	48.2	6.9
25.06.2014	54	64.9	6.8
08.07.2014	43	61.9	6.3
21.07.2014	80	55.5	7.2

The following graph and tables give an overview on micro- and macro nutrients. They also show the quite big difference between the single waste batches.

Figure 9 shows the different Kjeldahl-N amounts of the different waste batches.

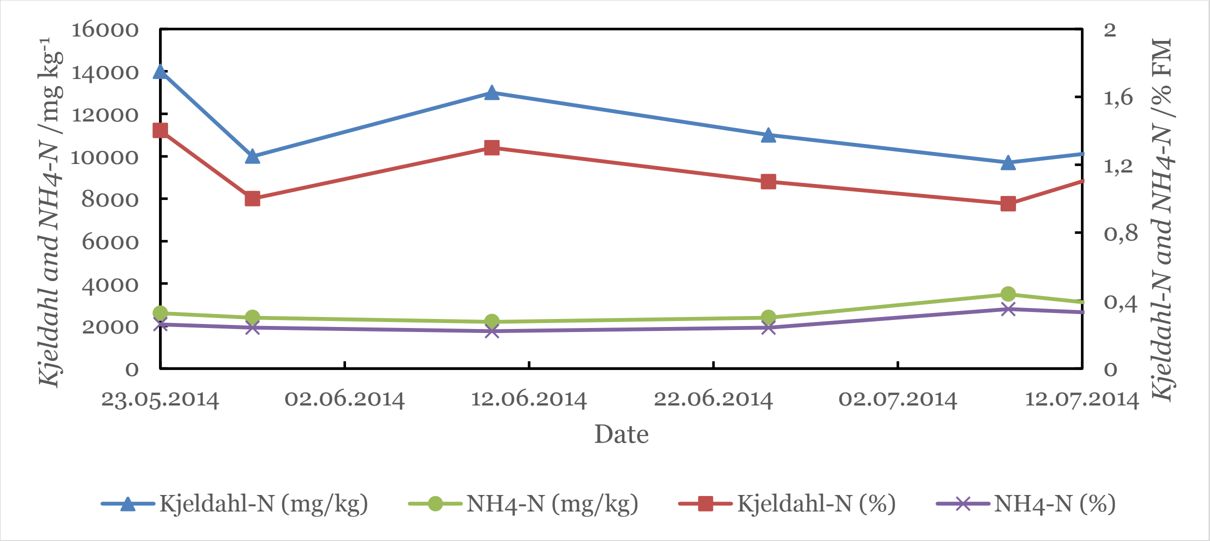


Figure 9: Kjeldahl-N contents of the single MSW batches.

Table 2 gives an overview on various macronutrients of the different MSW batches. The tests have been made by an external lab. Results can be found in the Appendix.

Table 2: Macronutrient contents of the single MSW batches.

Date	**Protein (%)**	**Fat (g / 100 g)**	**Fat (% TS)**	**Energy value (calculated) (MJ/kg)**	**Carbohydrates (calculated) (%)**	**COD-Cr (mg/L)**
23.05.2014	7.13	6.75	13.6	8.3	12	480000
28.05.2014	4.75	6.43	6.43	7.4	35	450000
10.06.2014	6.75	4.56	4.56	6.3	20	480000
25.06.2014	5.38	3.68	6.81	6.7	26	290000
08.07.2014	3.88	1.93	4.48	4.9	21	260000
21.07.2014	5.44	3.68	4.61	8.2	35	450000

Before feeding this waste into the fermenter, big pieces of disturbing material have been sorted out manually. This happened to prevent the moving parts from damage. Also harmful stuff like batteries have been sorted out to avoid high contamination with heavy metals. An exemplary summary of this kind of sorting will be given in the following.

Exemplary waste sorting, 16th July 2014

This waste sorting shall be suggestive of the complexity and problems arising from MSW as a substrate for biogas production.

Even though an advanced system of waste separation from the source is established, the whole variety of stuff people throw away can be found in the MSW. The exemplary waste sorting in the following gives an impression on the material and its complexity. It may also lead to a better understanding of the process related problem arising from its properties.

It must be said, that this sorting was meant to show what has been sorted out before the material went into the fermentation process. It is not a representative classification of the contents of MSW. Due to the size of Pilot B it was necessary to sort out for example bigger pieces of metal. These could have caused major damage to the system. Also bigger chunks of plastic foil have been sorted out to delay the stirrers getting wrapped in plastics. This sorting was done every day before the material then was fed into the fermenter.

Figure 10 shows an exemplary proportion of the share sorted out before feeding it to the fermenter. The range of material sorted out during the tests varied from approx. 10% - 25% of the original material due to the inhomogeneity of the MSW.

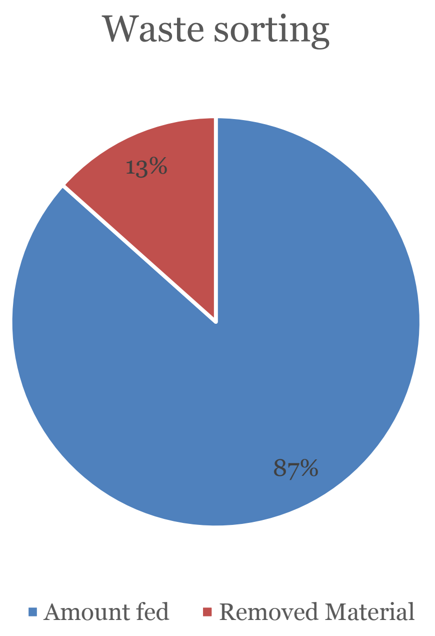


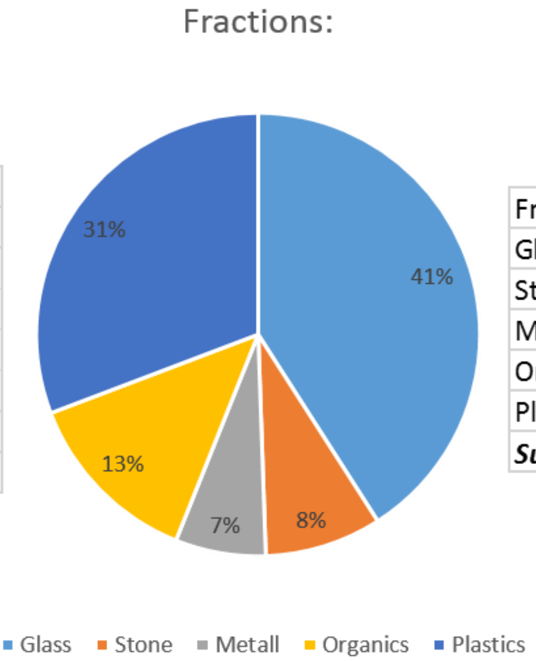
Figure 10: Mass proportions of sorted out waste for feeding of the digester.

Figure 11 shows the setup of the sorting. Of course this setup is not representative, but it should give a rough impression on the composition of the material.

Figure 11: Sorting setup; exemplary sorting on 16th July 2014 of waste to be fed to the fermenter

The following figures give an overview of different fractions that have been sorted out. Figure 12 also shows the share of the different fractions.

Waste sorting	weight [kg]
Sample 1	5,69
Sample 2	3,1
Sample 3	3,69
Sample 4	2,89
Sample 5	4,95
Sample 6	3,18
Sum	***23,5***



Fractions:	weight [kg]
Glass	1,49
Stone	0,31
Metall	0,24
Organics	0,48
Plastics	1,12
Sum	***3,64***

Figure 12: Fractions of different waste material after exemplary sorting of substrate meant to be fed to the fermenter. From the 23.5 kg of samples, 3,64 kg have been sorted out, the rest has been fed.

The following pictures will give an impression of the different fractions that have been sorted out.

Figure 13: Sorted out plastic fraction; 41% of total mass sorted out; containing all kinds of plastic, rubber, foil, and so on

Figure 14: Sorted out glass fraction; 31% of total mass sorted out

Figure 15: Sorted out stones; 8% of total mass sorted out; containing stones, shards of earthenware/porcelain

Figure 16: Sorted out metal fraction; 7% of total mass sorted out; consisting of metal and batteries

Figure 17: Sorted out fraction of organic matter; 13% of total mass sorted out; consisting of bones, wood pieces, cloth, cardboard, cork, and so on

Of course it was not possible to remove every part of disturbing stuff because this would have been way to time consuming. It was also depending of the individual operator, what and how many stuff had been removed.

As the plant should be a proof of technology, the absence of all the remaining disturbing material would have been a step into the wrong direction. In chapter 1.5.6 a description of impacts of the disturbing material on the pilot plant will be given.

1.3.2 Batch tests

The MSW (as mentioned in 1.3.1), shredded to a fraction <30 – 40 mm, has been examined in batch tests regarding its biogas potential. Samples of this waste have been sent to Germany to examine the biogas potential. Due to the inhomogeneity of the MSW the data gained from these test should be seen as an approximate benchmark. The results of batch test operation can be found in chapter 1.5.1 .

Municipal solid waste was roughly sorted before being used. Impurities such as big pieces of glass, plastic and iron were sorted out.

For general information on batch test operation see output report O.4.3. .

1.3.3 Continuous tests

Continuous tests with the MSW have been examined regarding their biogas potential in long-term continuous operation. This double test has been run in mesophilic conditions with a sanitation as a first step. The sanitation has been performed by filling the substrate into flasks and heating them at 70°C for at least one hour in a water bath.

Municipal solid waste was roughly sorted before being used. Impurities such as big pieces of glass, plastic and iron were sorted out. For general information on continuous test operation see output report O.4.3. .

1.3.4 Additional pilot scale tests with garage fermentation system

Besides the practical testing with Pilot B (see output report O.4.2., O.4.3.and O.4.4. for more details of previous tests in Lithuania and Estonia), a pilot scale garage fermentation system has been used during the Swedish operating period.
The use of this system has been taken into account, because it allows to use unsorted MSW. Unlike the other systems used, the substrate was utilized as it was provided by the VafabMiljö team (see Figure 8). In full scale this could save a pre-treatment of the waste, which would make the process much cheaper. On the other hand, the biogas yield would be lower, due to a high share of indigestible material.
Table 3 gives an overview on general data of the garage digestion system used in the Ostfalia laboratory.

Table 3: general fermenter data

component	data
inner volume	approx. 480 litres
substrate volume	approx. 125 litres
percolation liquid volume	approx.125 litres
data logging	temperature (substrate, percolation liquid, gas), gas composition, gas amount

In this garage fermentation system the substrate is stored in a removable tub. The percolation liquid is being sprinkled over the substrate. A further component are two packed columns. These should support a permanent colonization of microorganisms which are required for the process. This also should ensure a faster restart of a new batch. Furthermore the fermenter is equipped with different possibilities to record process relevant data. Figure 18 shows a flow sheet of the garage fermenter.

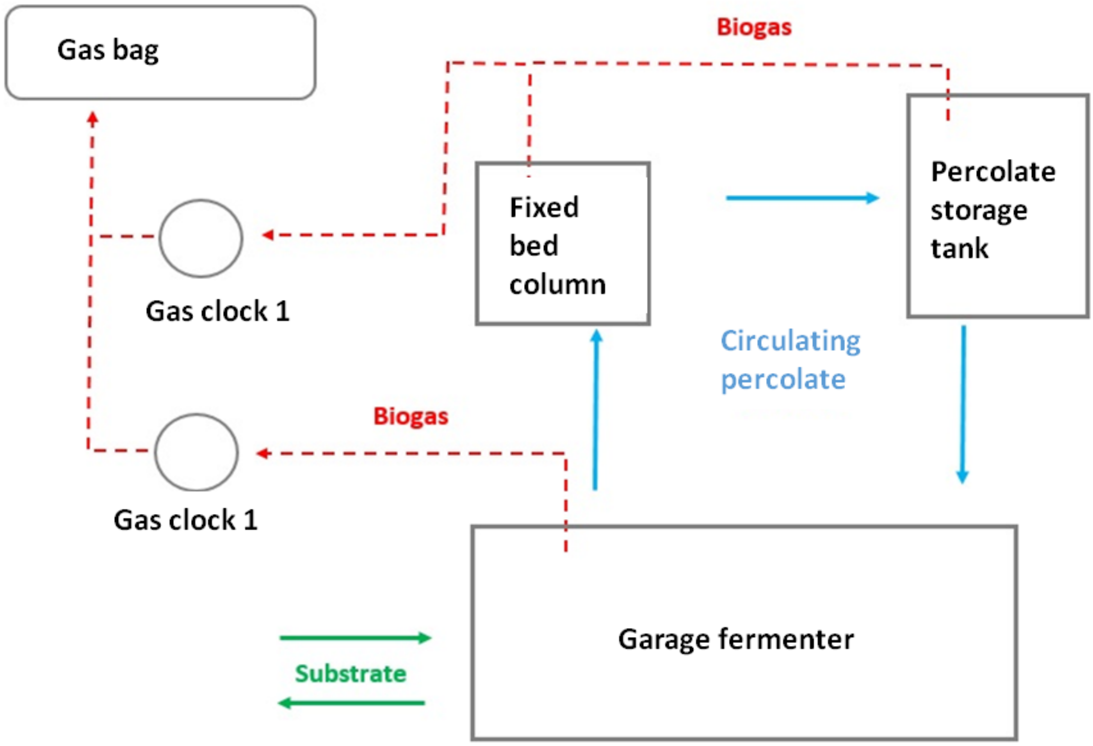


Figure 18: Flow sheet of the experimental lab size garage fermentation system.

Figure 19 shows the exterior of the garage fermenter. It is equipped with a hot water heating system. The percolation liquid is being sprinkled on the substrate. It is then drained at the end of the fermenter. It flows via two fixed bed columns to a percolation liquid storage tank.

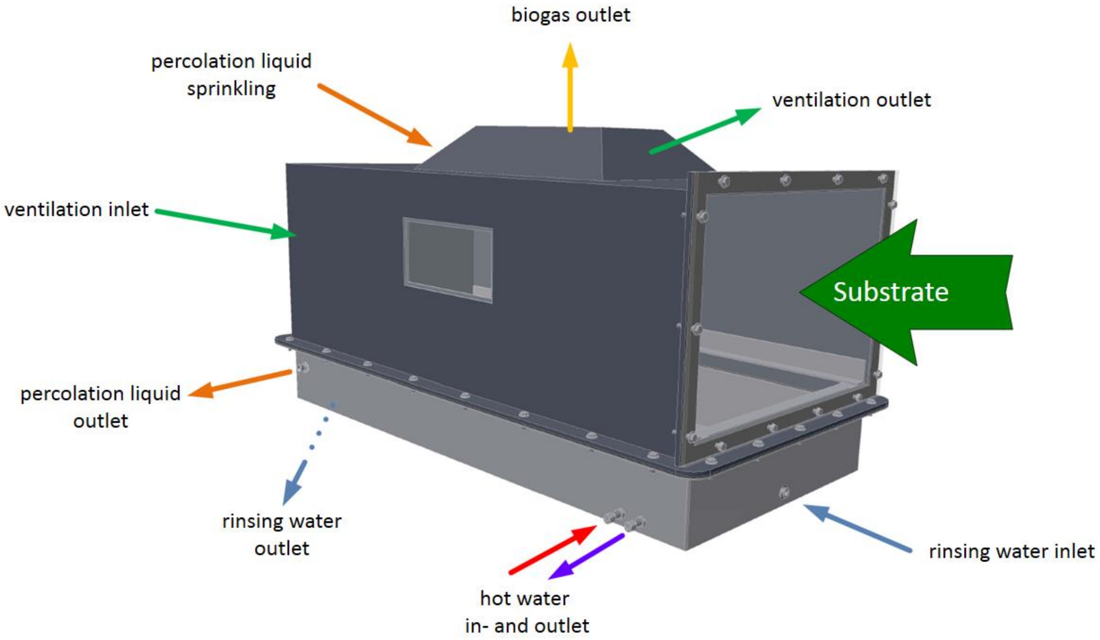


Figure 19: Exterior view of the garage fermenter and some of its components.

In Figure 20 a see-through view of the garage fermenter is displayed. The removable container has got holes in the bottom, so that the percolation liquid can drain. The temperature sensors for gaseous- and solid phase can also be seen.

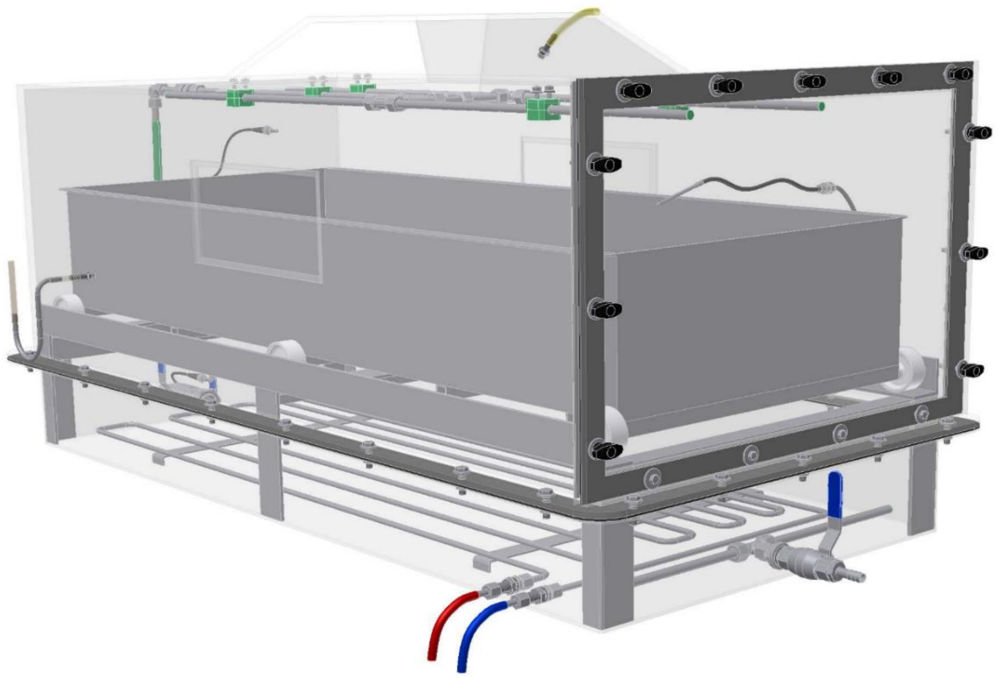


Figure 20: See-through view of the experimental garage fermenter with its components.

1.4 Timeline of the Swedish operating period

Table 4 gives an overview over mentionable events during the Swedish operating period. Major events will be described below.

Table 4: Timetable of mentionable events during the Swedish operating period.

Date	Event
09.04.2014	Plant arrival at Växtkraft plant site, Sweden; Installation of the plant
10.04.2014	Initial filling of the fermenter with liquid and solid digestate of the Växtkraft plant
11.04.2014	Minor maintenance work on stirrer 1 and heater circuit 1 relay
28.04.2014	Initial feeding with MSW; 3.4 kg/day
13.06.2014	Investor event
23.07.2014	Last day of feeding
24.07.2014	Shutdown of the plant, preparation to ship the plant back to Germany

In the following a more detailed description of some of the major events (see Table 4) will be given.

<u>10.04.2014: Initial filling of the fermenter with liquid and solid digestate of the Växtkraft plant</u>

Figure 21: Initial filling of the fermenter. (Top) liquid digestate of the Växtkraft plant. (Bottom) solid digestate of the Växtkraft plant to adjust the dry matter content.

After setting up all of the equipment, the initial filling of the fermenter has been done with the help of the Växtkraft team. A mobile digestate pump provided liquid digestate. The fermenter has been filled with approx. 300 litres of this digestate. Afterwards the addition of solid digestate was meant to fill the fermenter up to its operating volume of approx. 550

litres. It was also meant to adjust the dry matter content to round about 20%. The fermenter was then closed and heated up to a temperature of 55°C (thermophilic conditions).

13.06.2014: Investor event at VafabMiljö AB site in Västerås, Sweden

Figure 22: Impressions of the investor event in Västerås, Sweden.

After presentations explaining the project and the related technology a poster session had been held to give the possibility to communicate special topics in detail. Followed by a lively discussion concerning the project related issues. Both sides, project partners and external participants had a fruitful exchange about expectations from the project.
A visit to the site finalized the event. For more information regarding the stakeholder event see Chapter 3.

24.06.2014: Shutdown of the plant, preparation to ship the plant back to Germany

Figure 23: Impressions of the plant shutdown in Sweden. (left) Manual emptying of the fermenter with buckets. (center) Flushing with water to remove sediments. (right) Pilot plant on its way back to Germany.

Unlike in Lithuania and Estonia it was not possible to empty the fermenter with the help of a manure pump. The equipment could have become contaminated with the heavy metal polluted digestate.
The emptying has been done manually. Digestate has been stored in special containers and disposed separately.
Cleaning of the fermenter was also more intense than before, due to a lot of sediments and plastics wrapped around the stirrers (see chapter 1.5.6 for more details).
Collection and transport of the plant to Germany happened smoothly again.

1.5 Comparative reporting of on-site operational data with parallel laboratory gained data from Ostfalia lab

In this chapter gained data from lab and pilot tests will be shown. The gathered information from plant operation will be compared to the results of parallel laboratory analysis of the substrates used during the testing period. For materials and methods see O4.3.

1.5.1 Results of the batch tests of sorted MSW

There were two parallel mesophilic batch tests and two parallel thermophilic batch tests for the investigation of municipal solid wastes biogas potential. Figure 24 and Figure 25 show the cumulative methane volume per ton municipal solid waste (fresh matter). The waste was sorted before use as described earlier.

The production of methane per ton fresh mass varied in the parallel tests. In mesophilic batch test, sample 1 had a result of 94, 18 Nm³/ton fresh mass, while sample 2 had only 42, 30 Nm³/ton fresh mass. Similar situation happened in thermophilic batch test as well. However, the average methane production in mesophilic and thermophilic batch tests was almost the same, as the mesophilic batch test had a result of 68,24 Nm³/ton fresh mass and thermophilic one had a result of 68,71 Nm³/ton fresh mass in an average.

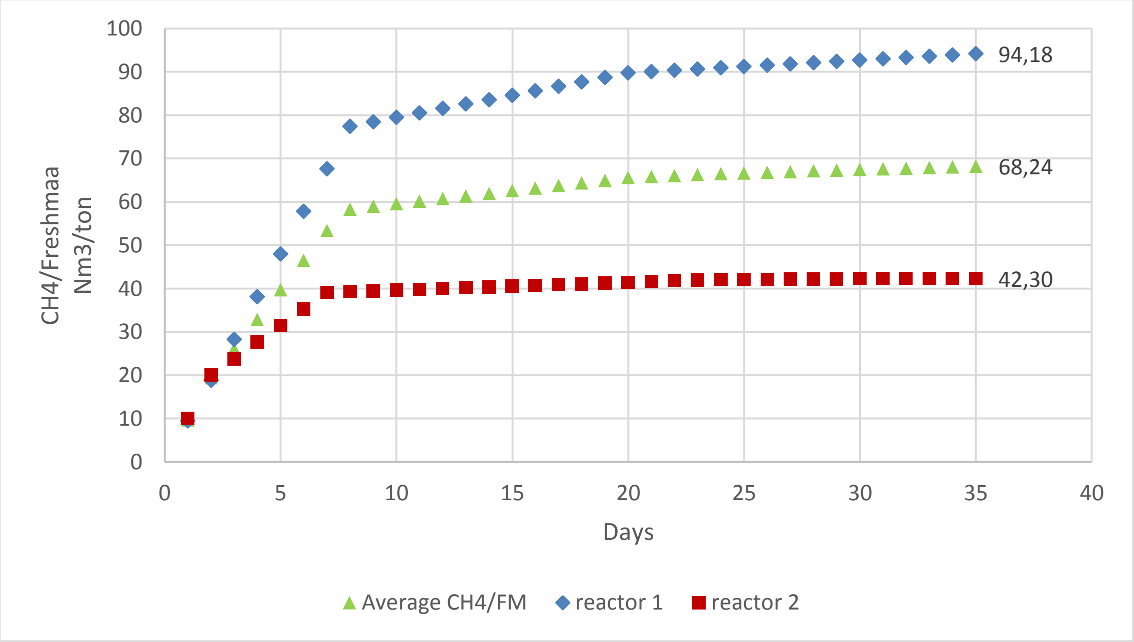


Figure 24: Results of Mesophilic batch test with sorted municipal solid waste.

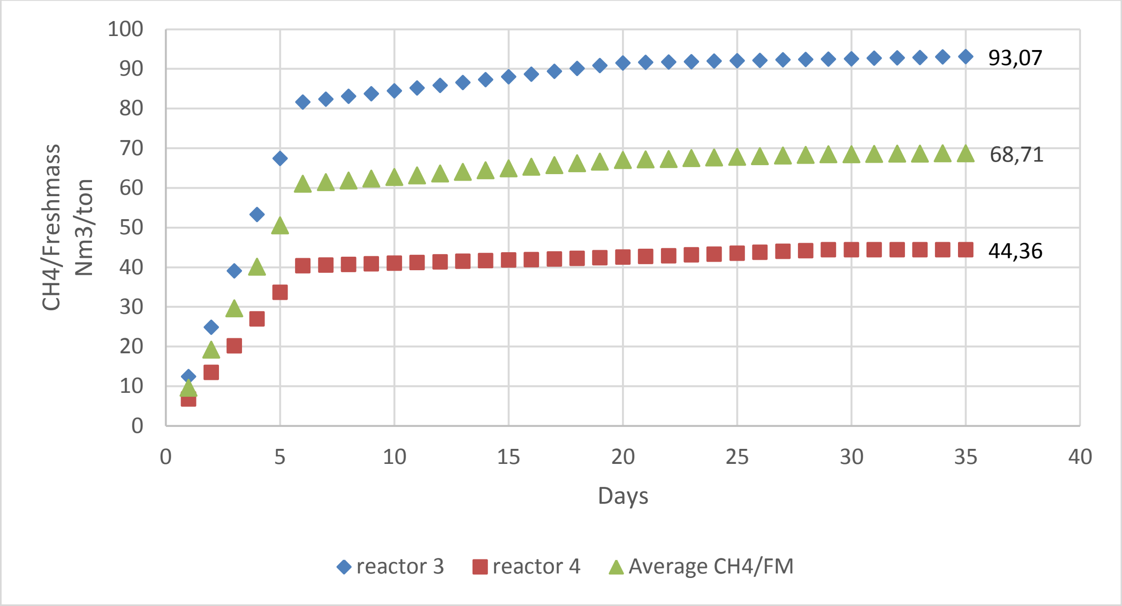


Figure 25: Results of Thermophilic batch test with sorted municipal solid waste.

Table 5 presents the fermentation data for sorted municipal solid waste batch tests. Mesophilic batch tests had higher average degradation rates of substrate than thermophilic ones. The substrate in reactor 2 had the highest degradation rate (78,77%) with lowest mass lost after 35 days test, while the substrate in reactor 4 had a lower degradation rate than the other three reactors (55,96%).

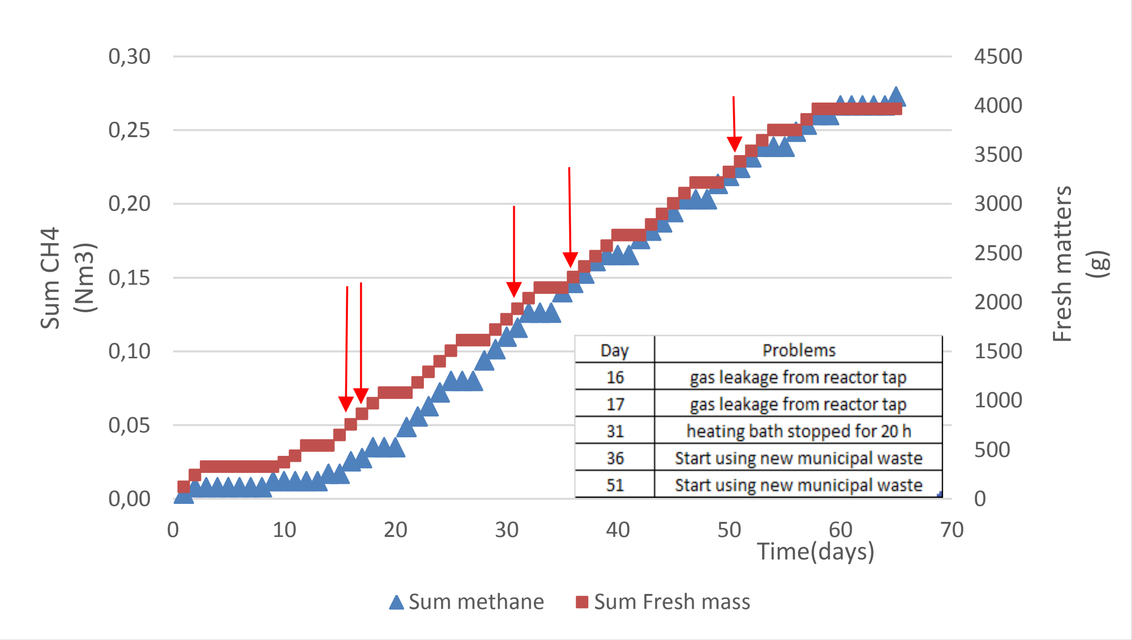
Table 5: Fermentation data for sorted municipal solid waste batch tests

		Fermentation test			abort	Mass different	Degradation rate
Temperature condition	Sample	Empty flask (g)	Inoculum (g)	Substrate (g)	Full flask after 35d	(g)	(%)
Mesophilic	Reactor 1	1497.5	3417.5	74.8	4972.2	17.6	72.70
	Reactor 2	1488.2	3399.0	75.0	4953.2	9.0	78.77
Thermophilic	Reactor 3	1665.0	3429.2	74.2	5147.0	21.4	77.99
	Reactor 4	1495.0	3370.4	75.0	4926.8	13.6	55.96

1.5.2 Results of the continuous fermentation test with MSW in Germany

Parallel to the operation of the pilot plant in Sweden continuous fermentation tests have been performed in Ostfalia laboratory. The aim was to show correlation between lab scale and pilot scale reactors. To achieve the best comparability the feeding amounts as well as the substrate composition should have been equal. Due to the inhomogeneity of the MSW this was hard to realize. Also the feeding amount could not be risen as high as in the pilot plant as the continuous test run in wet fermentation conditions.
There were two mesophilic wet reactors (reactor 3 and reactor 4) as parallel tests for the investigation of municipal solid waste biogas potential. Both reactors had the same substrate fed and same operations in the lab. Both reactors ran for 65 days. During weekends there was no substrate fed nor gas production measured. Both of the reactors had an average organic loading rate of 1, 74 kg oDM/ (m^3*d). On day 59 the substrate feeding stopped. The last gas measurement was on day 65th. The results of gas production and the operational parameters of each reactor are shown below.

Figure 26 shows the results of the cumulative methane yield and sum fresh municipal solid waste input for the reactor 3. The two lines have parallel growth trend, while on day 16 and 17 the two lines were not close to each other, due to gas leakages from the reactor valve. On day 31, temperature dropped in the reactor, causing the decrease in methane yield, which is noticeable in the graph below. In total 3965 g of sorted municipal solid waste was fed to reactor 3, and the total methane production was 0, 27272 Nm^3. The specific methane yield in reactor 3 was 68, 78 [(Vn) L/kg] CH_4/fresh mass.



Day	Problems
16	gas leakage from reactor tap
17	gas leakage from reactor tap
31	heating bath stopped for 20 h
36	Start using new municipal waste
51	Start using new municipal waste

Figure 26: Cumulative methane yield in comparison with total fresh mass input in reactor 3

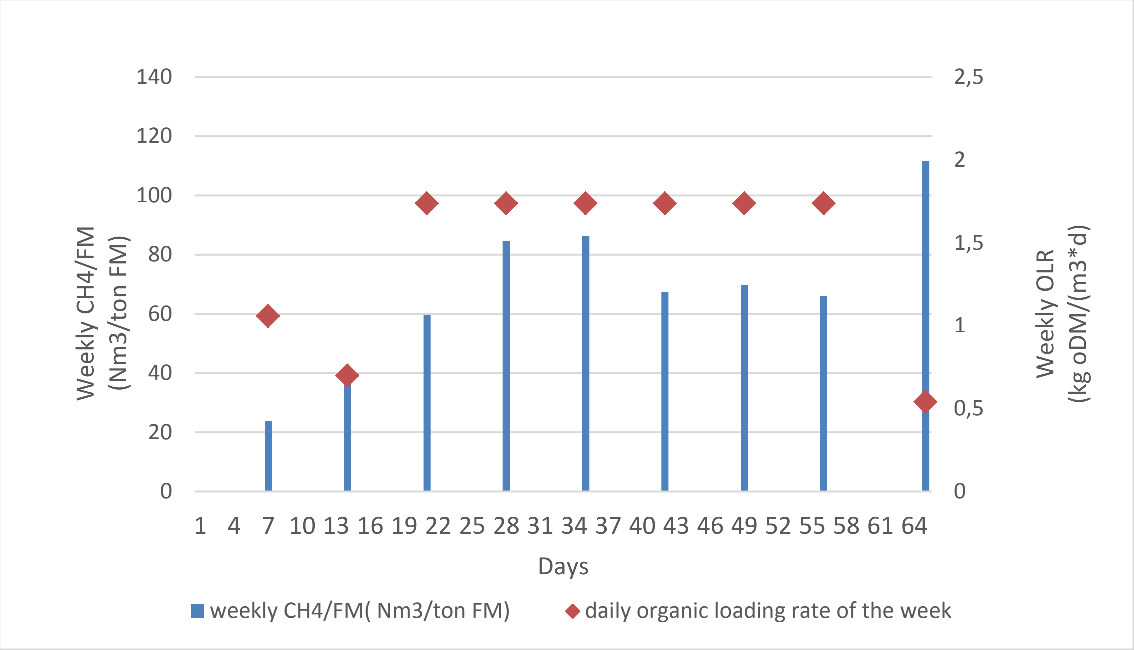
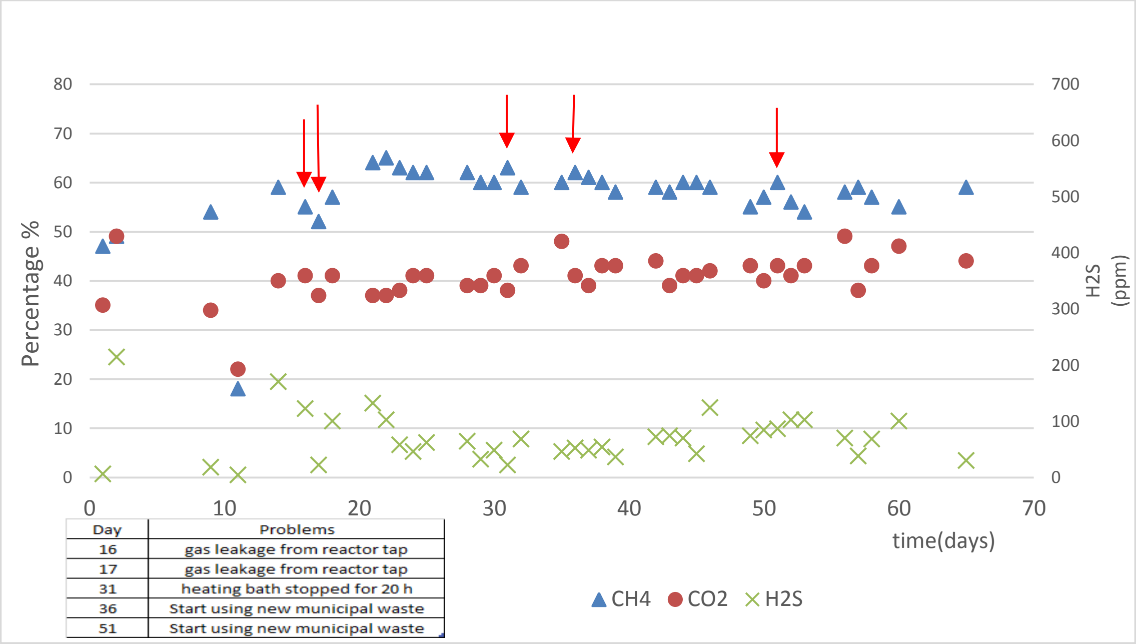


Figure 27: Weekly methane yield and organic loading rate in reactor 3

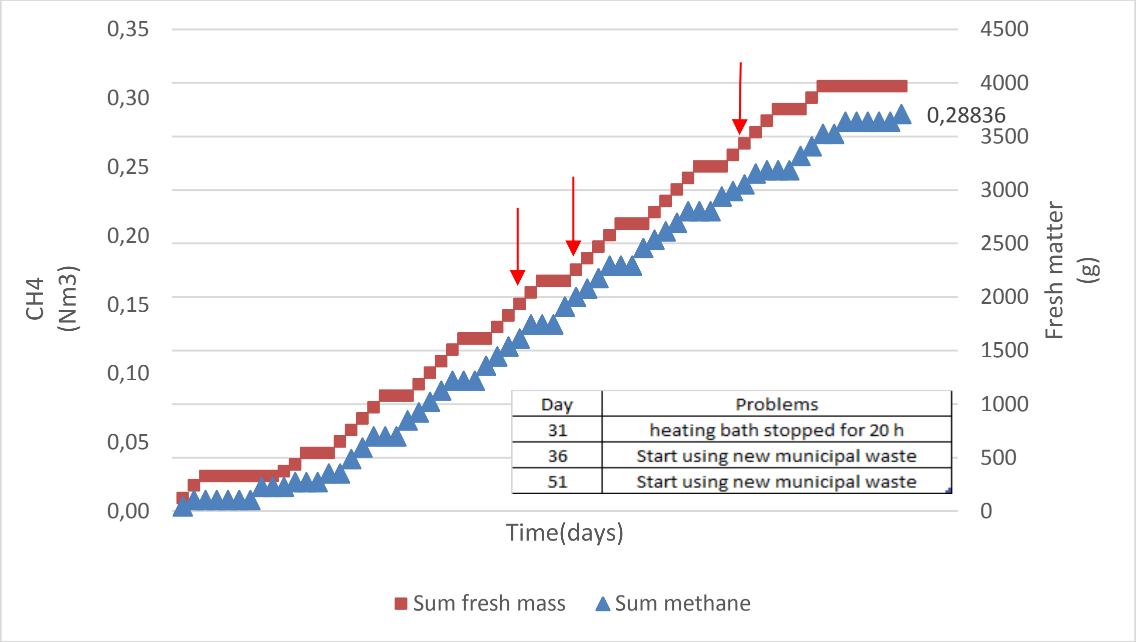
Figure 27 shows the results of weekly methane yield per ton fresh mass as well as the reactor's daily average organic loading rate of the week. The blue column is the average weekly methane production per fresh substrate input, which is calculated by dividing the sum fresh mass used of the week with the sum methane production of the week. The red point is the average daily organic loading within the same week. The organic loading rate was constant for 6 weeks (week 3 to week 8), and during these six weeks, the methane yield was higher in the third and fourth week and in the last three weeks the methane yield was similar. In the last week, there were only two days of feeding, in total 214g of fresh mass, and the gas production was collected from day 57 to day 65, in total 9 days instead of 7 days. Particularly worth mentioning is the much less substrate fed in the last week, which lead to the lower value as the divisor in the equation, resulting in the high value of CH_4/FM.



Day	Problems
16	gas leakage from reactor tap
17	gas leakage from reactor tap
31	heating bath stopped for 20 h
36	Start using new municipal waste
51	Start using new municipal waste

Figure 28: Biogas composition from reactor 3

Figure 28 shows detailed information of the biogas compositions. In the starting period, day 1 till day 11, the biogas composition showed big variations. On day 16 and 17, there was gas leaking from the reactor valve, the CH_4 amount in the collected biogas was lower. On day 31 the heating bath stopped working and temperature dropped to 21°C, it seemed the methane content was not directly influenced by this dramatic temperature change. On day 36 and 51, new municipal waste from Sweden has been used. In general, the CH_4 and CO_2 concentrations in biogas produced have been quite constant. The concentration of H_2S was rather low. The average CH_4 concentration in produced biogas was 57,32%.



Day	Problems
31	heating bath stopped for 20 h
36	Start using new municipal waste
51	Start using new municipal waste

Figure 29: Cumulative methane yield in comparison with total substrate fed to reactor 4.

Figure 29 shows the cumulative methane production in reactor 4 compared with the total substrate fed. The line of total CH_4 has the same trend as the line of total fresh mass used in the reactor 4. Reactor 4 produced 0, 29 Nm^3 methane and received 3965 g sorted municipal solid waste. The specific methane yield in reactor 4 was 73, 14 [(Vn) L/kg] CH_4/fresh mass.

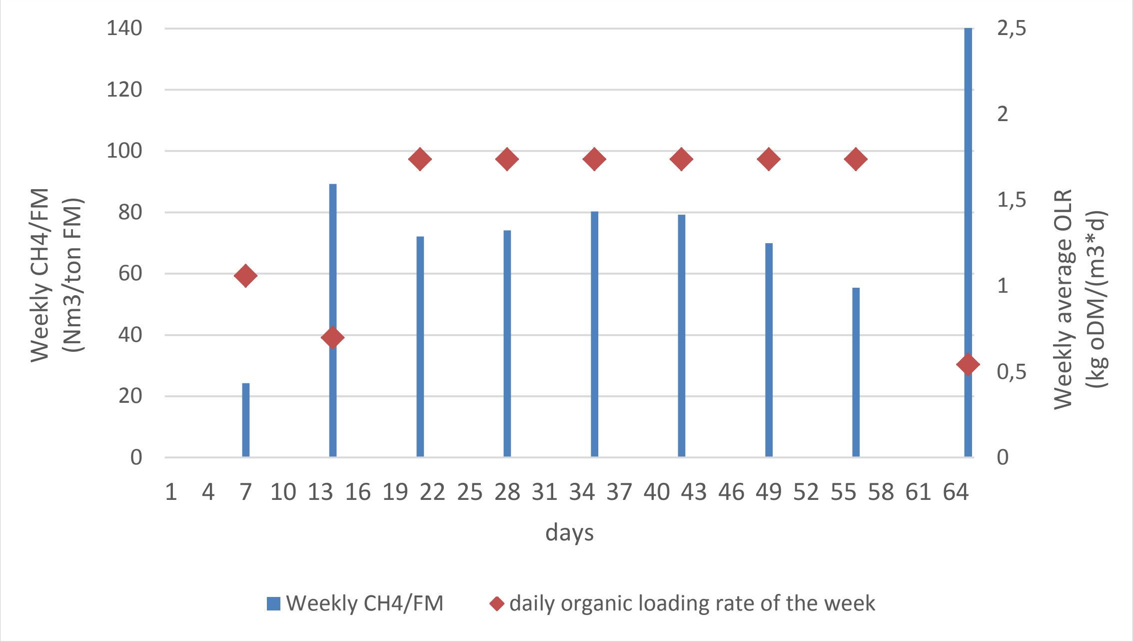
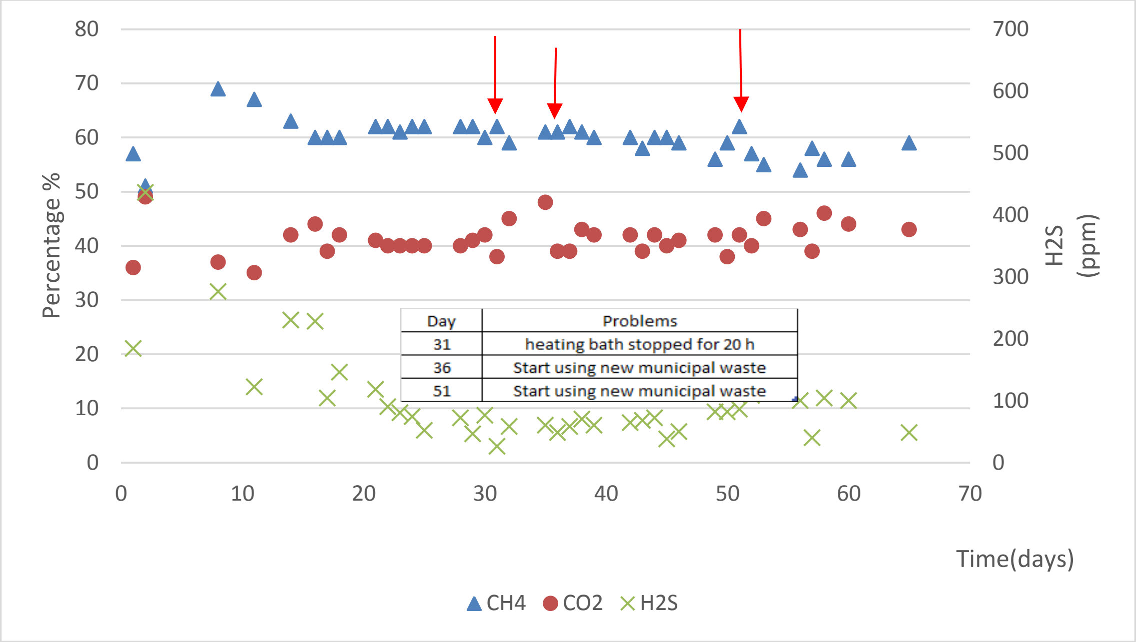


Figure 30: Weekly methane production and daily organic loading rate of the week in reactor 4.

Figure 30 shows the result of weekly methane production per ton fresh mass with the specific weekly average organic loading rate. The blue column is the average weekly methane production per fresh substrate input, which is calculated by dividing the sum fresh mass used in the week with the sum methane production of the week. The red point is the average daily organic loading rate within the same week. From week 3 to week 7, the value of CH_4/FM was similar, in week 8, the value was lower although the loading rate was the same as before. In week 9, only 214 g of substrate have been fed for the first two days of the week to the reactor, with an organic loading rate of 0,5 kg oDM/(m^3*d) and the gas production was collected from day 57 to day 65, in total 9 days instead of 7 days. Particularly worth mentioning is the much lower substrate fed in the last week, which lead to the lower value as the divisor in the equation, resulting in the high value of CH_4/FM.



Day	Problems
31	heating bath stopped for 20 h
36	Start using new municipal waste
51	Start using new municipal waste

Figure 31: Biogas composition from reactor 4

Figure 31 shows the biogas composition from reactor 4. Methane concentration of produced biogas from reactor 4 was quite stable, data of CH_4 amount was generally higher than 50%. On day 32, after heating bath stopped working and temperature in the reactor dropped to 21°C, the CH_4 amount of produced biogas was lower than the average value, at the same time, the CO_2 concentration increased a bit. H_2S concentration was around 300 ppm at the beginning of the fermentation process, and decreased gradually from day 8 to day 21, since day 22, the H_2S concentration in the produced biogas was in a steady level with small variations.

1.5.3 Results from garage fermentation of MSW in Germany

The garage fermentation system has been run in two batch operations. In the first run, the unsorted MSW has been mixed with material from a previous batch, run with corn silage. Figure 32 gives an impression on the materials.

Figure 32: (left) Material from previous run with corn silage. (center) MSW from Sweden. (rigth) Mixed materials.

Figure 33 shows the average biogas production rate per hour on the left ordinate. The related methane amount given in percentage of volume is shown on the right ordinate. It is noticeable that the production of biogas started from day 1. From day 11 there was a strong reduction in the production rate.

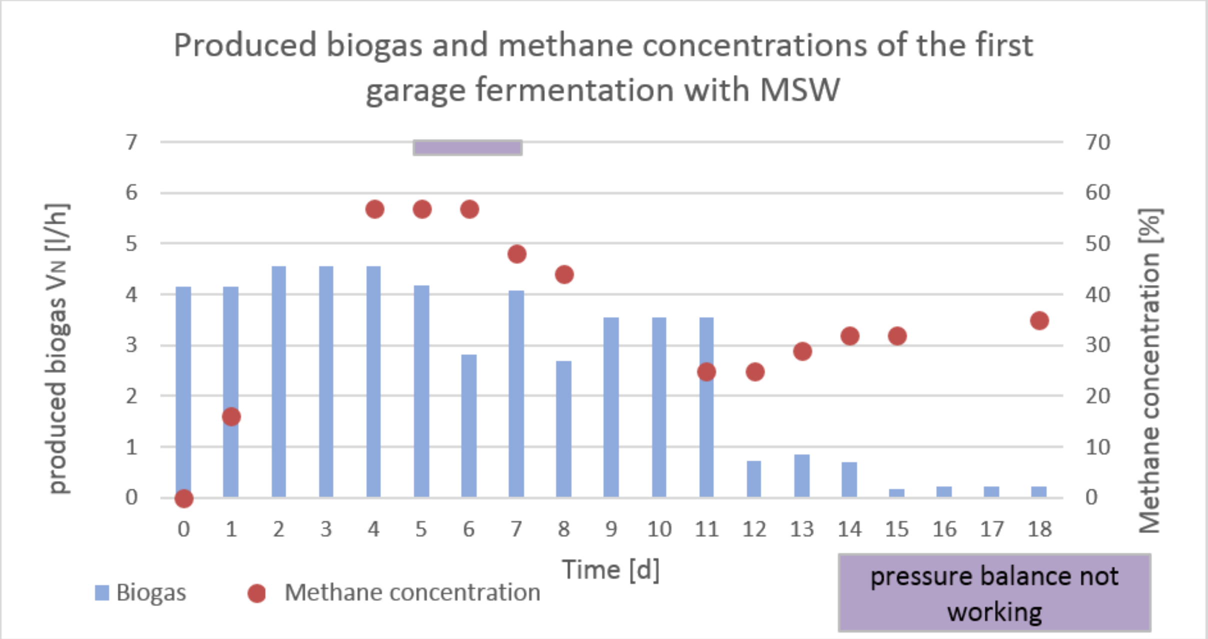


Figure 33: Produced biogas volume and its methane concentration of the first garage fermentation with unsorted MSW.

Due to minor technical problems (blocked hose) there might have been air getting into the process, causing the irregular measurements from day 6 on.

Figure 34 shows the cumulative methane production of the first garage fermentation with MSW in standardized conditions per ton fresh matter. There is a constant rise of the production. The last value is approx. 50,1 [Nm³ Methane/t FM].

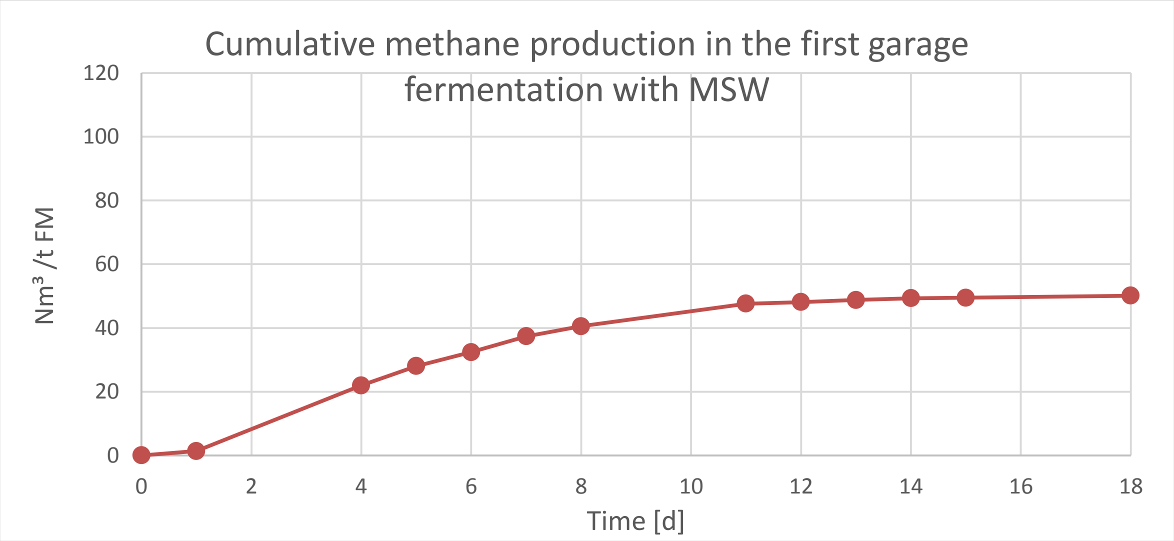


Figure 34: Cumulative methane production in the first garage fermentation with MSW.

As there has been material from former batch operation mixed with the MSW, a correction of these values was necessary. For example the rest gas potential of the corn silage left in the system had to be taken into account. This correction resulted in a total methane production of approx. 65.2 [Nm³/t FM (MSW)] in this batch. This would mean an average methane content of 55.7% and on overall biogas volume of 117.1 [Nm³/t FM (MSW)]

To see how much rest gas potential was left after ending the first run with the garage fermenter, a batch test has been performed like described in chapter1.3.2 .
Figure 35 shows the result of these tests. The rest gas potential, approx. 2.4 [Nm³ CH_4/t FM (residues)] is pretty low. Which means that the degradation in the garage fermenter was quiet effective.

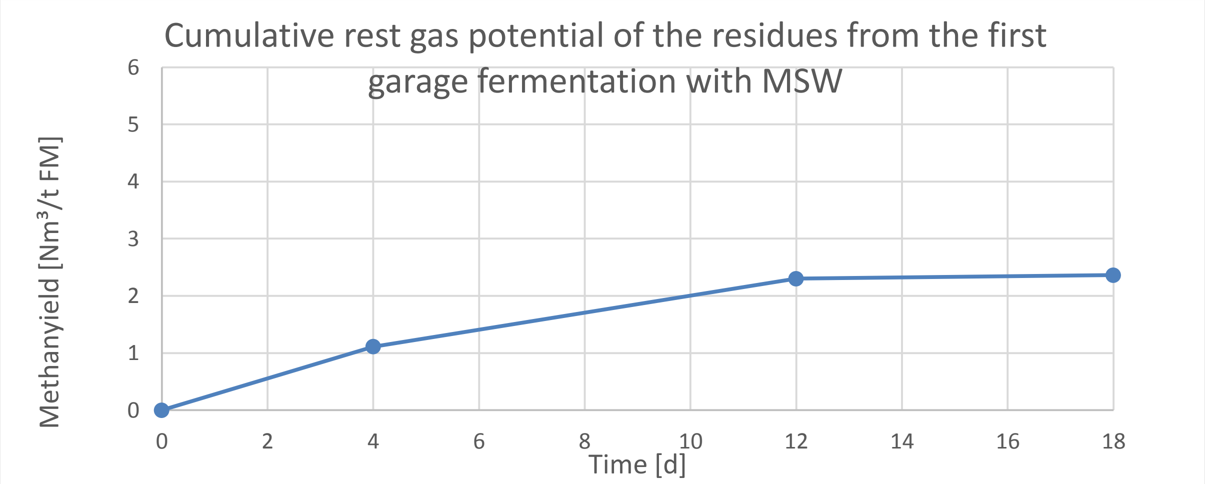


Figure 35: Cumulative rest gas potential of the residues from the first garage fermentation with MSW.

Fehler! Verweisquelle konnte nicht gefunden werden. shows the average biogas production rate per hour on the left ordinate. The related methane amount given in

percentage of volume is shown on the right ordinate. It is noticeable that the production of biogas started from day 1. From day 5 there was a significant reduction in the production rate.
The maximum production rate is approx. 5 [l/h], the maximum methane amount is 63%.

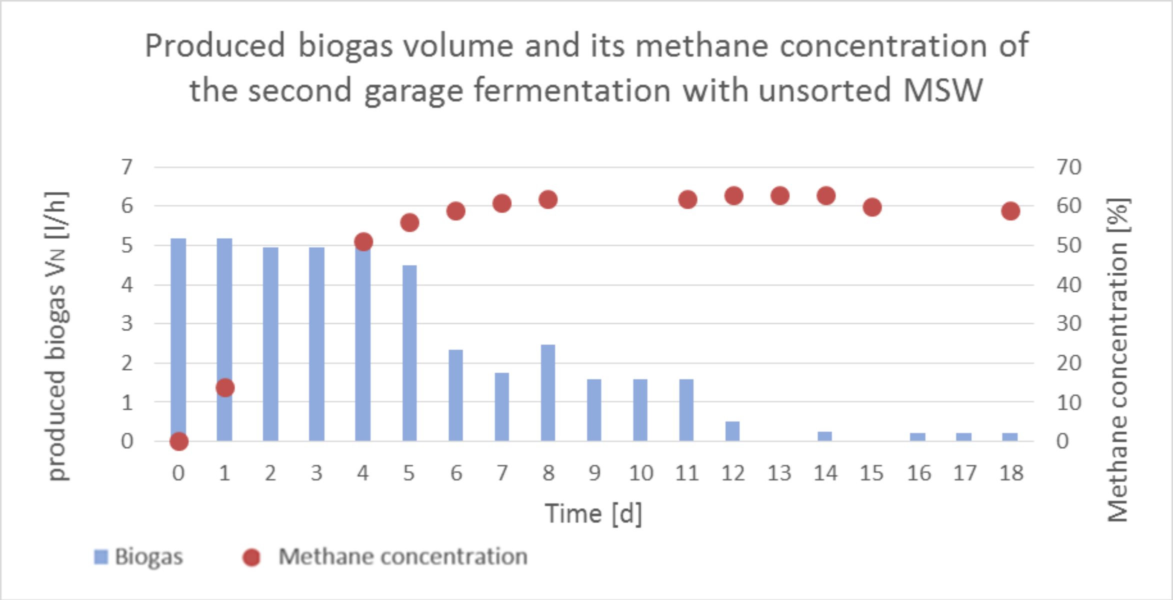


Figure 36: Produced biogas volume and its methane concentration of the second garage fermentation with unsorted MSW.

Figure 37 shows the cumulative methane production of the first garage fermentation with MSW in standardized conditions per ton fresh matter. There is a constant rise of the production. The last value is approx. 41.5 [Nm³ Methane/t FM (MSW)].

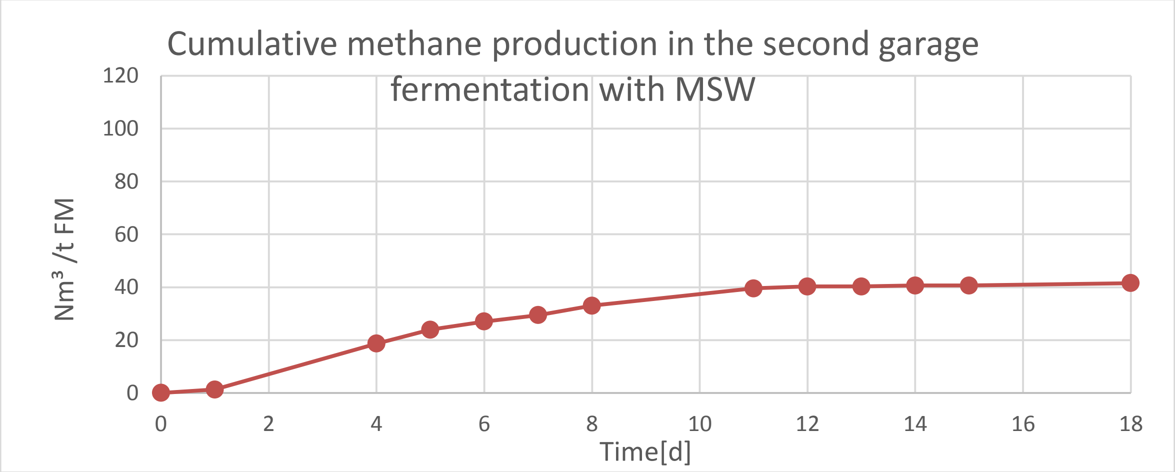


Figure 37: Cumulative methane production in the second garage fermentation with MSW.

As there has been material from former batch operation mixed with the MSW, a correction of these values was necessary. This correction resulted in a total methane production of approx. 42.7 [Nm³/t FM (MSW)] in this batch. This would mean an average methane content of 54.3% and on overall biogas volume of 81.4 [Nm³/t FM (MSW)]

1.5.4 Results from pilot plant operation with MSW in Sweden

The pilot plant has been fed with pre-sorted MSW as exemplary described in chapter 1.3.1 . The feeding rate has been raised during time of operation which can be seen in the organic loading rate and its resulting retention time in Figure 38. The final loading rate was approx. 4.0 [kg VS/m³*day]. Due to a lack of personnel and time it was not possible to have the complete fermenter volume exchanged for at least one time.

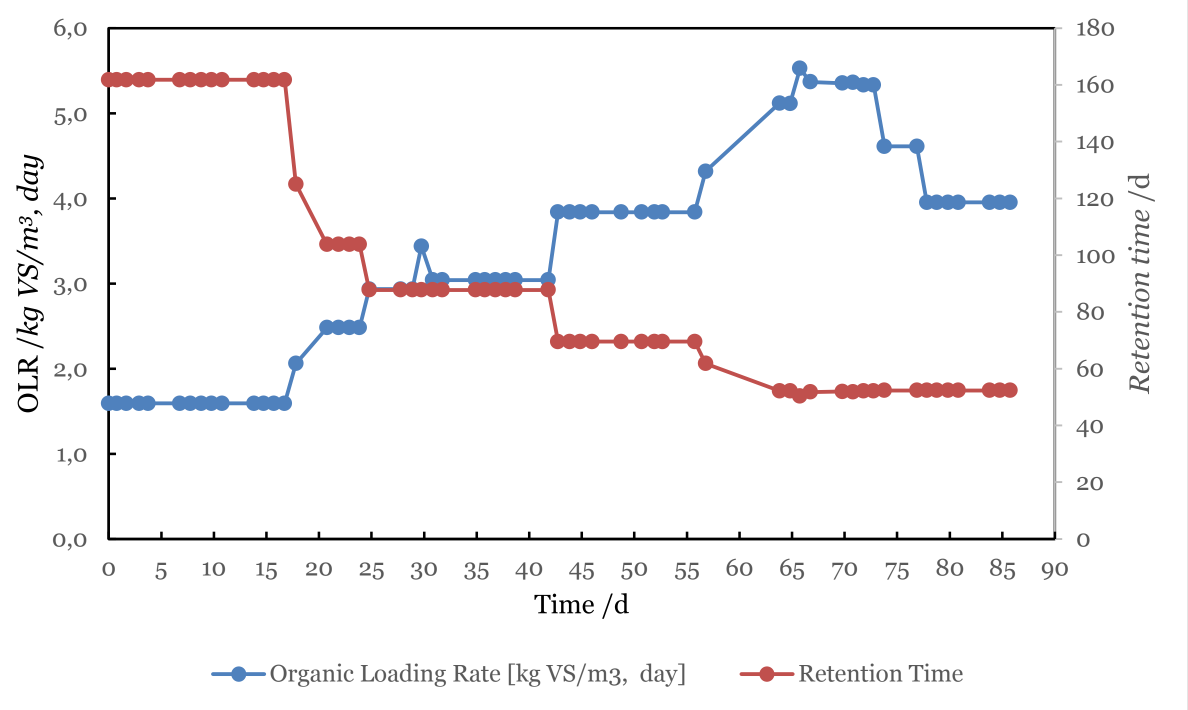


Figure 38: Overview on Pilot B loading rate and resulting retention time during operating period in Sweden.

Figure 39 shows the progression of the dry matter (TS) and organic dry matter (VS) content of the digestate during the Swedish operating period. Starting from approx. 15% TS, the dry matter content of the digestate went up to approx. 30% TS at the end of the operating period.

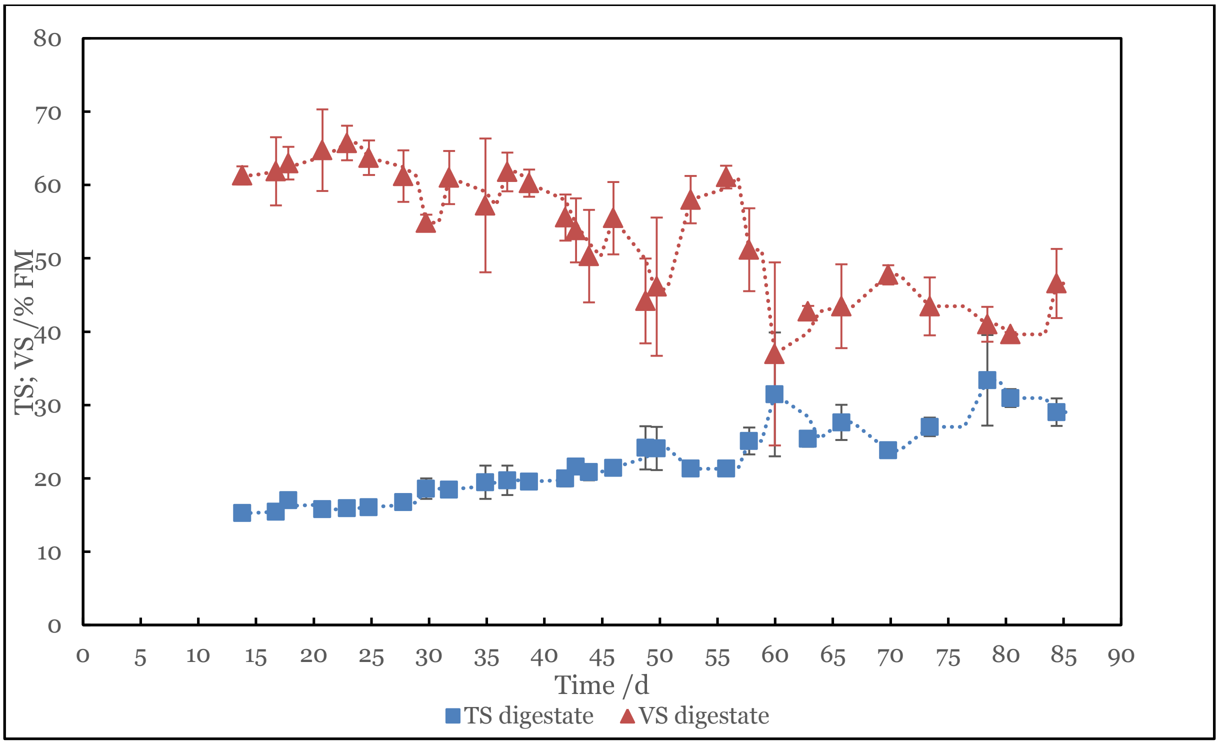


Figure 39: Dry matter (TS) and organic dry matter (VS) content of the digestate removed from Pilot B during time of operation.

Figure 40 shows the development of the biogas yields, referring to the organic dry matter input, the fresh matter input and per m³ of reactor volume. The average biogas yield per ton of MSW fresh matter is approx. 130 m³ / Mg (FM).

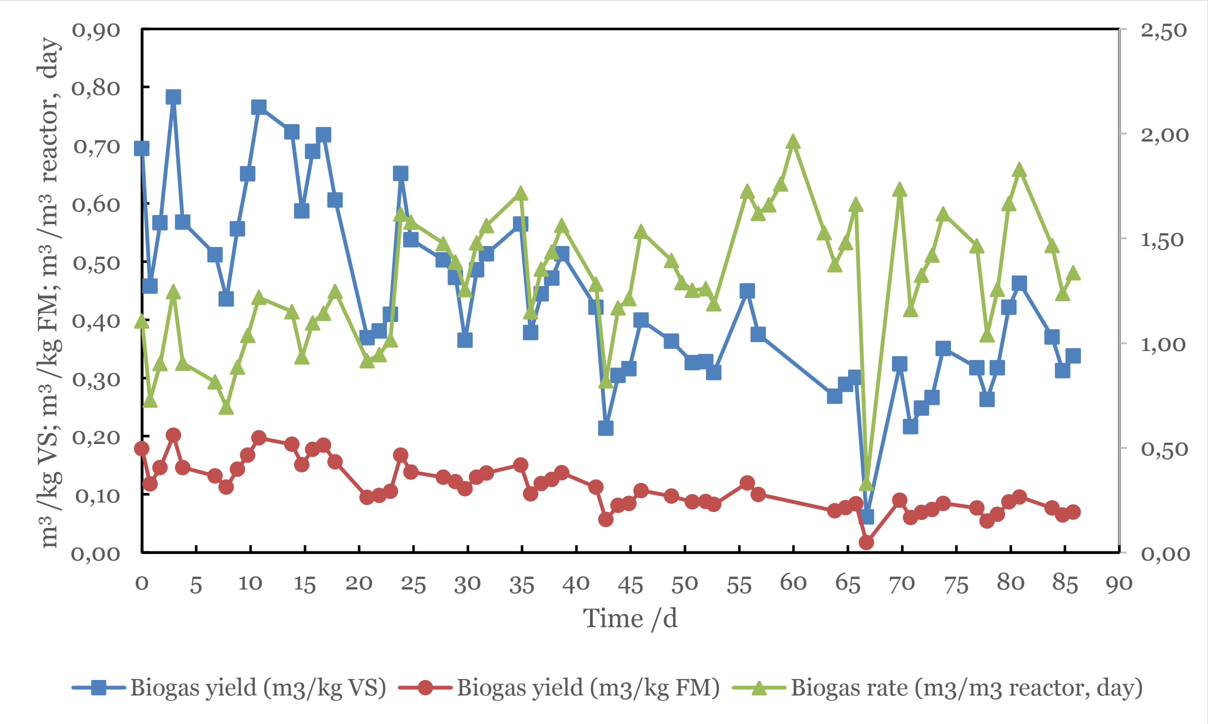


Figure 40: Biogas yields of the MSW during the Swedish operating period.

Figure 41 shows the development of the different gas concentrations. As the measuring device for H2S was broken, these values are missing. The average methane concentration in the biogas was 58.29%, resulting in an average methane yield per ton of fresh MSW of 75.7 m³/ Mg (FM).

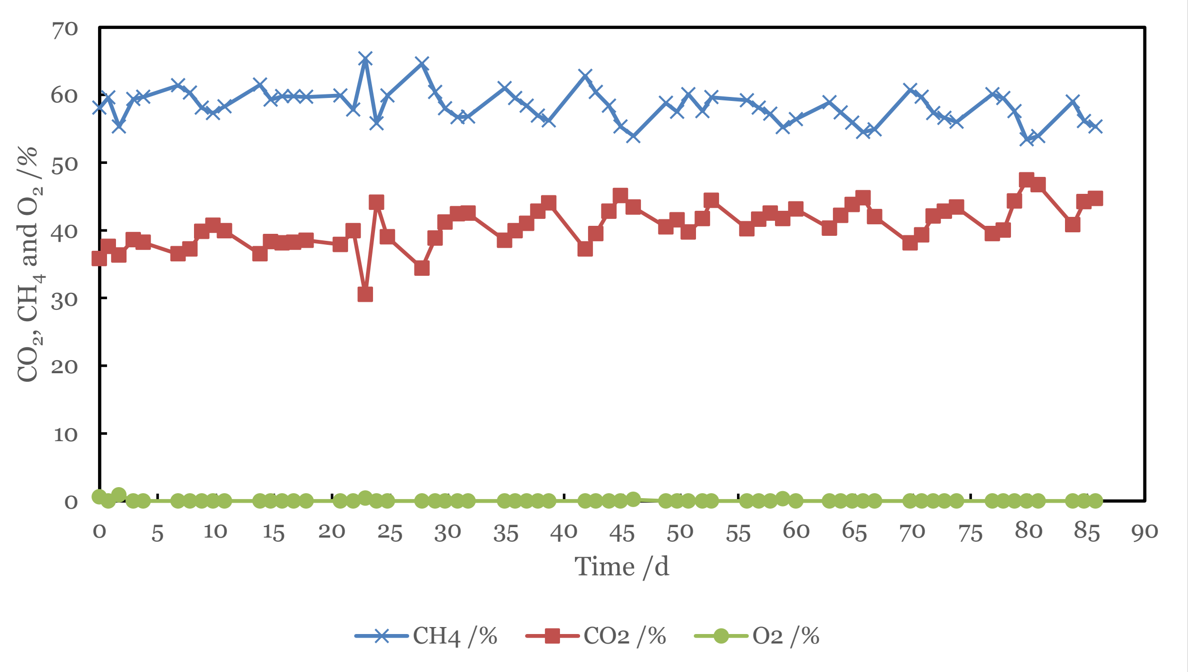


Figure 41: Concentrations of CH_4, CO_2 and O_2 in the produced biogas.

Figure 42 shows the development of the volatile organic acids (VOA) in comparison to the total anorganic carbonate (TAC) (VOA/TAC ratio). Starting with stable condition around 0.3 the VOA/TAC went up to a maximum of 0.9 at the end of operation. This also relates to the high amount of volatile organic acids shown in Figure 43. Even though the process could have been seriously inhibited, the fermenter still produce satisfying amounts and concentrations of biogas.

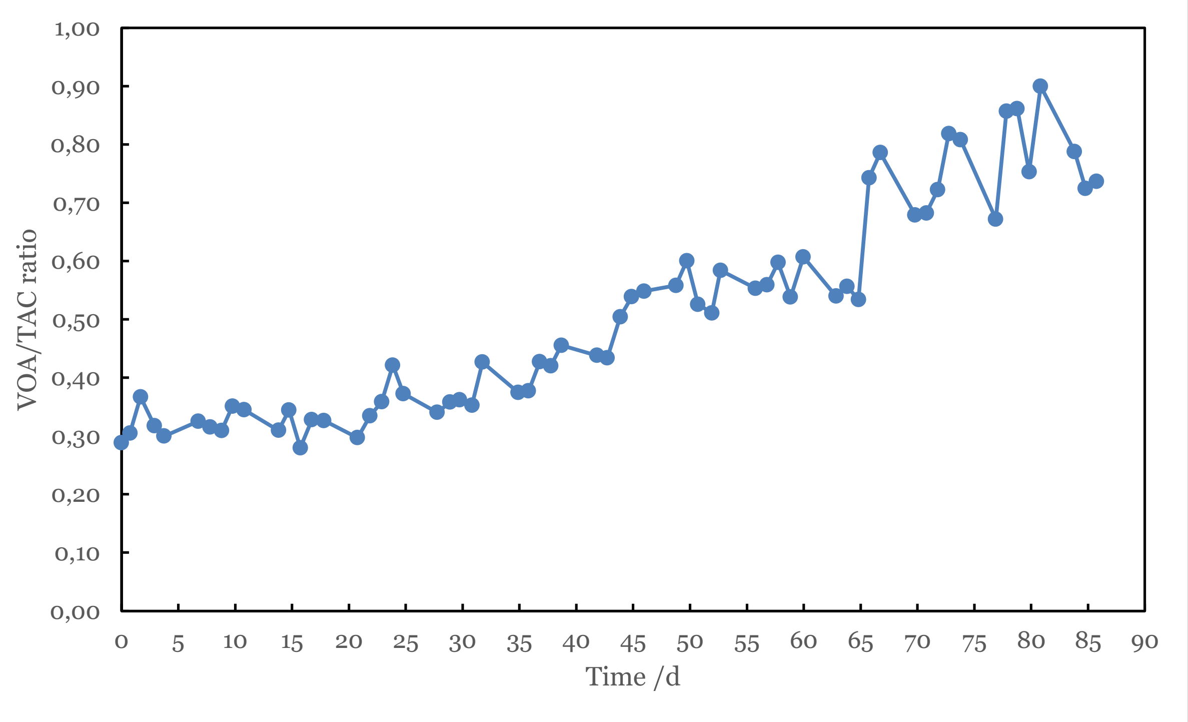


Figure 42: Development of VOA/TAC ratio during the time of fermenter operation.

In Figure 43 the development of relevant volatile organic acids. The concentration responses to the organic loading rate (Figure 38) and the VOA/TAC ratio (Figure 42).

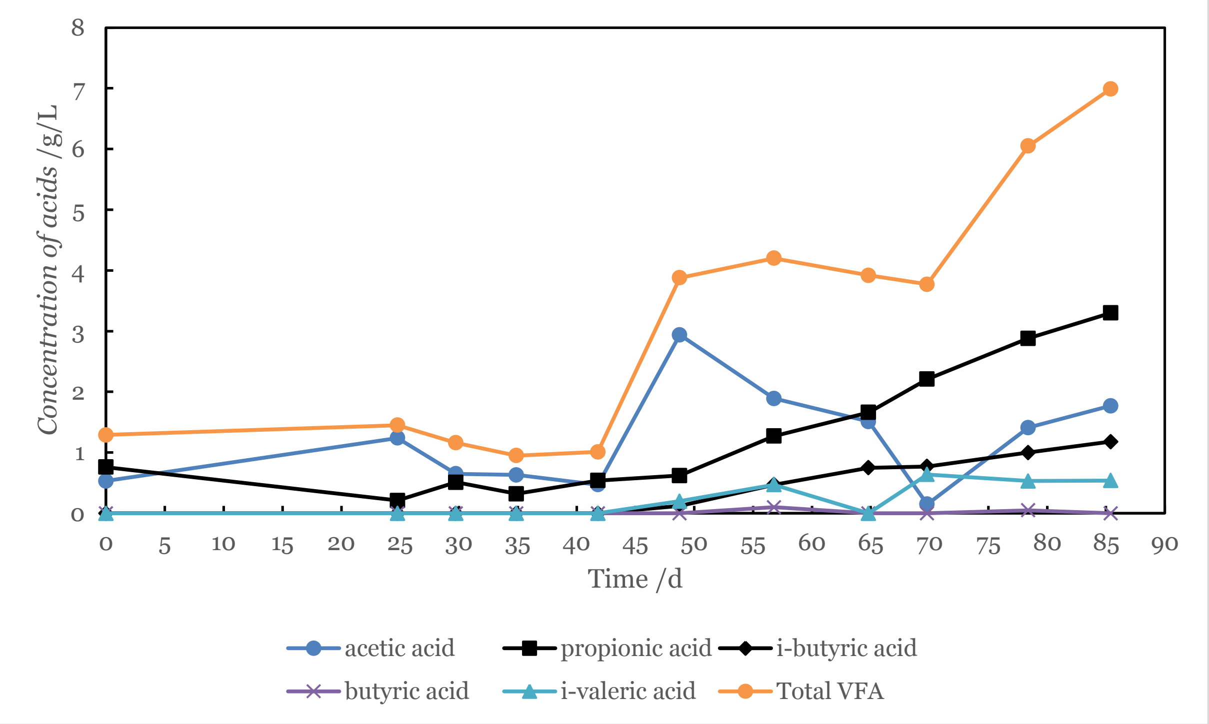


Figure 43: Development of volatile organic acid concentrations in the digestate.

Although the concentration of the acids rose during the testing period, no inhibitory effect for biogas production could be observed. As the pH only varied in a narrow range, the buffer capacity of the MSW seemed to be pretty high.

1.5.5 Comparison

In the following, the results from the different fermentation methods mentioned above shall be compared.
Table 6 gives an overview of the methane yields from each of the different fermentation methods.

Table 6: Results of each fermenter for overall comparison

Fermenter Type	Substrate pre-treatment	Average CH4/fresh mass (Nm^3/Mg FM)
Average from thermo- and mesophilic batch tests	Sorted, sanitation at 70ºC for 1 h	68.48
Mesophilic Wet Digester	Sorted, sanitation at 70ºC for 1 h	70.96
Thermophilic Dry Garage Fermenter	Unsorted, no pre-sanitation	53.95
Thermophilic Plug Flow Fermenter	Sorted, no pre-sanitation	75.78

Results show, that plug flow dry digestion offers the best methane yield per ton of fresh MSW (75.78 Nm^3/Mg FM). The results of the mesophilic wet digestion are close to the one from dry digestion, but it must be said that the possible organic loading rate of these fermenters is much smaller. So that in comparison the overall production rate of a full scale plant of comparable dimension would be much lower.
Garage fermentation has the lowest production rate (53.95 Nm^3/Mg FM). But it must be taken into account, that the waste used in the garage fermentation has not been pre-sorted. So at least up to 25% of the input material would not have been biodegradable.

Overall data show a good biogas production by MSW. Compared to literature data, biowaste produces approx. 110 Nm^3 (biogas)/Mg (FM) [19] with a methane content of 60%. This data matches quite well with the data gained in the practical tests with MSW. With consideration of the share of undegradable matter in the MSW the results are very promising.

1.5.6 Digestate and leftover handling

From plug flow digester

One main problem when working with MSW as a substrate is the handling of the digestate. Due to a huge bandwidth of harmful substances in the MSW that can accumulate in the digestate the disposal or follow up utilization as a fertilizer can become problematic.
The disturbing materials such as stones, metal parts and plastics can also cause heavy damages to the fermenter equipment. Resulting from these difficulties, the amount of digestate that needs to be treated should be kept to a minimum. To avoid technical process problems, a reduction of disturbing material, as mentioned above, should be taken into account. The best solution for MSW as a substrate would be a mechanical pre-sorting of the waste. While disturbing parts would be removed, the resulting size of fermenters would lower as well. Also the biogas yield in comparison to the input material would rise.

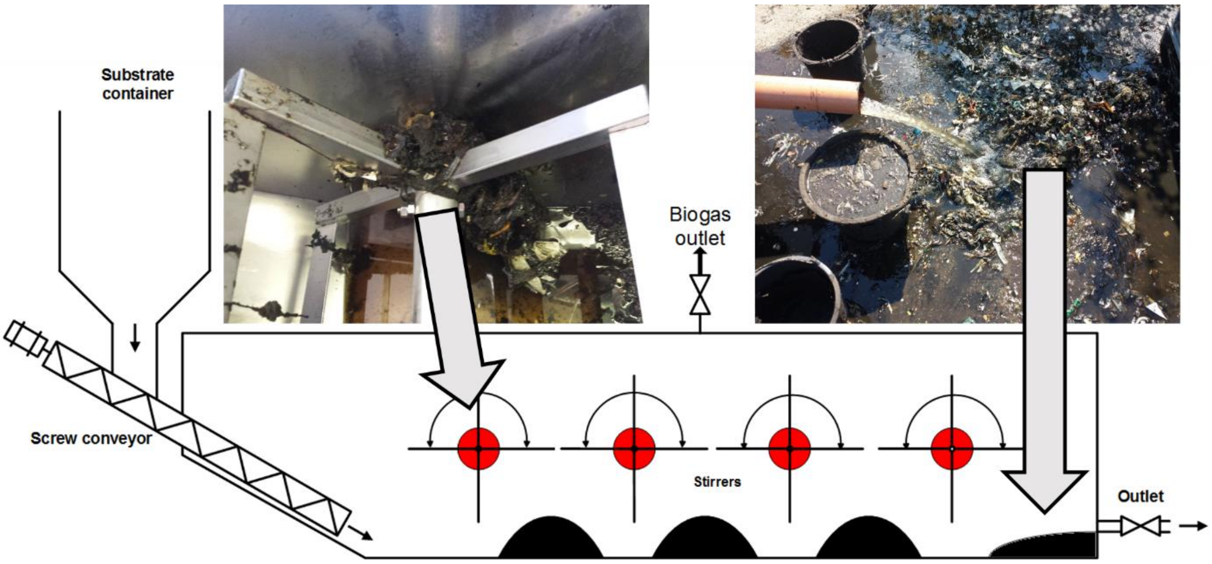


Figure 44: Plastics wrapped around the stirrer shaft/blades (left, red). Glas, stones and metal parts sediments (right, black).

From garage fermenter

Of course, material handling in the garage fermenter was much easier, as there are no moving parts. Figure 45 and Figure 46 show the container of the garage after the two batches. The yellow quadrangles show areas where the sprinkled percolation liquid washed away. The red marked area has not sufficiently been sprinkled with the liquid. If you look at the material in detail, there are areas with less degraded matter. So the percolation system needs a little work over.

Figure 45: Residues in the container of the garage fermenter after first batch.

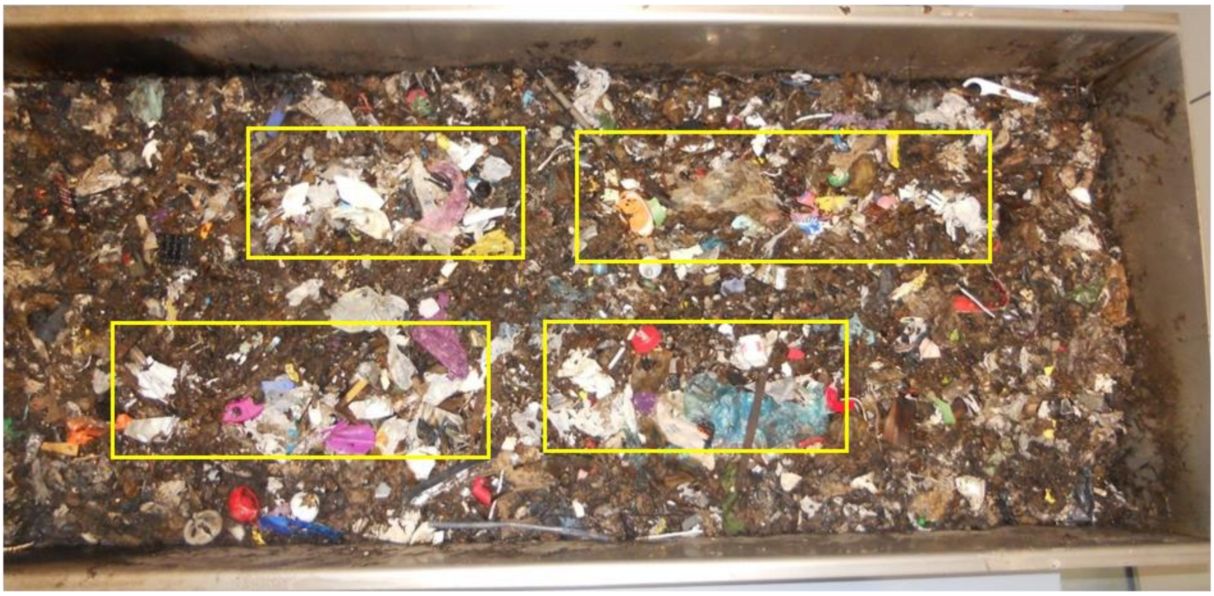


Figure 46: Residues in the container of the garage fermenter after first batch.

Digestate washing, 21th July 2014

To check the composition of the digestate, a daily amount of removed material has been washed.

The removed amount of 8.19 kg fermentation residues has been put into a sieve (screen size 2 mm). Than the material has just been washed with water to flush all soluble matter.

Before and after the washing the material has been weighed. See Figure 47 and Figure 48 for the setup.

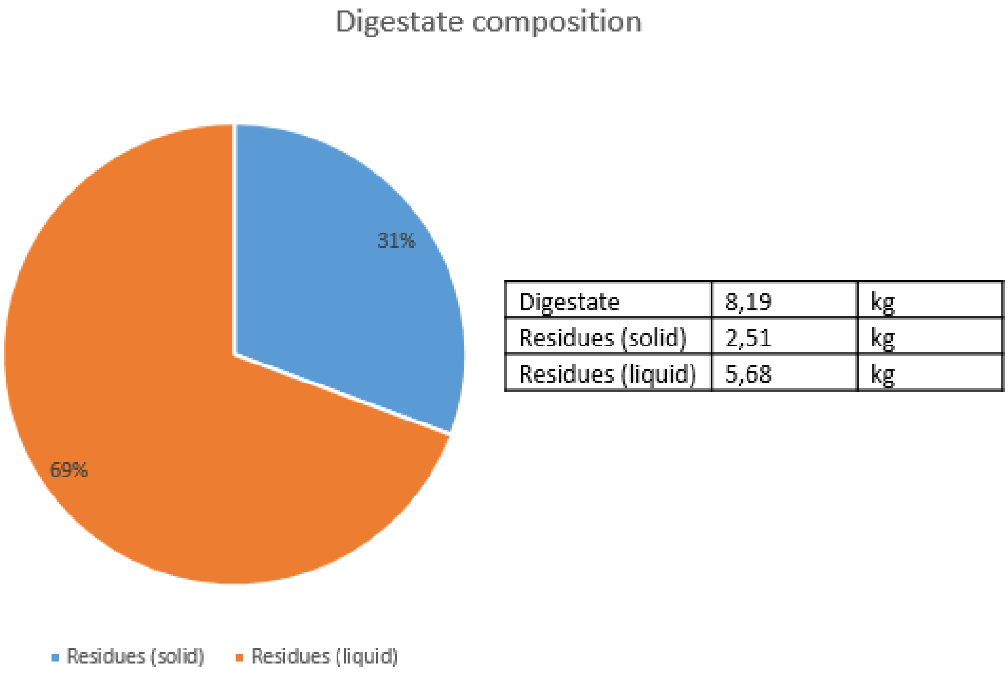
Figure 47: Leftovers after washing of the fermentation residues. 26% of digestate wet matter.

Figure 48: Impression of the residues after digestate washing.

Figure 49 shows the remains after digestate washing. Compared to the input material the degradation of the organic material is obvious.

Figure 49: Residues after washing the digestate.

The amounts of solid and liquid (≤ 2 mm / soluble) can be seen in Figure 50.



Digestate	8,19	kg
Residues (solid)	2,51	kg
Residues (liquid)	5,68	kg

Figure 50: Digestate composition.

The biological treatment of MSW leads to high contents of heavy metals so that in Germany in accordance to the Waste Disposal Directive and the EU Landfill directive the disposal of the digestate from MSW fermenters is obligatory. The biological treatment of MSW is not seen as recycling but as a pre-treatment before disposal and thus in its aims equivalent to those of waste incineration:

- minimisation of volume and mass
- inertization of the waste (minimization of the organic fraction)
- concentration of pollutants

The digestate of the treated waste is stabilized (mostly aerobically composted) to reduce smell emissions and improve the deposit ability and afterwards landfilled.

The concentrations of selected heavy metals is displayed in the following tables and figures. All of the selected heavy metals show the trend of accumulating during the time of operation. For more significance a long term study is necessary.

Table 7: Concentrations of selected heavy metals (Cu, Cr, Ni, Zn, Mn) in the digestate.

Date	Cu (mg/kg TS)	Cr (mg/kg TS)	Ni (mg/kg TS)	Zn (mg/kg TS)	Mn (mg/kg TS)
28.04.2014	47	19	11	110	-
22.05.2014	79	63	33	260	310
04.06.2014	89	58	25	310	320
17.06.2014	93	94	36	300	290
01.07.2014	100	130	63	300	270
15.07.2014	90	57	28	320	270
23.07.2014	93	110	40	320	270

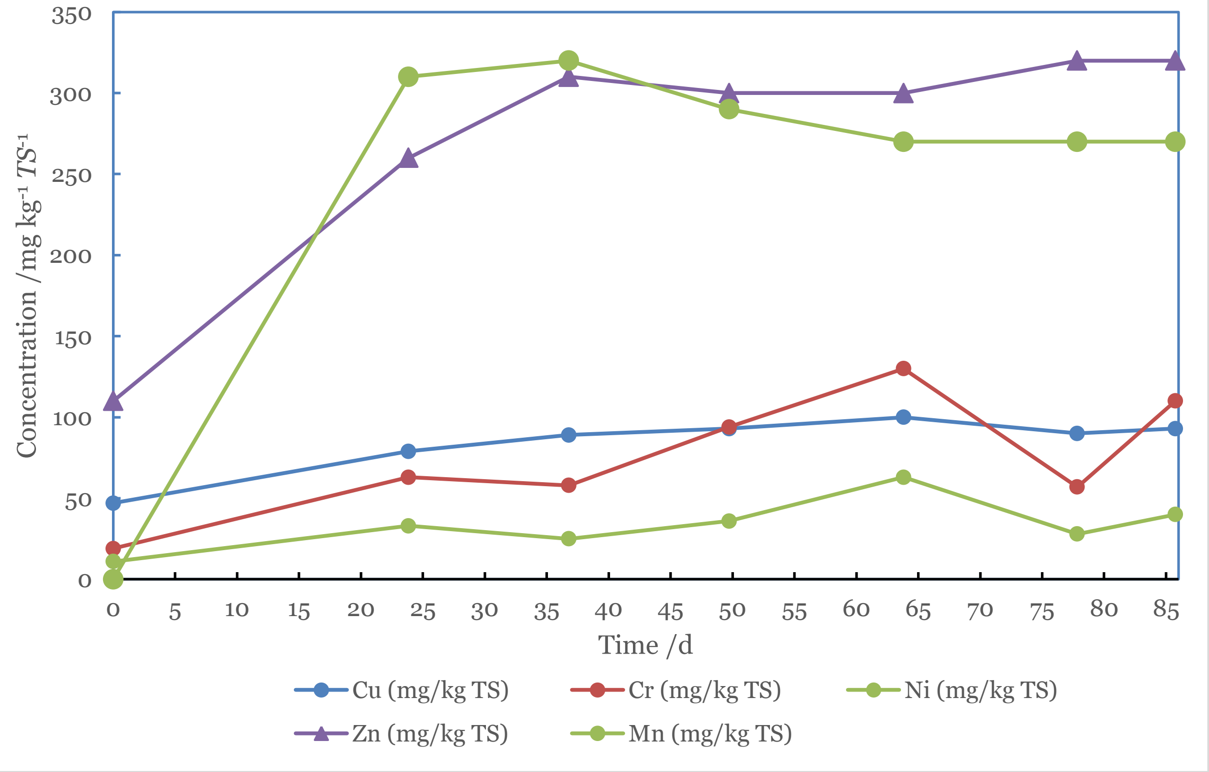


Figure 51: Concentrations of selected heavy metals (Cu, Cr, Ni, Zn, Mn) in the digestate.

Table 8: Concentrations of selected heavy metals (Pb, V, As, Mo, Co, Hg) in the digestate.

Date	Pb (mg/kg TS)	V (mg/kg TS)	As (mg/kg TS)	Mo (mg/kg TS)	Co (mg/kg TS)	Hg (mg/kg TS)
28.04.2014	5.9	-		3.1	4.8	0.033
22.05.2014	16	11	1.8	-	5.6	0.026
04.06.2014	21	13	2.2	-	6.4	0.036
17.06.2014	26	14	2.2	-	5.4	0.039
01.07.2014	27	14	2.2	-	4.5	0.037
15.07.2014	28	8.4	1.8	-	3.6	0.043
23.07.2014	49	10	2	-	3.5	0.035

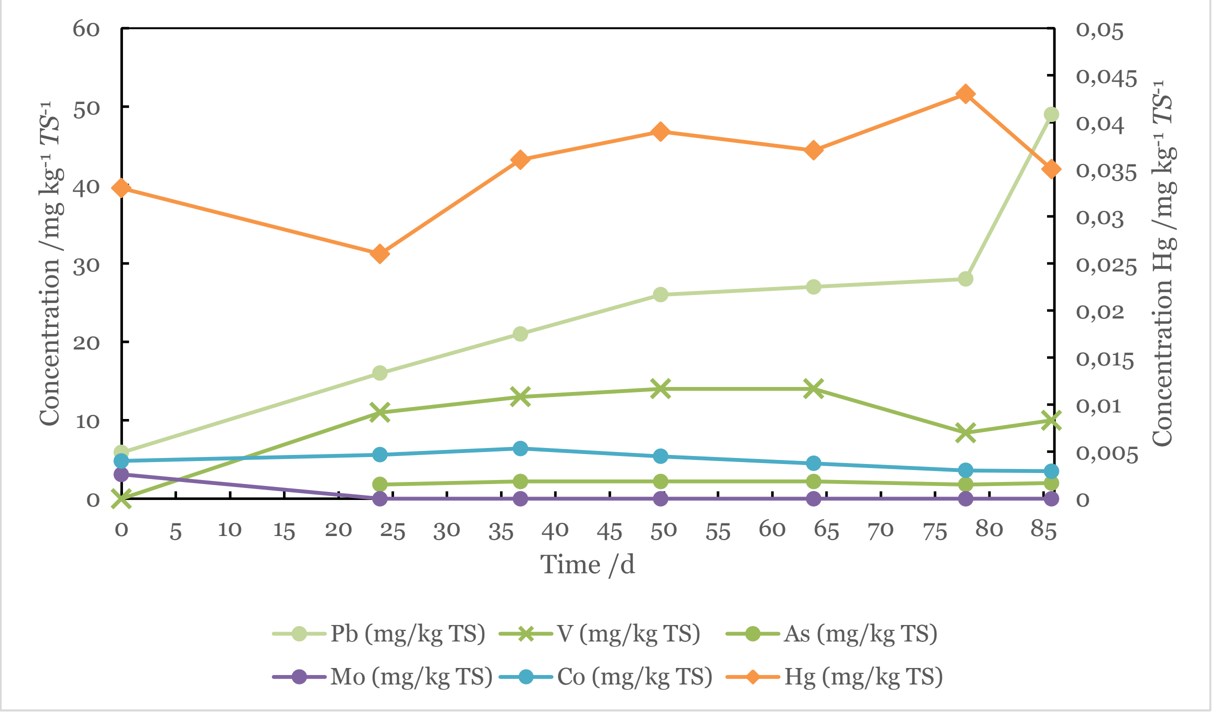


Figure 52: Concentrations of selected heavy metals (Pb, V, As, Mo, Co, Hg) in the digestate.

1.6 Technological up-scaling to implementation

Based upon the data gained from the practical testing, the necessary size of two full scale plants (plug flow- and garage digester) will be calculated.
It is assumed, that 30,000 Mg of municipal solid waste (MSW) are available per year. This material will be used as it is for the calculations of the garage fermentation system. For the plug flow dry digester it is assumed that on an average 20% of the material will be sorted out before feeding it to the fermenter.
More assumptions that are the basis of these calculations are given in Table 9 and Table 10.

Table 9: Assumptions for up scaling calculations of a full scale plug flow dry digester.

Available substrate (MSW pre-sorted) for plug flow digestion	24,000 Mg/a (FM)
Estimated VS(%FM) of the MSW	34%
Methane yield plug flow digester	75 Nm^3/Mg (FM)
Organic loading rate of the plug flow digester	8 – 10 kg(oDM)/m^3*day

The estimated methane productivity of MSW makes it possible to calculate the producible volume of methane:

$$V_{CH4} = m_{MSW} * \eta_{CH4\,per\,Mg\,MSW} = 24{,}000\ \frac{Mg}{a} * 75\ \frac{Nm^3}{Mg\ (MSW)} = \underline{1{,}800{,}000\ \mathrm{Nm}^3(CH_4)}$$

The assumed organic loading rate of 8 kg (oDM)/m^3*d for the fermenter, as well as the organic dry matter content of the substrate (34% of FM) allows to calculate the necessary fermenter volume:

$$V_{fermenter} = \frac{m_{manure} * w_{oDM}}{oLR * 365\ d} = \frac{24{,}000\ Mg * 0.34\ m^3 * d * 1{,}000\ kg\ a}{8\ kg(oDM) * 365\ d\ a\ Mg} = \underline{2{,}794.5 m^3}$$

The assumed organic loading rate of 10 kg (oDM)/m^3*d for the fermenter, as well as the organic dry matter content of the substrate (34% of FM) allows to calculate the necessary fermenter volume:

$$V_{fermenter} = \frac{m_{manure} * w_{oDM}}{oLR * 365\ d} = \frac{24{,}000\ Mg * 0.34\ m^3 * d * 1{,}000\ kg\ a}{10\ kg(oDM) * 365\ d\ a\ Mg} = \underline{2{,}235.6 m^3}$$

If two fermenters would be run in parallel operation, this could result in a fermenter size of approx. 1,500 m^3 each. It would allow flexibility for more substrate or a lower loading rate. Should sanitation be an issue, the parallel operation could ensure a sanitation effect in thermophilic conditions. In this case the two fermenters would have to be fed/extracted with a 24h delay.

Table 10 shows the assumptions made for the calculation of the full scale garage fermenter.

Table 10: Assumptions for up scaling calculations of a full scale garage digester.

Available substrate (MSW) for garage fermentation	30,000 Mg/a (FM)
Estimated VS(%FM) of the MSW	34%
Methane yield garage digester	54 Nm^3/Mg (FM)
Time for one batch	28 + 2 days[1]
Number of garages	10[1]

[1] Based on data of garage fermentation plant of AWB Munich (Renewable Energy for Munich – Green Electricity from Biowaste, 2014) [20]

The estimated methane productivity of MSW makes it possible to calculate the producible volume of methane:

$$V_{CH4} = m_{MSW} * \eta_{CH4\,per\,Mg\,MSW} = 30{,}000\ \frac{Mg}{a} * 54\ \frac{Nm^3}{Mg\ (MSW)} = 1{,}620{,}000\ \text{Nm}^3(CH_4)$$

The calculations are made for 10 separate garages to be run in multi batch, meaning each of them in a different state of fermentation. The residence time is calculated with 28 days + 2 days of emptying, maintenance and feeding per batch. This amount of fermenters is common as mentioned in Renewable Energy for Munich – Green Electricity from Biowaste, 2014.

This would mean that every one of the ten fermenters can be filled 12 times in a year. With a buffer for maintenance and cleaning work. For ten fermenters this would mean 120 batches per year.
The feeding amount for each batch would result in 250 Mg per batch.
Assumed that one garage would be filled half way up and the density of the waste to be 1 Mg/m^3, the volume of one garage would be 500 m^3. This could mean a box in the dimensions of approx. 15 m x 7 m x 5 m (L x W x H).

Summary

This report describes the practical aspects of Pilot B (pilot scale dry digestion biogas reactor) testing period in Sweden from April 2014 till August 2014. It deals with the investigation of suitable technical implementations for the use of municipal solid waste (MSW) as a substrate for biogas production for full scale biogas implementation in Sweden.

In order to gather the necessary information on substrate usability and its long term process behaviour a parallel approach has been realised. Laboratory work on the one hand as well as pilot scale examinations of the MSW on the other hand led to usable conclusions for further implementation planning.
On the basis of the results from the practical testing period calculations could be made regarding the necessary full scale fermenter sizes.

This report shall show how a concrete implementation approach will look like, consisting of:

- Identification of available usable substrates (in the best case consisting of waste)
- Laboratory substrate analysis regarding specific methane yields
- Parallel examination of fermentation behaviour in lab- and pilot size
- Calculation of plant design on the basis of the previously gained information
- Giving proof of technology for the use of MSW as a substrate for dry digestion biogas plants

Results of heavy metal analysis show an accumulation of these hazardous substances in the digestate. A long term study is recommended. It also must be checked individually if the local legal limits for hazardous substances are being satisfied.

In Table 11 you can see an overview of the main performance data of Pilot B during the Swedish operating period.

Table 11: Overall data for Pilot B operating period in Sweden

Operating time	86 days
Overall mass MSW	446.97 kg
Overall volume of produced biogas	44.88 Nm^3
Overall volume of methane	26.09 Nm^3
Resulting average methane concentration	58.3 %
Fermenter temperature	55°C (thermophilic)
Overall electricity consumption	1,787.9 kWh

2. Financial implementation report

The financial implementation report for the project phase in Sweden has a special background. In Sweden it is already decided that a new biogas plant will be built which will be operated by the Swedish company Växtkraft. Substrates which will be used are biowaste and organic parts in residual waste (see a detailed description in chapter 1.3.1)
Therefore two different biogas plant models were considered, plug flow fermenter system and garage fermenter system, both operated with municipal solid waste (MSW).

2.1 Introduction

The financial implementation report aims for answering the question, if the chosen kind of installation and especially the use of the chosen substrates is profitable, considering a period of 20 years.

The main financial and economic aspects are:
- Investment costs
- Operating costs
- Proceeds

Also in this project phase, different scenarios and the results, which arose from the operation of Pilot B and the pilot garage fermentation system, will among others be basis for the consideration of the planned large-scale biogas plants.
Therefore the detailed investigation of the data which have an influence on the cash flow is an important requirement for the decision making process. Based on the investigated data the cash flow of exemplary biogas plants will be determined in the following of this project. Anyhow it is again important to notice, that biogas plant Pilot B and the pilot garage fermentation system are experimental plants and not for commercial production of biogas.

2.1.1 General overview of the national political and legislative framework in Sweden regarding waste and energy

For Sweden a vision exists that in 2050 there will be a sustainable and resource efficient energy supply which don’t causes any net emission of greenhouse gases to the atmosphere. [1]

- Actual situation

Overall 233 anaerobic digestion plants with a total energy production of 1,473 GWh/year existed in Sweden in 2011. Most of them (135) were operated with sewage sludge, 19 with biowaste. About 50% of the produced biogas was used as vehicle fuel. In 2012 the biogas of 57 plants was upgraded, 8 of them were connected to the grid. [2]

- Targets

According to the Swedish Parliament the share of renewable energy will be at least 50% of the total energy usage in 2020. Besides the share of renewable energy in transport sector have to become 10%. As a target for 2030 Sweden's vehicle fleets have to be independent from fossils fuels and without any net emissions of greenhouse gases into the atmosphere [1]

- **Municipal solid waste (MSW)**

In 2002 landfill of sorted combustible waste and in 2005 landfill of organic waste was banned. The recycling of MSW reached 49% in the year 2010, what means only 1% less than the target set in the Waste Framework Directive for 2020. [3]

- **Biowaste**

Biowaste in Sweden exists almost completely of waste from households, only a small amount is organic material from gardens. About 60 % of the Swedish municipalities have a separate collection of food waste. Thus in 2013 711,450 tons of organic household waste (370,070 tons food waste and 341,038 tons green waste) were acquired. [18]

2.1.2 Description of pilot B site surroundings; the (see detailed information in chapter 1.1)

Västerås, a city in Swedish province Västmanland, ca. 100 km west of Stockholm, has about 111,000 inhabitants (see also chapter 1.1). [4]

The municipalities in the region with about 300,000 inhabitants took part in the planning process for the biogas plant. 90 % of the households in the region participate in the source separation scheme for biowaste, which is voluntary. They are collecting the biowaste in special paper bags.
The ”Växtkraft-plant” for the treatment of source separated household waste (14,000 tons), ley crops(5,000 tons) and liquid waste (grease trap removal sludge) (4,000 tons), was installed in the year 2005. The plant produces about 15,000 MWh biogas per year (see also chapter 1.1). [5]

- **Waste amounts**

A forecasting about waste amounts of Västeras city came to the result, that the total amount of residue waste, catering waste and packaging and newspapers are expected to increase in the range of 20 % from 2011 (appr. 40,000 tons) to 2019 (appr. 48,000 tons). The estimation is based on the assumption that waste generation per household increases by 2% per year and that the number of inhabitants in Västeras increases with 1,000 people per year. Waste minimization effects have not been taken into account. Figure 53 shows the forecasting of the generated waste amounts. [17]

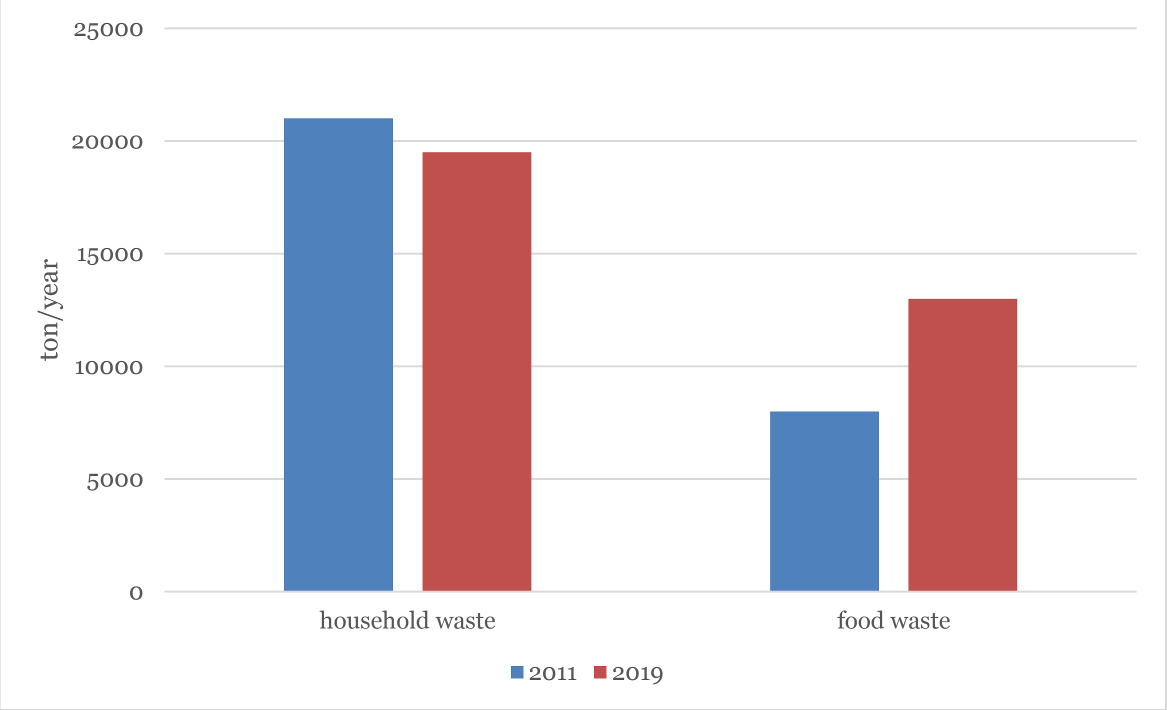


Figure 53: forecast for 2019 for residual waste and food waste at an annual population growth of 1000 inhabitants and an annual increase in the volume of waste per household with 2% [17, partly and adapted].

2.1.3 Description and evaluation of implementation Scenario 1: treatment of the organic fraction of household waste (30 – 40 mm) (see also chapter 1.5)

The treatment of municipal household waste is considered in two different kinds of plant systems:

- Batch fermentation in garage fermenters
- Continuous fermentation in plug flow fermenter

For the use as substrate in plug flow fermenters, the household waste has to be shredded into pieces of 30 to 40 mm and contaminants like metals or glass will be sorted out. For the operation of the garage fermenters a less intensive pre-treatment of the MSW is supposed to be necessary. Spoken in general terms just a crushing of the waste into a smaller fractions might be likely. Therefore, economy calculations for garage fermentation of MSW will not consider any aspects, which are going to be affected by substrate pre-treatment.

- **Analytics at Ostfalia labs**

Ostfalia University analyzed the biogas potential of the pre-treated municipal solid waste, according to plug flow fermentation demands, in lab.

Biogas yields:

- Batch fermentation tests: about 68 Nm^3/t fresh mass
- Lab garage fermenter: 54 Nm^3/t fresh mass
- Pilot B respectively plug flow fermenter: 75 Nm^3/t fresh mass

The gas potential of the garage fermenter is lower, because the material is not presorted and therefore more material which is not useful for the process is in between the substrate.

The results of the laboratory tests are listed in chapter 1.5 .

2.2 Reporting under consideration of on-site operational data

Pilot B is located on the area of an existing biogas plant, because the task was to find additional solutions for the production of biogas. The advantage was that the existing infrastructure could be used and also the substrate for the pilot tests was available at the waste treatment area as well as the pretreatment facility.

The region of Västmanland has to fulfil the targets to produce three times more biogas till 2016. [10]
Therefore the idea was to use hackled municipal waste for anaerobic digestion.

Pilot B and the pilot garage fermenter system were therefor operated with this hackled municipal waste. The results of these in situ tests and also of laboratory tests which were done in Ostfalia labs have been used for the below mentioned economic calculations.

2.2.1 Investigated data concerning tariffs and prices

Crucial factors when considering the implementation of biogas technology are the valid tariffs and prices for energy. They were also collected for the project phase in Sweden and listed in Table 12.

Table 12: Swedish tariffs.

Electricity (household consumers)	**Electricity (industrial consumers)**	**Vehicle fuel (gas)**	**District heating**
0.1474-0.3302 €/kWh (consumption dependend)[2] [6]	0.0495-0.1387 €/kWh (consumption dependend)[1] [6]	1.47 €/Nm^3 [7]	0.041 €/kWh (excl. VAT) [9]
fresh water	**Average monthly salary (of different sectors)**	**Natural gas (household consumers)**	
1.19 €/m^3[8]	3,291 €/month [6]	0.1011-0.1581 €/kWh (consumption dependend)[3][6]	

[1] incl. network charges, tax and charge for green certificate; VAT not included
[2] incl. network charges, tax, VAT and charge for green certificate
[3] incl. tax, VAT and network charges

2.3 General information concerning financial and economic implementation of biogas technology (in reference to German biogas plants)

In output report 4.3 and also in report 4.4 different aspects of the implementation of biogas technology were been considered.
Therefore general information concerning the occurring investment and operating costs were given based on different German biogas plants and also on general data which were available from different sources.
Thus chapter 3.3 for the project phase in Sweden is based on the information given in the former output report but updated in some cases and complemented with some additional information.

2.3.1 Cost factors

As mentioned in the former output reports besides investment costs for the building of the biogas plant there are operational costs. For the calculation of cash flows in advance for the consideration of the profitability of the implementation of biogas technology both kinds of expenses have to be taken into account.

2.3.2 Specific investment costs

Depending on the size of the biogas plant especially the specific investment costs are varying. Below (Table 13) specific investment costs are listed. As they are still valid for the considerations in ABOWE they are mentioned again in this chapter:

Table 13: specific investment costs related to biogas plant (CHP-unit) size [11](German literature source).

Size of biogas plant	**Specific investment costs**
75 kWel	ca. 9,000 €/kWel
150 kWel	ca. 6,500 €/kWel
250 kWel	ca. 6,000 €/kWel
500 kWel	ca. 4,600 €/kWel
750 kWel	ca. 4,000 €/kWel
1 MWel	ca. 3,500 €/kWel

These amounts are key values for the calculation of average investment costs of biogas plants. They were determined by investment costs for different German agricultural biogas plants. When thinking about special requirements concerning the operation of biogas plants as the use of for example municipal solid waste in garage fermenters there might be adjustments and modifications necessary. That could be additional costs for pre-treatment of the substrate. Apart from that in Sweden is no CHP-unit necessary, because there will be no production of electricity but the use of conditioned biogas mainly as fuel. That means the costs for the upgrading of the biogas have to be considered.

In the below done calculations for model biogas plants it was tried to consider many facts. See therefore more detailed specific investment costs in Table 14.

Here the specific investment costs for biogas plants with biogas upgrading are listed.

Table 14: economic key figures concerning investment costs for biogas plants [11].

Size of biogas plant	**Specific investment costs**
Biogas plant with biogas upgrading 400 Nm³/h	ca. 9,600 €/Nm³*h
Biogas plant with biogas upgrading 700 Nm³/h	ca. 9,100 €/Nm³*h
Biogas upgrading facility	
400 Nm³/h	3,600 €/Nm³*h
700 Nm³/h	2,400 €/Nm³*h

As mentioned in output report 4.3 it has to be taken into account that the investment costs for biogas plants using biowaste as substrate are about one third higher than for biogas plants using for example renewables (see Figure 54). Therefore Figure 54 is included into this report again.

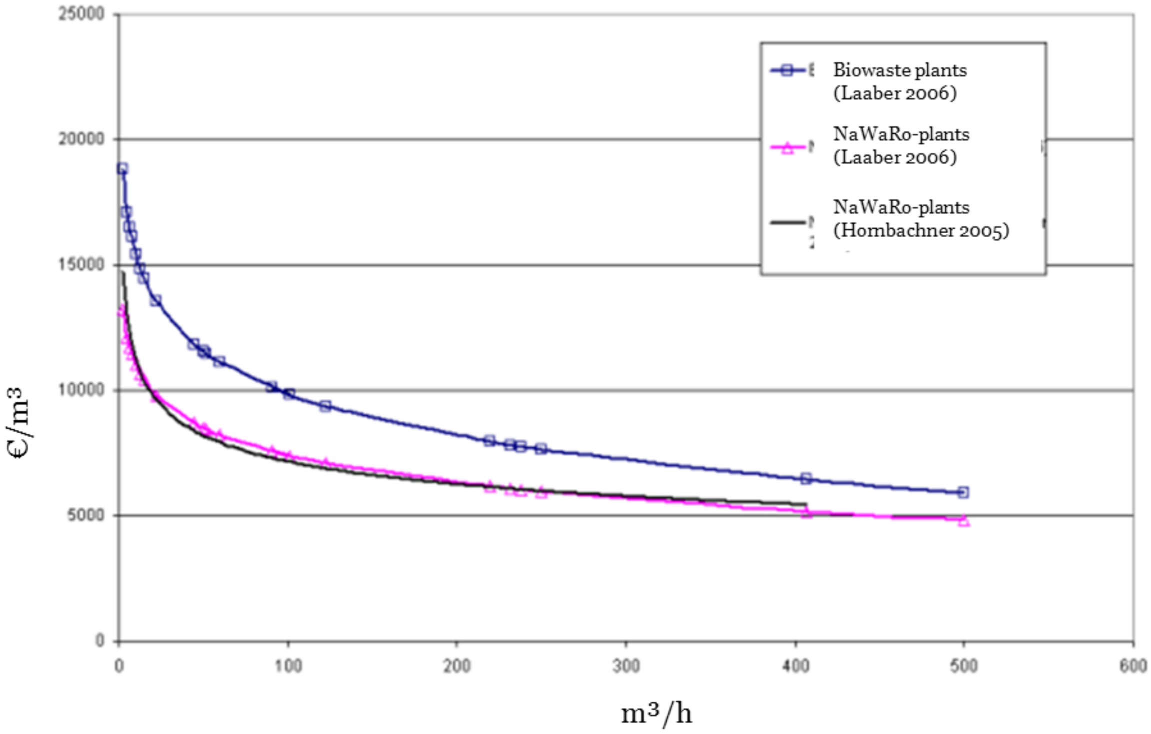


Figure 54: specific investment costs (without CHP and biogas processing in €/m³ related to size of biogas plant (m³/h) [12].

What has to be mentioned again, is that all these specific costs are based on data of different German biogas plant. Depending on the considered country different cost items are varying strongly. Especially the personnel expenses have to be adapted individually.

2.3.3 Operating costs

The operating costs of a biogas plant have to be adapted to the special requirements. Besides general information concerning personnel costs and revenues, the following cost items are to be mentioned:

- Maintenance and repair
- Purchased services and goods: analytics, fresh water, waste water, diesel for wheel loader, others
- administrative costs
- Service contracts
- Operational costs for the upgrading facility
- Own heat demand
- Own electricity demand
- Costs for transport and disposal of digestate
- Insurance

The calculation methods for these cost items are specified in Table 18.

The digestate of the planned process has probably to be disposed of. Therefore additional operating costs (e.g. for incineration) have to be considered. (see calculation of cash flows, Table 17 and Table 18).

The key values for these cost items are mostly basing on average costs which occurred for German biogas plants. The key values can be found in Table 18.

2.3.4 Biogas upgrading

For the upgrading of the biogas additional operating costs will occur. Besides the need of electricity, maintenance, repair and working time there is especially a high need of water.

In Figure 55 additional operating costs for the biogas upgrading (here by pressure water scrubbing) are shown in relation to the hourly biogas production. A liquefied gas dosage is actually (at Växtkraft plant) not necessary and therefore not included in the below mentioned calculations.

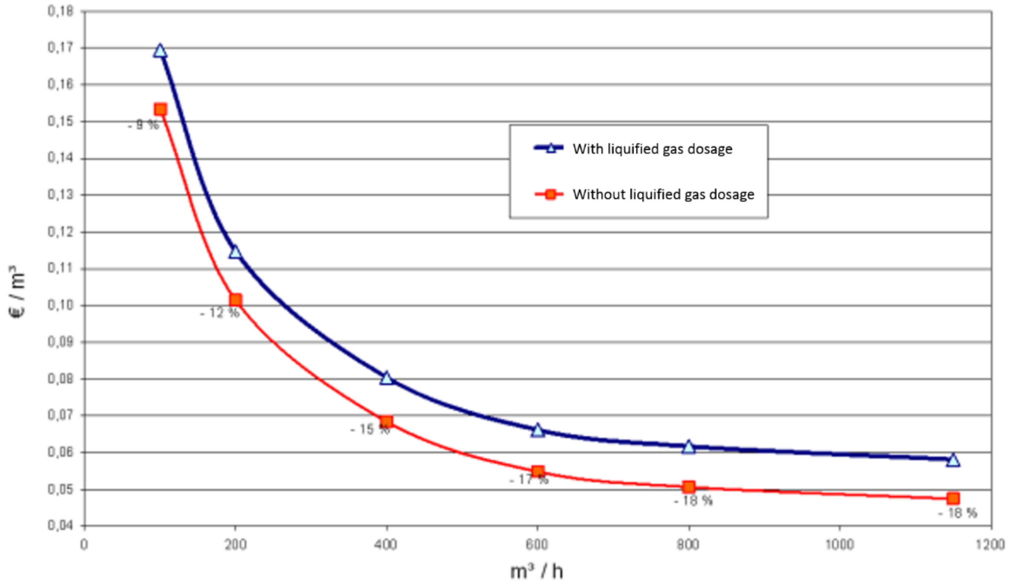


Figure 55: operating costs with and without liquified gas dosage by pressure water scrubbing dependent on the plant size [16].

2.3.5 Personnel costs

Based on Figure 56 the personnel costs which occur for the operation of a biogas plant (working hours) were calculated. The figure was already included into output report 4.4.

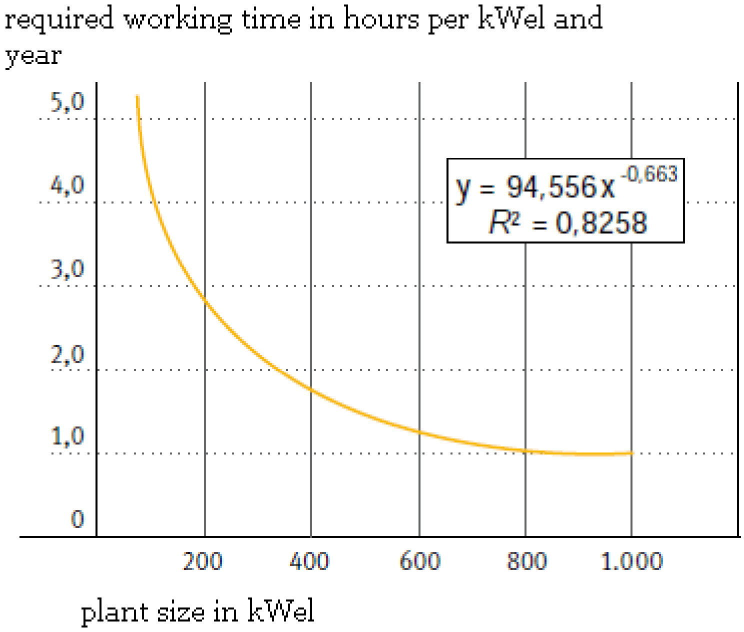


Figure 56: required working time for maintenance (without feeding) [13].

Figure 56 has to be considered critically because the resulting required working hours seem to be insufficient for the operation of biogas plants, especially of plants of bigger sizes.

Especially when thinking about garage fermenter systems the additional effort for feeding has to be taken into account. Therefore additional working hours are necessary. Basing on data of KTBL (Kuratorium für Technik und Bauwesen in Landwirtschaft-Advisory board for technology and building in agriculture) these additional costs can be considered with an average value of 2 min/ton (plug flow fermenter system). [14]

The differences in the required working time are of high importance and have to be considered according to the installation engineering.

Depending on the pretreatment of the used substrate, in case of Sweden organic amounts of municipal solid waste (MSW), there might occur additional personal costs.

In case of the MSW it is probably necessary to sort impurities like plastics, glass and hazardaous waste out of the substrate.

2.3.6 Revenues

Generated revenues of a biogas plant can be:

- Sale of electricity
- Sale of heat
- Sale of gas
- Sale of digestate
- Gate fees for the treatment of MSW and biowaste

For the case of Sweden only the sale of biogas has been considered, because there will be no production of electricity but upgrading of the biogas.

The upgraded biogas will mainly be used as vehicle fuel.

In case of the use of biowaste or municipal solid waste the operator of the biogas plant will get gate fees. Therefore also an income from the substrates can be considered.

2.4 Economic and Financial implementation in reference to Swedish models and conditions

The target of the project in case of Sweden is the implementation of a biogas plant operated with MSW. Therefore different kinds of technologies and also the economy have been considered.

With data of German biogas plants (data from operators or other data sources) and results of other researches the theoretical construction and economic calculation as well as the consideration of the development of cash flows over a period of 20 years was done.

In chapter 2.3 additional information (in addition to O4.3 and O4.4) to general data were collected concerning the investment and operational costs of biogas plants.

2.4.1 Investment costs

The investment costs for biogas plants with upgrading of the biogas are based on Figure 55. In the case of Sweden the produced biogas will be used as vehicle fuel and therefore sold by filling stations. The investment costs for the filling stations were not considered, because the existence of the stations was assumed.

2.4.2 Operating costs Pilot B

Target goal of the operation of Pilot B in Sweden was to use pre-treated municipal waste as input material. The material was shredded to 30-40 mm and impurities like glass, metals and plastics were sorted out.

As it applied also for the Lithuanian and Estonian project phase the operation of Pilot B itself was only for experimental training and substrate testing but not for commercial and profitable production of biogas. Also here the outcomes of the operation of Pilot B shall become the basis for the implementation of a full scale dry digestion plant.

The operating costs for Pilot B are listed in Table 15. Here the required working hours, the energy consumption (electricity), the consumption for laboratory work and the produced biogas were gathered.

Table 15: operating costs Pilot Plant B.

	amount	**expenses in €/month**
Electricity consumption	580 kWh/month	37
Water consumption	1200 l/month	1.43
Consumable lab materials		20.96
Required working time	2 h/day*person	823
Substrates: MSW	10.5 kg FM/day	-
Total produced biogas amount	41 Nm^3/day	
total		ca. 882

2.4.3 Proceeds and subsidies

- **Substrates**

The actual situation in Sweden raised the question if the organic amounts in municipal solid waste are suitable for anaerobic digestion. If the results of the project ABOWE show that this consideration is technically and economically feasible, a biogas plant will be built using this material as substrate.

As it is actually given at the existing biogas plant the operator therefor will earn revenues from the use of MSW.

- **Upgraded biogas**

In case of Sweden the production of electricity by a CHP-unit is out of the question. The produced upgraded biogas would be sold as vehicle fuel. Therefore filling stations are already existing.

- **Digestate**

The residues of the biogas process are generally suitable for the use as fertilizer and soil conditioner when using biowaste as substrate. The use of MSW and the handling of the produced digestate is one of the questions which has been discussed among the stakeholders during this project phase and further on. The question how the digestate will be disposed of is finally not resolved.

- **Funding**

In Sweden there is no carbon dioxide or energy tax on biogas. In 2013 that was a value of 68 €/MWh compared to petrol.

Moreover the income tax will be reduced by 40% when using biogas for company natural gas vehicles.

For the marketing of new technologies and solution for biogas investment grants are possible up to an amount of 45% of the investment costs. [2]

2.4.4 Calculation of model biogas plants

As in the former output reports model biogas plants were calculated based on the results of the Pilot B operation and lab tests at Ostfalia University (see chapter 1.6) Additional results are available from the operation of the pilot garage fermenter system. Basing on these results an economic estimation was done in the following (see Table 17).

Figure **57** illustrates which calculations (concerning financial aspects) were done in relation to the different scenarios.

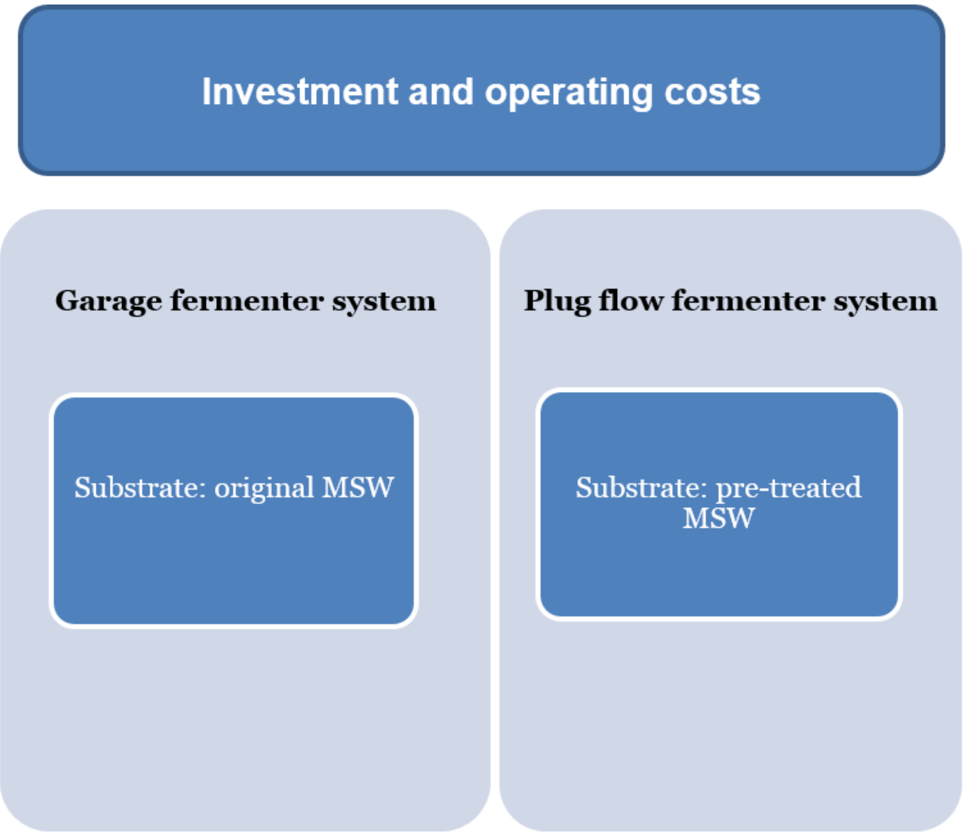


Figure 57: Illustration of considered biogas plants

Because the considered biogas plant systems vary in technique as well as in operation the calculation of the cash flow differs in the used key values.

Background information regarding plug flow fermenter system

- Investment costs:

The investment costs for a plug flow fermenter system refer to Table 14 as well as the information given in Table 17. There is no CHP-unit necessary but an upgrading facility for the biogas, so the investment costs depend on the amount of the produced biogas.
The investment costs for the upgrading facility were considered in the economic calculations, the costs for the filling stations not.

For the operation of a plug flow fermenter system a complex pretreatment of the material, when using e.g. waste, is necessary. The investment costs for the biogas plant therefore can be increased by up to 30% (see figure 1).

The treatment also causes material which is not usable for digestion, in case of MSW the sorting of the material for the operation of Pilot B made a sum of 20%. That means only 80%

of the MSW are suitable for anaerobic digestion (see also chapter 1.3.1 concerning the waste sorting).

- Reinvestments:

Reinvestments for pumps were considered for every 4 years and onetime the whole biogas upgrading facility (amount spread over the period of 20 years).

- Operating costs:

The personnel costs refer to Figure 56. For the feeding of the fermenter additional working time of 2 min/ton was added. Also costs for one person for the administrative work were taken into account.
The energy demand for the upgrading of the biogas was considered based on Figure 55.

Background information regarding garage fermenter system

- Investment costs:

Considering the investment costs of a garage fermenter system there might the advantage that no complex pretreatment of the substrate is necessary. That means that less additional costs will occur; specific costs cannot be estimated, therefore economy calculation will be done without consideration of additional investment costs for pre-treatment.
Also here the investment costs for the upgrading facility were considered in the economic calculations, the costs for the filling stations not.

- Reinvestments:

Costs for reinvestment of the percolate pumps are assessed after every 4 years and onetime the reinvestment of the whole upgrading facility (spitted over the period of 20 years).

- Operating costs:

The operating costs vary in comparison to the plug flow fermenter system in many aspects:

- Electricity demand: the electricity demand is lower, because there are e.g. no stirrers needed
- Personnel requirements: for feeding and emptying of the garages there is a higher need of working time; therefore the personnel costs have to be set at a higher level. Especially the resulting working hours of figure 2 have to be adapted.
- Vehicle fuel: higher need of vehicle fuel for the wheel loaders

2.4.5 Calculation of cumulative discounted cash flows

For the calculations the following assumptions were made (partly based on Table 12):

- gate fees incineration (costs): 30 €/t (estimation)
- gate fees MSW (revenues): 60 €/t (estimation)
- tariff for electricity: 0.06379 €/kWh + VAT
- tariff for district heating: 0.041 €/kWh + VAT
- tariff for gas as vehicle fuel: 1.16 €/Nm^3

The tariffs are based on the references mentioned in Table 16.

Table 16: data for biogas plant with plug flow fermenter and garage fermenter (based on own lab tests/pilot tests and calculations).

	Plug flow fermenter	Garage fermenter
Substrate: MSW for plug flow fermenter: 56 % CH4-amount, 75 Nm^3/ton MSW for garage fermenter: 56 % CH4-amount, 54 Nm^3/ton[1]	30,000 tons (untreated) resulting 24,000 tons MSW (pretreated), 75 Nm^3/ton FM	30,000 tons MSW, 54 Nm^3/ton FM
resulting theor. biogas yield (eff. 90%, estimation)[2]	2,892,857 m3 Biogas/a	2,603,571 m3 Biogas/a
resulting theor. methane yield (gas loss max. 2%)	1,619,676 m3 Ch4/a	1,428,840 m3 Ch4/a
digestate	19,977 tons	26,379 tons

[1] result from lab size fermenter and Pilot B operation

[2]in case of batch test results

Table 17: cost items for the cash flow calculation of a biogas plant with a plug flow fermenter (start values).

Cost item	**Costs in €**	
	Plug flow	**garage**
Investment costs (total)[2] - Upgrading facility[2]	4,121,330[6] 1,545,499	2,853,229 1,069,961
Operational expenses		
- Maintenance and repair[3]	43,392	39,054
- Maintenance, repair and operation of upgrading facility[4]	216,964	182,250
- Other purchased services and goods (analytics, fresh water, waste water, others)[3]	28,928 28,928	26,035 26,035
- Other administrative costs[3]	86,818	77,755
- Heat production[3]	77,039	23,188
- Electricity[3]	49,517	71,870
- Personnel costs (operational labour, feeding and administrative labour)[5]	20,606	14,266
- Insurance	86,785	78,107
- Other operational costs (service contracts)[3]	62,930	63,377
- Transport costs (digestate)[1]	599,322	791,390
- Digestate disposal[1]		

Revenues - Gas sale[1] - Income from substrates[1]	 1,878,824 1,800,000,00	 1,657,454 1,800,000

[1] based on estimation, at the time of start-up
[2] based on Table 13
[3] based on Table 18
[4] based on Figure 54
[5] based on Figure 56
[6] incl. 30% addition

Table 18: determined key values for cash-flow calculation (valid for plug flow fermenter system).

Key value	**Number**	**Method for determination**	**Source/ database**
investment costs	€/Nm^3*h (table 2)	average values of different agricultural biogas plants	literature [FNR]
personnel costs	€/month	based on figure 2	literature [FNR]
working time per day and month	8 hours/day 160 days/month		general assumption
additional personnel costs (administrative)		depending on the size of the plant;	
service contracts	0.03(€/Nm^3)*biogas yield (Nm^3/a)	calculation of average values	data of different German biogas plants
maintenance and repair[2]	0.015 (€/Nm^3)* biogas yield (Nm^3/a)	calculation of average values	data of different German biogas plants
purchased services and goods	0.01 (€/Nm^3)*biogas yield (Nm^3/a)	calculation of average values	data of different German biogas plants
other administrative costs	0.01 (€/Nm^3)*biogas yield (Nm^3/a)	calculation of average values	data of different German biogas plants
Operating costs for upgrading	0.07 €/m^3	based on figure 55	
operating hours of the plant	8760 h	general assumption	
Insurance	0.5% (of investment)	general assumption	
discount rate	10%	general estimation	
increment rate (revenues; biogas)	6%	general estimation	
increment rate (digestate sale)	2%	general estimation	
increment rate	2%	general estimation	

(operational costs)				
	plug flow	**garage**		
additional personnel costs (feeding)	2 min/ton[4]	4 min/ton		literature [FNR]
own electricity demand	15 % of produced energy[3]	5 % of produced energy[3]	calculation of average values	data of different German biogas plants
own heat demand	26.3% of produced heat[1]	26.3 % of produced heat[1]	calculation of average values	data of different German biogas plants

[1] based on [14]; based on the theor. value in case of electricity production with CHP-unit
[2] 0.025 (€/Nm^3)*biogas yield (Nm^3/a) for biogas plants with CHP-unit
[3] estimation; based on the theor. value in case of electricity production with CHP-unit
[4] based on [14]

Results of the cash flow calculations

Based on the data which are listed in Table 16, Table 17 and Table 18 theoretical cumulative discounted cash flow calculations were made (see figure Figure 58).

- Plug flow fermenter system

Basing on a theoretical amount of 30,000 tons municipal solid waste (MSW), what means after a pre-sorting an amount of 24,000 tons would be available for the anaerobic digestion (based on the results of the pilot B-testing), a plug flow fermenter system was been calculated. The results are related to the assumption that all of the produced biogas will be upgraded and sold as vehicle fuel. The filling stations and other necessary peripheral equipment is already available and therefore no additional investment costs occur.

- Garage fermenter system

Because there will probably no complex pretreatment of the substrate necessary, the calculation based on the whole amount of 30,000 tons MSW for the anaerobic digestion. Apart from that the same assumptions as for the plug flow fermenter are valid.

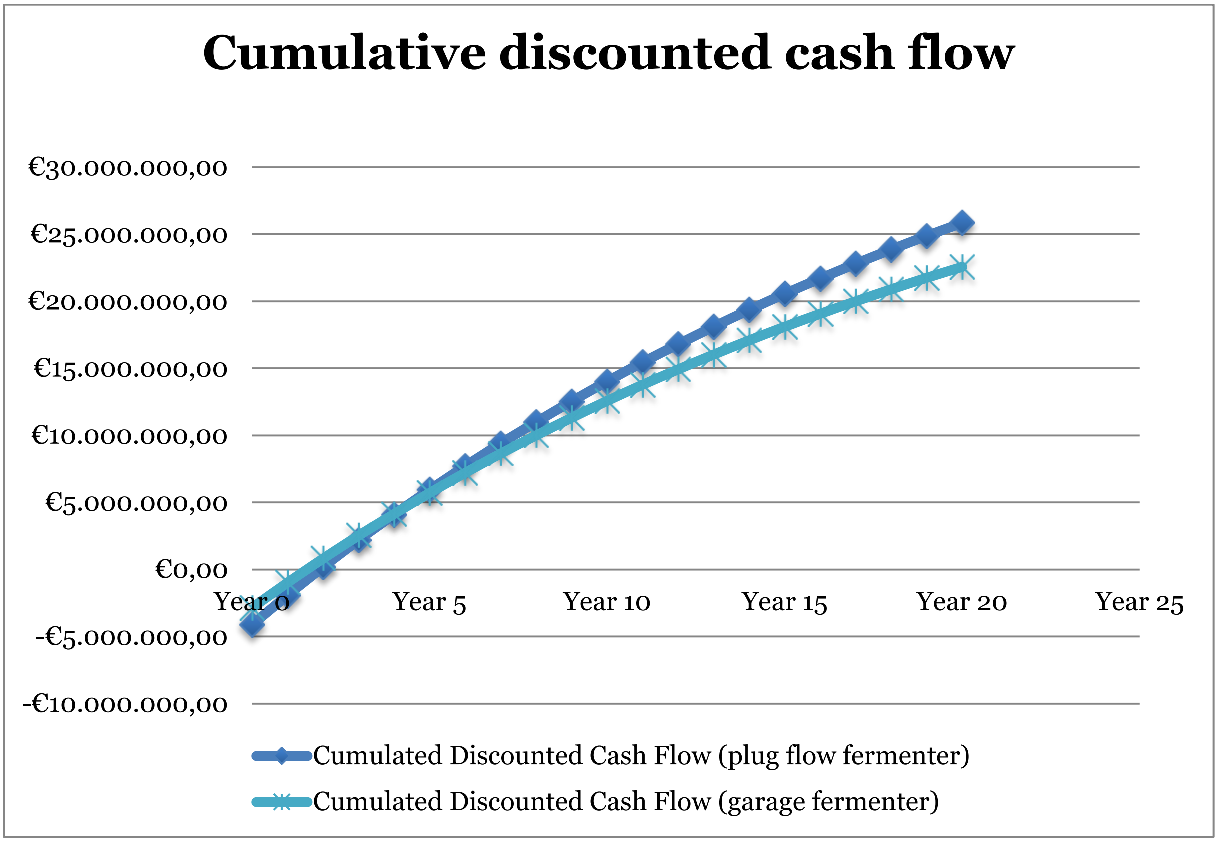


Figure 58: cumulative discounted cash flow for biogas plant with plug flow fermenter and garage fermenter.

Both calculated and presented cumulative cash flows are based on assumptions. These assumptions have to be considered critically and have to be updated continuously. Therefore the calculations can only give rough tenements concerning the development of the cash flows.

However the theoretical and exemplary calculations show the profitability of the possible scenarios. The garage fermenter as well as the plug flow fermenter system would reach the “break-even point” within the first two years (provided the external periphery and also management and administration is largely available) under the assumed conditions. Here the earned profit out the sale of the biogas is one of the most influential factors.

For the development and planning of a real biogas plant offers of manufacturers for sure have to be obtained.
The upper described scenarios and cash flow models can only be seen as rough considerations.

For a detailed calculations the data have to be adapted to the real conditions and requirements.

2.4.6 Summary and outlook

The discounted cash flow constitutes a calculation method to estimate the attractiveness of an investment opportunity. The discounted cash flow method is often used in investment finance calculating the future cash flows present values. The purpose of a DCF analysis is to estimate the benefit which will arise from an investment and to adjust for the time value of money. [15]

Based on the data given in Table 17, Table 17 and Table 18 cash flow calculations were made for a plug flow fermenter system and a garage fermenter system.
The substrate which was used for the theoretical calculation was shredded municipal waste. The waste which was used for the garage fermenter system was not been pre-sorted, the waste for the plug flow fermenter system was been pre-sorted (glass, metals, plastics, contaminants).

For the calculation data were used, based on key values and experience. The calculation was made for a period of 20 years, so that the cash flow and therefore the break-even point could be mapped.

Both model calculations show that the use of MSW is profitable within a few years, but the results apply only for the mentioned cases and conditions.

3. Strategy of communication

The last stop of the dry digestion pilot, pilot B, within the ABOWE project was in Västerås, Sweden. It was situated on the property of an already existing wet digestion biogas plant. The local partners, the Mälardalen University as well as naturally VAFAB (the operator of the biogas plant), have comprehensive expertise with regard to the digestion technology. The objective of the operation period of pilot B had clearly been specified before its arrival in Sweden and VAFAB had strongly been involved.

Pilot B operation should prove that the dry digestion technology is capable to treat biowaste and municipal solid waste in a stable way and show that the methane yields are viable with the overall aim to gain trust in dry digestion technology.

VAFAB got the order to triple the biogas production within the next three to four years and has been searching for possibilities to increase the productivity of the already existing plant and to find a technology that is proved and stable to treat waste streams that have not been treated by now. The operation of the existing wet digestion plant is expensive, a fact that leads to the search of alternative technologies.

Not only the Västerås municipality but also others in Sweden have decided to use much more biogas in public transport so that stakeholders from other regions are interested in the results of the pilot B operation.

To inform them and to ensure their engagement with the aim to foster investment into dry digestion technology a strategy of communication had been implemented, that includes elements of

- Marketing strategies
- Change processes

This part of the output report considers these elements more deeply and gives guidelines for a successful communication in the field of technology transfer.

3.1 Stakeholders

Marketing defines, that the media and the ways, which are used to inform and persuade possible buyers has to be chosen under consideration of the target group, which is in this case the group of stakeholders.

Responsible for the selection and naming of the stakeholders are the regional partners, which have the best insight into which person, which organisation and which association that could have an interest in the piloted technique. In the Swedish case the following organisations were identified as interesting stakeholders to be invited to the pilot B stakeholder event.

Municipalities
Surahammar Kommunalteknik
Strängnäs Energi och Vatten
Örebro municiplaity

Waste management companies
Vafab Miljö AB
Eskilstuna Energi och Miljö (also an energy company)
Uppsala Vatten och Avfall
SYSAV
RENOVA
VMAB
Borås Energi och Miljö (also an energy company
Nårab
SRV
Gästrike Återvinnare AB

Energy companies
Ena Energi, Enköping
Sala Heby Energi AB
Mälarenergi AB
Göteborg Energi
EON
JEBIO
Karlstad Energi
Borlänge Energi
Scandinavian Biogas Fuels AB
Kristianstad Biogas AB
Swedish Biogas International

Authorities
Swedish Energy Agency
County Administrative Board

Other
JTI – Swedish Institute of Agricultural and Environmental Engineering
Gymninge farm
Nibble farm
Avfall Sverige – the Swedish Waste Management and Recycling association
Energigas Sverige- The Swedish Gas Association
Norrlandsjord & Miljö AB

3.1.1 Stakeholder Identification

Leading questions for identifying stakeholders in Sweden have been:

- Who is affected by the results of the project?
- The area of responsibility of which institution is affected?
- Which people with influence are interested in the technology?
- Which inspection authorities have to be involved in the decision process?
- Which institutions are able and willing to invest money into new technologies?
- Which people of the personal network of the local project partner could be involved?
- What could be an obstacle?
- Who has a problem that could be solved by the technology of anaerobic dry digestion?

The more the identified stakeholders are affected by the topic, the better the personal relationship to the inviting local partner the more likely is, that the invited people will attend and actively participate.

3.2 Local partners

The local project partner in Sweden has been Mälardalen University. The local partner has been in contact with and got help from the host for the pilot plant, the waste management company VafabMiljö, represented by its CEO Per-Erik Persson, to identify stakeholders.

From the communicative point of view the local partner are designing the way of communication in the country, they bring in their personal and professional network as the source of all activities regarding presenting and representing the project.

3.3 Media

In case of Sweden following media has been used:

3.3.1 Internet

The newsletter and all reports are published on the ABOWE web site.

3.3.2 Newsletter

Using the template of the ABOWE project a national newsletter edition has been established. The newsletter´s impact on the external stakeholder has not been measured but it can be considered as one successful part of the stakeholder management in Sweden. The strong impact for the internal stakeholder can be shown, due to the direct experience of the reporting team.

The used newsletter is a mixture of old style and new media. It is available as hardcopy and can be sent by mail. It is published on the project´s web site, it is being sent via email and it could be posted on social media.

One newsletter was published during the operation period in Sweden, at least one more is going to be published afterwards. The content of the newsletter is focused on the results of the WP 4 activities.

Impact

The internal impact of the newsletter was perceivable especially in the days before the final editing. To fix the content and to write short articles it is obligatory that the agreements between the partners are clear and that everybody knows what to do. Intensive discussions accompanied the editing process of the newsletter that created security and clarity for the partners.

Newsletter

About six weeks before the stakeholder meeting the newsletter was sent to the participants and all the other stakeholders who got an invitation for that event.

Content of the first Newsletter was:
Dry digester pilot arriving in Sweden
A short introduction
Piloting at VAFAB Västerås, Sweden
Short description of project´s objectives
Activities while piloting the dry digester at VAFAB
Description of activities and announcement of stakeholder event
Pilot B dry digester
Short description of pilot B
Comparing technologies
Description of the dry digestion and the additional considered garage fermentation system

(For the complete Newsletter see Appendix 1.)

3.3.3 Events

Two events were organized during the stay of pilot B in Sweden with the aims:

- To inform
- To activate
- To come into contact
- To learn

Preparatory meeting

About three month before the arrival of pilot B in Sweden a preparatory meeting took place. Participants were

- Peer Erik Persson from VAFAB
- Eva Thorin, Patrik Klintenberg, Eva Nordlander, Johan Lindmark, Sebastian Schwede, Yuying Li from Mälardalen University
- Thorsten Ahrens, Tim Freidank, Silvia Drescher-Hartung, Andreas Behnsen from Ostfalia University

Summary of discussion

The dry digester will be operated at VAFAB for four months, from April to July. The population of the region is about 300,000, and there are more than 10,000 businesses that generate waste.
The substrate that is being tested is the fine fraction of the residual waste. The fine fraction is obtained by crushing and screening the residual waste (size <40 mm). The residual waste is currently being incinerated but contains organic matter with a high biogas potential that decreases the heating value during incineration.
This waste is complex, containing a mix of hard and soft plastic, paper, metal, glass, and a varying amount of organic material. The purpose of the testing is to determine if it is technically and economically viable to produce biogas from this waste. The biogas potential of the domestic waste will be investigated. Various variables related to loading and retention time will be tested to find the most optimal process, for this challenging but potentially valuable waste stream.

While carrying out the technical tests, key stakeholders in the waste sector in Västmanland County is being informed about the project and results from the piloting.
The 13th of June key stakeholders were invited to a half-day workshop where the dry digester was discussed and demonstrated. The purpose of the meeting was to inform stakeholders and to discuss how dry digestion can be a solution to current and future waste management needs in the region and beyond.
In preparation for this event the project team contacted stakeholders and conducted an informal interview to learn more about challenges and opportunities in the waste sector in Västmanland County. Posters presenting the project and results so far were also prepared (see Appendix 2).

Stakeholder event

In the start phase of pilot B the stakeholders were invited to a first meeting in 13th of June from 8.30 a.m. to 1.00 p.m. The meeting was held at the site of Vafab Miljö where the pilot was situated and a visit of the pilot plant was included in the meeting, figure 59.

Figure 59: Visitors at pilot B

Focus of that meeting was to activate the stakeholders and to initiate networking among them and with the project partners. Results of that meeting were documented and used for the further investigations in Sweden.

Participants

At the stakeholder meeting (including poster session, figure 60) the following stakeholders were represented:

- VafabMiljö – responsible for the handling of waste it is owned by 12 municipalities; the municipalities in the county of Västmanland together with the municipalities Heby and Enköping.
- Örebro municipality
- Ekologiplan – linked to Örebro municipality)
- Avfall Sverige – the Swedish Waste Management and Recycling association with 400 members from both the public and the private waste management and recycling sectors
- Uppsala municipality
- Uppsala Vatten och Avfall – responsible fort the handling of waste in Uppsala
- Gästrike Återvinnare AB – Service for municipalities and enterprises in waste management
- JTI – Swedish Institute of Agricultural and Environmental Engineering

Figure 60: Poster Presentation at the Stakeholder event

Discussion

Focus was the discussion of the prospect of the dry digestion technology in Sweden.

Framework

In several municipalities in Sweden biogas is used as a fuel in the public transport system. VAFAB Miljö AB is producing biogas from waste in the County of Västmanland. Also the municipalities represented at the stakeholder event are producing biogas in their municipalities. They reported that the production of biogas has to be doubled in some municipalities even tripled within the coming 3-4 years, due to the fact, that the number of buses using biogas as fuel increase considerably. To meet that needs, several strategies are mentioned, such as digestion plants for the treatment of pig manure, trials to increase the biogas production from sewage sludge or the digestion of wetland grass, energy crops, cut lawn and cut from roadsides.

Digestate

On national level the suggestion for a discussed digestate law is to limit the heavy metal content in the digestate. It is a challenge to find customers for digestate that is polluted with heavy metals. If the law is adopted it could be a threat for existing biogas plants, say the participants of the event.

In 2013 about 900,000 tons of digestate were produced in Sweden, 90% of the amount was returned as fertilizer on the fields. Forest authorities are not willing to have the digestate put in the woods as a fertilizer.

Regarding substrate the operator of biogas plants that are using “non-waste” or clean waste streams want to avoid any risk that might pollute the digestate in a way that it must not be used as fertilizer in agriculture any more.

There is still no long term solution for digestate from MSW digestion

Dry digestion technology

Experiences in Västerås show that for the operation of a wet digestion plant a lot of maintenance is necessary. For further project VAFAB Miljö AB prefers low tech solutions that help to satisfy the increasing demand.

Experiences show, that the investments in wet digestion technology are comparable with those into dry digestion, maybe a little lower for latter. Crucial are the maintenance costs which are seen to be considerably lower with dry digestion technology.

Expectations

The stakeholders named their expectations regarding the results of the stay of pilot B in Sweden:

Economic aspects
Pilot B should answer questions that are necessary to write the procurement documents, i.e. technological aspects as well as order of investment costs and operational cost. High tech by low tech – is it possible to run that complex waste stream with relatively low maintenance costs.

Waste characterization
Is pilot B able to handle the MSW without further pretreatment?
What amounts of generated biogas are expected for the waste stream that is considered?

Independency of municipalities
In Sweden there is no national strategy. Necessary is to prove that the biogas technology is better than fossil fuels and to strengthen municipalities who act independently from national strategies because on national level the support is small.

3.4 Curriculum of pilot B staff training

Training was done in Estonia and Lithuania.

The curriculum in this report shall give an idea of what kind of content was trained in the different phases and what skills and competencies should be acquired.

3.4.1 Training at Pilot B in Sweden

The training was realized at the pilot B in Sweden the first week for start up with the employee (Johan Lindmark) at Mälardalen University who was then responsible for the operation of the plant in Sweden.

Content

Get to know the starting and operating of the pilot B, including the different phases of the AD process and the parameters to be analysed.

To get to know continuous tests for evaluation of different substrates for biogas production, determination of different parameters for process and substrate evaluation (DM, oDM, NH_4-N, VOA/TOA, pH, CH_4-, CO_2-, H_2S-concentrations, concentrations of organic acids).

Objectives

The objectives of that training were, to acquire following skills and competencies:

- to take trials and to do the necessary test
- to interpret the analysed parameters in the way to recognize that the process is stable
- to run the pilot B and to react on troubles

After the training the trainee should know the experiences of the operation, how to do trouble shooting and how to interact with the direct environment.

3.4.2 Operation as Training

Location area

The surrounding area in Sweden was the waste treatment plant, who was quite curious to see, if the dry digestion technology is able to handle the MSW.

3.5 Summary

The actual situation in Sweden lead to the discussion if the organic matter in the residual municipal solid waste after source sorting are suitable for anaerobic digestion. If the results of the project ABOWE show that this consideration is technically feasible the possibility that a dry digestion biogas plant will be built using this fraction of the MSW as substrate is much more likely.

3.5.1 Marketing strategy

Pilot B operation should prove that the dry digestion technology is capable to treat biowaste and municipal solid waste in a stable way and show that the methane yields are viable with the overall aim to regain trust in dry digestion technology. The known technology of dry digestion shall be shown as a useful and economically interesting possibility to treat different kinds of waste. The experts in Västerås may decide to foster or to hinder the implementation of this technology. So the marketing strategy was, to reach these important stakeholders and to convince them, that the dry digestion is a good answer to the question: How can we better exploit the energetic potential that is captured in the biogenic part of our waste?

The communication strategy enabled the WP4-Team and the project partners from WP2 to come into contact with the important stakeholders and deliver data and information to them that was noted. The discussions showed, that the question is not if digestion plants are built but what kind of technology is going to be chosen.

To meet the needs of the main stakeholders, the garage fermentation was presented as an additional technology that can anaerobically treat municipal solid waste. The results of the tests in the pilot garage fermenter in the laboratory of Ostfalia delivered helpful additional data for the decision process of the stakeholders.

3.5.2 Change process

The dry digestion technology in Sweden is known as a technology which is not capable to successfully treat MSW. Experiences with that technology created a bad reputation in Sweden.

The stay of pilot B sensitised the neighbours of the site where it stayed that the technology can be handled and that it is robust with regard to impurities. They could see, that a trained operator can run the plant in a secure way and that methane yields are sufficient. The experts could see, that the anaerobic digester can treat fed substrates and that the process is stable.

One main aspect of the discussion in Sweden couldn´t be solved by the dry digestion technology and there the garage fermentation process could have advantages. It is the question, how to minimize high heavy metal contents in the digestate. Whereas garage fermenter show stable contents an accumulation of heavy metals in the digestate of pilote B could be seen. How far the process of accumulation is processed on the long term run and comparison with wet digestion must be investigated in further studies.

4. References

[1] Regeringskansliet: The Swedish National Action Plan fort the promotion of the use of renewable energy in accordance with Directive 2009/28/EC and the Commission Decision of 30.06.2009, Annex to Government 2010.06.23, I27, Doc. 2010/742/E (in part) 2009/7789/E, http://ec.europa.eu/energy/renewables/action_plan_en.htm, (accessed July 2014)

[2] Persson, T. (SGC, Svenskt Gastekniskt Center AB): Markets and trends in Nordic countries, http://www.sgc.se/ckfinder/userfiles/files/Markets%20and%20trends%20in%20Nordic%20countries_.pdf?PHPSESSID=70ffd24bb1d897704160109b6f6140fa, (accessed July 2014)

[3] Reichel, A. (EEA project manager): Municipal waste management in Sweden, European Environment Agency, February 2013

[4] Västeras Stad: http://www.vasteras.se/languages/english/Sidor/englishwelcometovasteras.aspx, (accessed May 2014)

[5] Svensk Växtkraft AB: The Växtkraft project in Västeras, January 2007, http://www.vafabmiljo.se/filarkiv/pdf/vaxtkraft/vkeng07.pdf, (accessed May 2014)

[6] SCB (Statistics Sweden), http://www.scb.se/en_/Finding-statistics/, (accessed July 2014)

[7] Gasbilen, http://www.gasbilen.se/Att-tanka-din-gasbil/Aktuella-priser, (accessed July 2014)

[8] MälarEnergi, http://www.malarenergi.se/sv/privat/vatten-avlopp/priser/, (accessed July 2014)

[9] MälarEnergi, http://www.malarenergi.se/sv/foretag/varme-och-kyla/priser-fjarrvarme/vasteras/, (accessed May 2014)

[10] personal information: Per-Erik Persson, Vafabmiljö, January 2014

[11] Fachagentur Nachwachsende Rohstoffe e.V. (FNR): Faustzahlen Biogas, http://biogas.fnr.de/daten-und-fakten/, (accessed September 2013)

[12] HEI Hornbachner Energie Innovation, http://www.biogas-netzeinspeisung.at/technische-planung/, (accessed September 2013)

[13] Fachagentur Nachwachsende Rohstoffe e.V.(FNR) (2013): Leitfaden Biogas – Von der Gewinnung zur Nutzung, Druckerei Weidner, Rostock, ISBN 3-00-014333-5

[14] KTBL (Kuratorium für Technik und Bauwesen in Landwirtschaft-Advisory board for technology and building in agriculture): Arbeitserledigungskosten verschiedener Verfahren zur Erzeugung von Biogas, KTBL-Arbeitsprogramm Kalkulationsunterlagen 2011, unveröffentlicht, in: [13]

[15] Investopedia: Discounted Cash Flow – DCF, http://www.investopedia.com/terms/d/dcf.asp, (accessed November 2013)

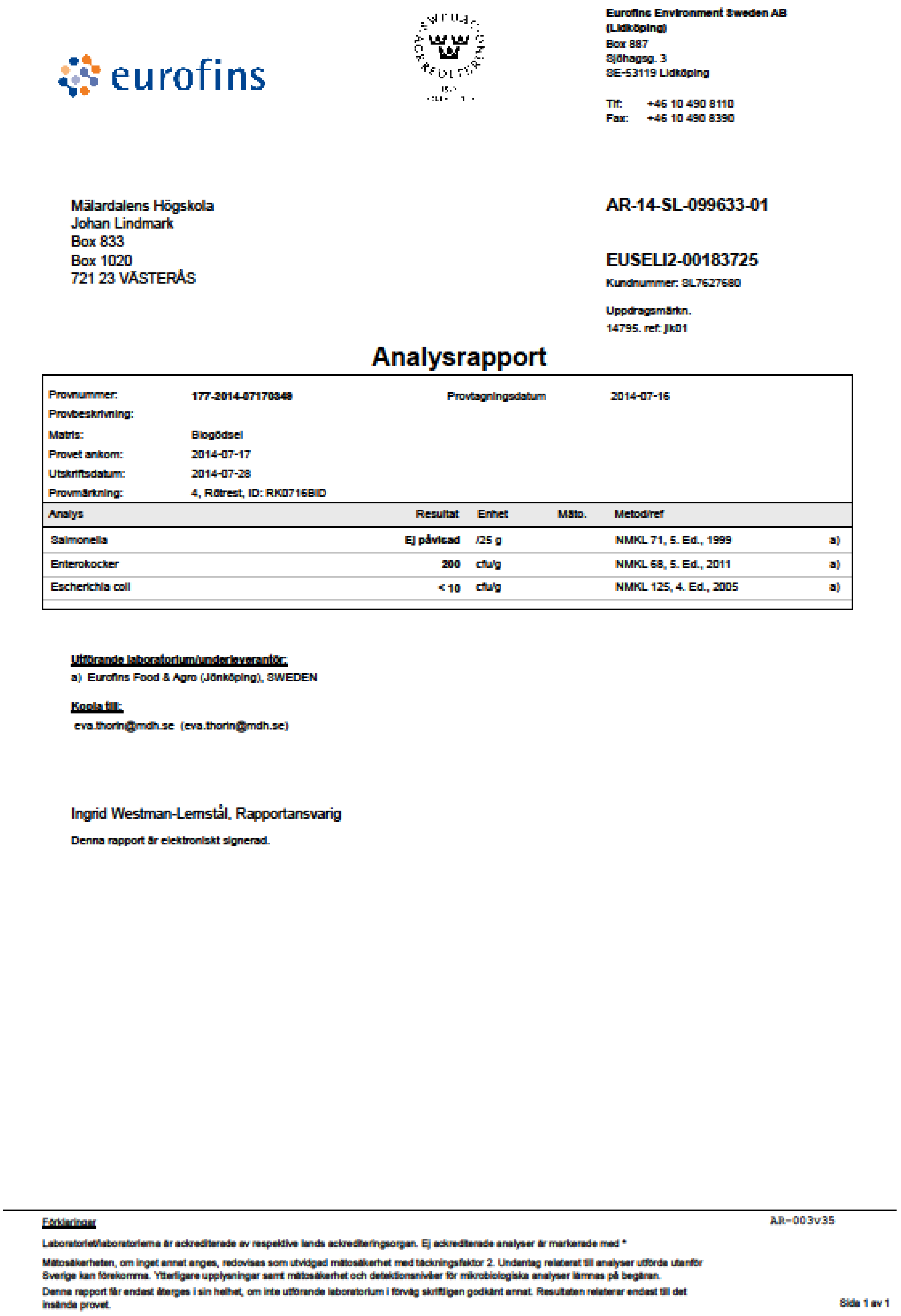
[16] HEI Hornbachner Energie Innovation, http://www.biogas-netzeinspeisung.at/technische-planung/aufbereitung/aufbereitungsverfahren/druckwasserwaesche.html, (accessed July 2014)

[17] Västeras Stad: [Avfallsplan 2014 – 2019 (only Västeras City); Beslutad av kommunfullmäktige Västerås stad, 2014-06-04 http://www.vasteras.se/Tvarsnittsdokument/Teknisk%20n%C3%A4mnd/Avfallsplan_2014-2019_utan_bilagor.pdf, (accessed September 2014)

[18] European Compostnetwork ECN: Organic Resources and Biological Treatment, Country Report of Sweden, http://www.compostnetwork.info/sweden.html, (accessed September 2014)
[19] Graf, Bajhor; Biogas – Erzeugung, Aufbereitung, Einspeisung; Oldenbourg Industrieverlag GmbH, 2011; page 285
[20] AWB Munich (Renewable Energy for Munich – Green Electricity from Biowaste, 2014)

5. Appendix

5.1 Results from external labs



Eurofins Environment Sweden AB (Lidköping)
Box 887
Sjöhagsg. 3
SE-53119 Lidköping

Tlf: +46 10 490 8110
Fax: +46 10 490 8390

Mälardalens Högskola
Johan Lindmark
Box 833
Box 1020
721 23 VÄSTERÅS

AR-14-SL-099633-01

EUSELI2-00183725

Kundnummer: SL7627680

Uppdragsmärkn.
14795. ref: jlk01

Analysrapport

Provnummer:	177-2014-07170349	Provtagningsdatum	2014-07-16
Provbeskrivning:			
Matris:	Biogödsel		
Provet ankom:	2014-07-17		
Utskriftsdatum:	2014-07-28		
Provmärkning:	4, Rötrest, ID: RK0716BID		

Analys	Resultat	Enhet	Mäto.	Metod/ref	
Salmonella	Ej påvisad	/25 g		NMKL 71, 5. Ed., 1999	a)
Enterokocker	200	cfu/g		NMKL 68, 5. Ed., 2011	a)
Escherichia coli	< 10	cfu/g		NMKL 125, 4. Ed., 2005	a)

Utförande laboratorium/underleverantör:
a) Eurofins Food & Agro (Jönköping), SWEDEN

Kopia till:
eva.thorin@mdh.se (eva.thorin@mdh.se)

Ingrid Westman-Lemstål, Rapportansvarig

Denna rapport är elektroniskt signerad.

Förklaringar

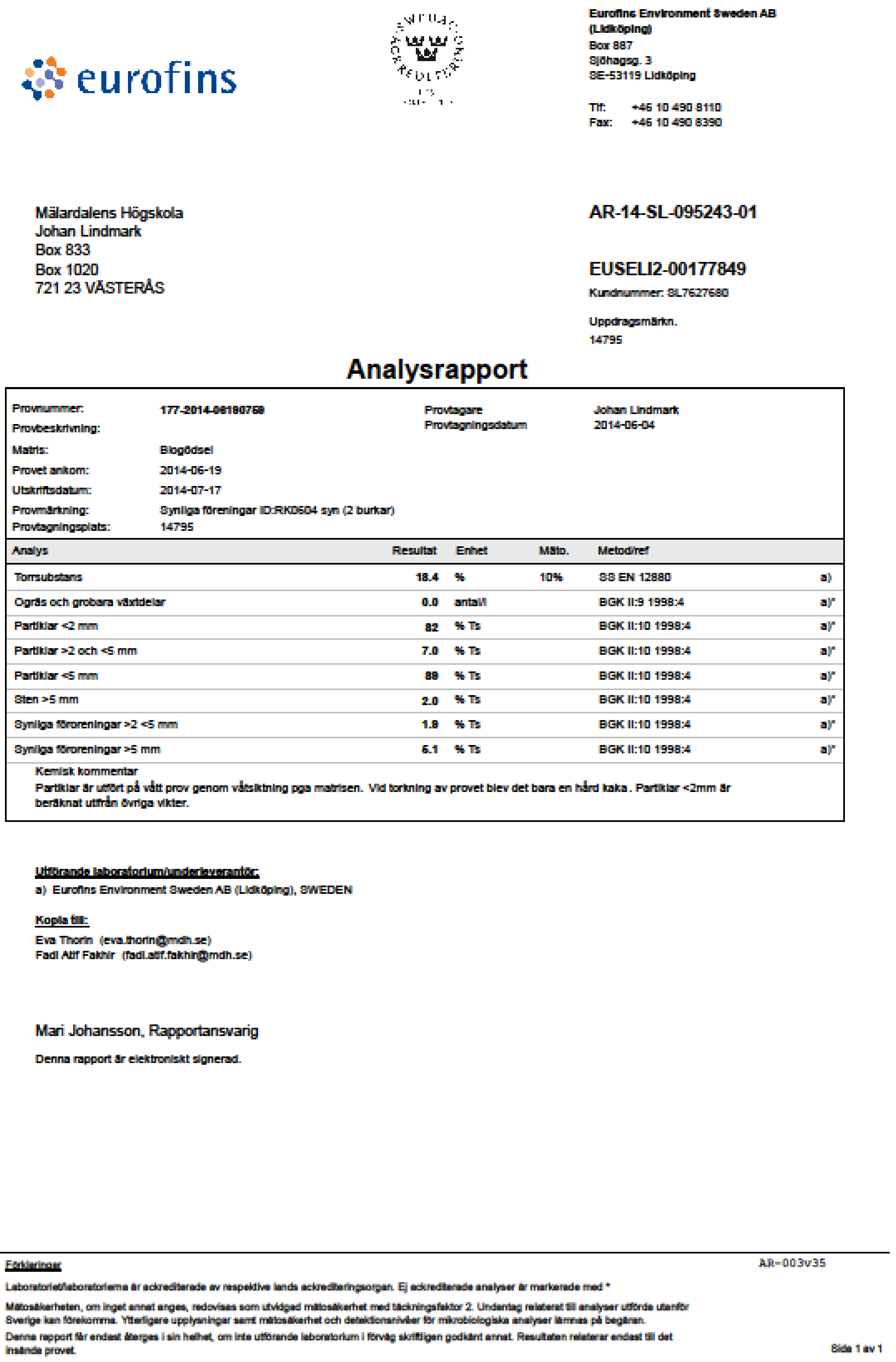
Laboratoriet/laboratorierna är ackrediterade av respektive lands ackrediteringsorgan. Ej ackrediterade analyser är markerade med *

Mätosäkerheten, om inget annat anges, redovisas som utvidgad mätosäkerhet med täckningsfaktor 2. Undantag relaterat till analyser utförda utanför Sverige kan förekomma. Ytterligare upplysningar samt mätosäkerhet och detektionsnivåer för mikrobiologiska analyser lämnas på begäran.

Denna rapport får endast återges i sin helhet, om inte utförande laboratorium i förväg skriftligen godkänt annat. Resultaten relaterar endast till det insända provet.

AR-003v35

Sida 1 av 1



Eurofins Environment Sweden AB (Lidköping)
Box 887
Sjöhagsg. 3
SE-53119 Lidköping

Tlf: +46 10 490 8110
Fax: +46 10 490 8390

Mälardalens Högskola
Johan Lindmark
Box 833
Box 1020
721 23 VÄSTERÅS

AR-14-SL-095243-01

EUSELI2-00177849
Kundnummer: SL7627680

Uppdragsmärkn.
14795

Analysrapport

Provnummer:	177-2014-06180769	Provtagare	Johan Lindmark
Provbeskrivning:		Provtagningsdatum	2014-06-04
Matris:	Biogödsel		
Provet ankom:	2014-06-19		
Utskriftsdatum:	2014-07-17		
Provmärkning:	Synliga föreningar ID:RK0604 syn (2 burkar)		
Provtagningsplats:	14795		

Analys	Resultat	Enhet	Mäto.	Metod/ref	
Torrsubstans	18.4	%	10%	SS EN 12880	a)
Ogräs och grobara växtdelar	0.0	antal/l		BGK II:9 1998:4	a)*
Partiklar <2 mm	82	% Ts		BGK II:10 1998:4	a)*
Partiklar >2 och <5 mm	7.0	% Ts		BGK II:10 1998:4	a)*
Partiklar <5 mm	89	% Ts		BGK II:10 1998:4	a)*
Sten >5 mm	2.0	% Ts		BGK II:10 1998:4	a)*
Synliga föroreningar >2 <5 mm	1.8	% Ts		BGK II:10 1998:4	a)*
Synliga föroreningar >5 mm	6.1	% Ts		BGK II:10 1998:4	a)*

Kemisk kommentar
Partiklar är utfört på vått prov genom våtsiktning pga matrisen. Vid torkning av provet blev det bara en hård kaka. Partiklar <2mm är beräknat utifrån övriga vikter.

Utförande laboratorium/underleverantör:
a) Eurofins Environment Sweden AB (Lidköping), SWEDEN

Kopia till:
Eva Thorin (eva.thorin@mdh.se)
Fadi Atif Fakhir (fadi.atif.fakhir@mdh.se)

Mari Johansson, Rapportansvarig

Denna rapport är elektroniskt signerad.

Förklaringar

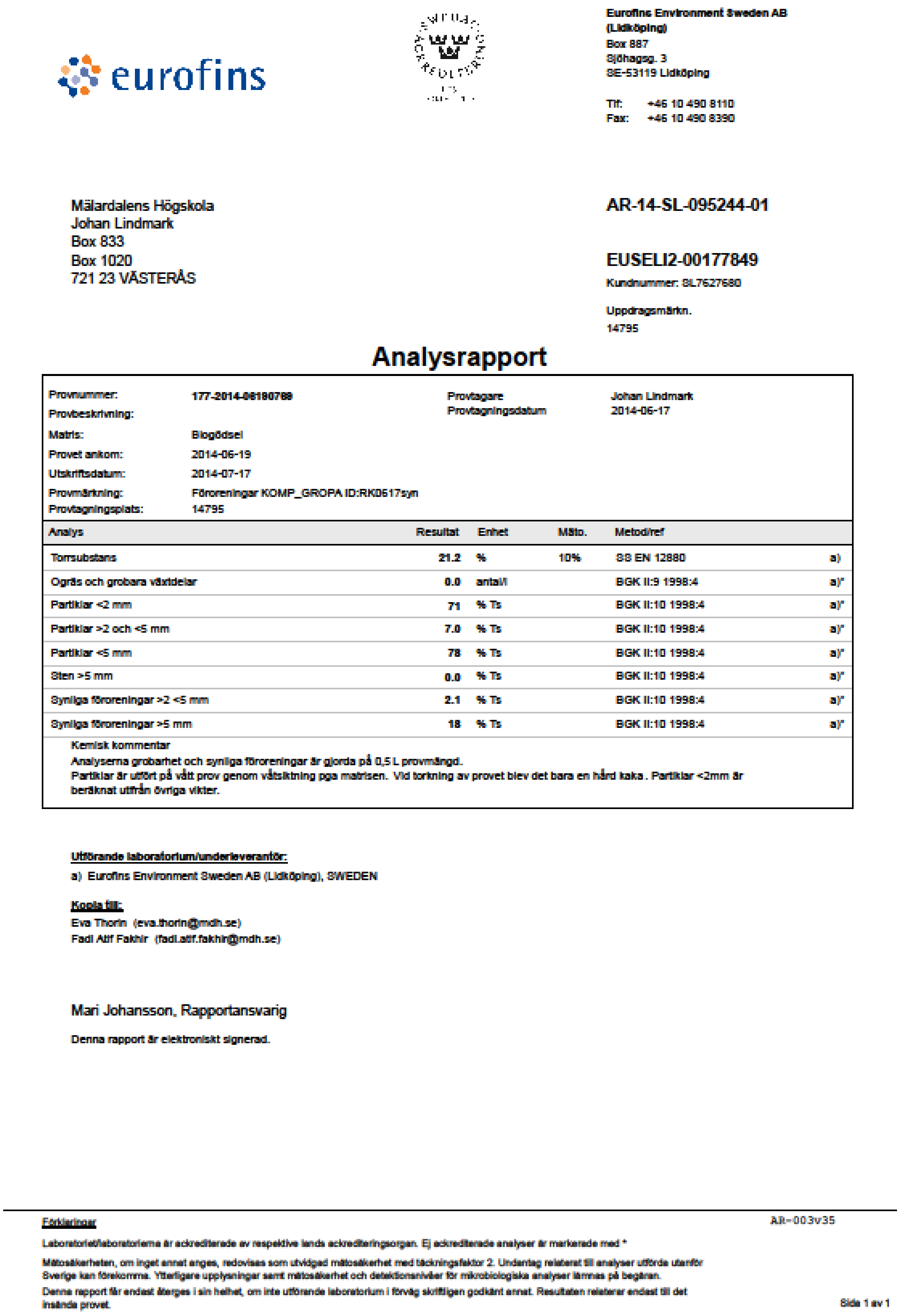
AR-003v35

Laboratoriet/laboratorierna är ackrediterade av respektive lands ackrediteringsorgan. Ej ackrediterade analyser är markerade med *

Mätosäkerheten, om inget annat anges, redovisas som utvidgad mätosäkerhet med täckningsfaktor 2. Undantag relaterat till analyser utförda utanför Sverige kan förekomma. Ytterligare upplysningar samt mätosäkerhet och detektionsnivåer för mikrobiologiska analyser lämnas på begäran.

Denna rapport får endast återges i sin helhet, om inte utförande laboratorium i förväg skriftligen godkänt annat. Resultaten relaterar endast till det insända provet.

Sida 1 av 1



eurofins

Eurofins Environment Sweden AB (Lidköping)
Box 887
Sjöhagsg. 3
SE-53119 Lidköping

Tlf: +46 10 490 8110
Fax: +46 10 490 8390

Mälardalens Högskola
Johan Lindmark
Box 833
Box 1020
721 23 VÄSTERÅS

AR-14-SL-095244-01

EUSELI2-00177849

Kundnummer: SL7627680

Uppdragsmärkn.
14795

Analysrapport

Provnummer:	177-2014-06180789	Provtagare	Johan Lindmark
Provbeskrivning:		Provtagningsdatum	2014-06-17
Matris:	Biogödsel		
Provet ankom:	2014-06-19		
Utskriftsdatum:	2014-07-17		
Provmärkning:	Föroreningar KOMP_GROPA ID:RK0617syn		
Provtagningsplats:	14795		

Analys	Resultat	Enhet	Mäto.	Metod/ref	
Torrsubstans	21.2	%	10%	SS EN 12880	a)
Ogräs och grobara växtdelar	0.0	antal/l		BGK II:9 1998:4	a)*
Partiklar <2 mm	71	% Ts		BGK II:10 1998:4	a)*
Partiklar >2 och <5 mm	7.0	% Ts		BGK II:10 1998:4	a)*
Partiklar <5 mm	78	% Ts		BGK II:10 1998:4	a)*
Sten >5 mm	0.0	% Ts		BGK II:10 1998:4	a)*
Synliga föroreningar >2 <5 mm	2.1	% Ts		BGK II:10 1998:4	a)*
Synliga föroreningar >5 mm	18	% Ts		BGK II:10 1998:4	a)*

Kemisk kommentar
Analyserna grobarhet och synliga föroreningar är gjorda på 0,5 L provmängd.
Partiklar är utfört på vått prov genom våtsiktning pga matrisen. Vid torkning av provet blev det bara en hård kaka . Partiklar <2mm är beräknat utifrån övriga vikter.

Utförande laboratorium/underleverantör:
a) Eurofins Environment Sweden AB (Lidköping), SWEDEN

Kopia till:
Eva Thorin (eva.thorin@mdh.se)
Fadl Atif Fakhir (fadl.atif.fakhir@mdh.se)

Mari Johansson, Rapportansvarig

Denna rapport är elektroniskt signerad.

Förklaringar

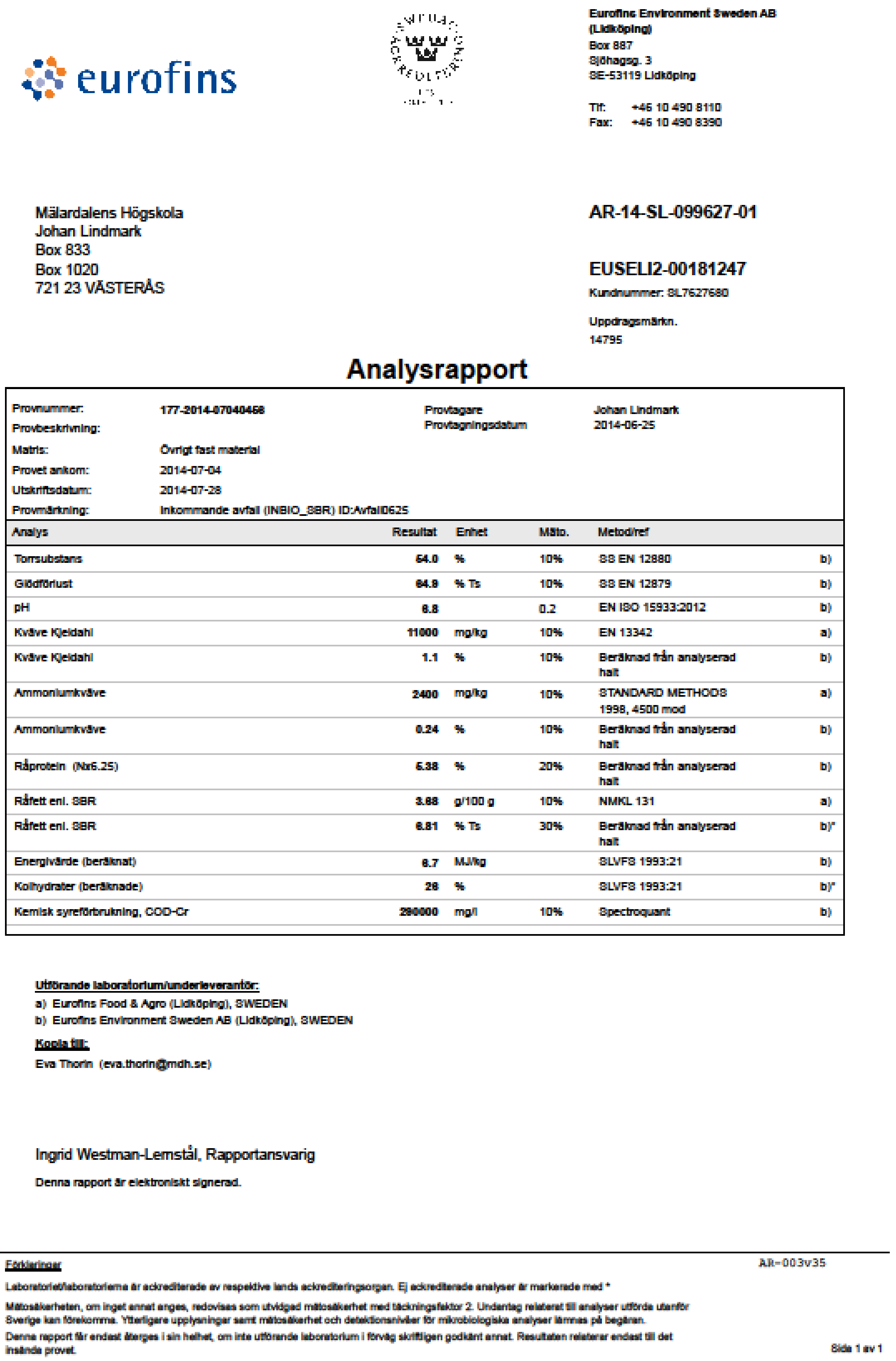
AR-003v35

Laboratoriet/laboratorierna är ackrediterade av respektive lands ackrediteringsorgan. Ej ackrediterade analyser är markerade med *

Mätosäkerheten, om inget annat anges, redovisas som utvidgad mätosäkerhet med täckningsfaktor 2. Undantag relaterat till analyser utförda utanför Sverige kan förekomma. Ytterligare upplysningar samt mätosäkerhet och detektionsnivåer för mikrobiologiska analyser lämnas på begäran.

Denna rapport får endast återges i sin helhet, om inte utförande laboratorium i förväg skriftligen godkänt annat. Resultaten relaterar endast till det insända provet.

Sida 1 av 1



Eurofins Environment Sweden AB
(Lidköping)
Box 887
Sjöhagsg. 3
SE-53119 Lidköping

Tlf: +46 10 490 8110
Fax: +46 10 490 8390

Mälardalens Högskola
Johan Lindmark
Box 833
Box 1020
721 23 VÄSTERÅS

AR-14-SL-099627-01

EUSELI2-00181247

Kundnummer: SL7627680

Uppdragsmärkn.
14795

Analysrapport

Provnummer:	177-2014-07040468	Provtagare	Johan Lindmark
Provbeskrivning:		Provtagningsdatum	2014-06-25
Matris:	Övrigt fast material		
Provet ankom:	2014-07-04		
Utskriftsdatum:	2014-07-28		
Provmärkning:	Inkommande avfall (INBIO_SBR) ID:Avfall0625		

Analys	Resultat	Enhet	Mäto.	Metod/ref	
Torrsubstans	54.0	%	10%	SS EN 12880	b)
Glödförlust	84.8	% Ts	10%	SS EN 12879	b)
pH	6.8		0.2	EN ISO 15933:2012	b)
Kväve Kjeldahl	11000	mg/kg	10%	EN 13342	a)
Kväve Kjeldahl	1.1	%	10%	Beräknad från analyserad halt	b)
Ammoniumkväve	2400	mg/kg	10%	STANDARD METHODS 1998, 4500 mod	a)
Ammoniumkväve	0.24	%	10%	Beräknad från analyserad halt	b)
Råprotein (Nx6.25)	6.88	%	20%	Beräknad från analyserad halt	b)
Råfett enl. SBR	3.88	g/100 g	10%	NMKL 131	a)
Råfett enl. SBR	6.81	% Ts	30%	Beräknad från analyserad halt	b)*
Energivärde (beräknat)	8.7	MJ/kg		SLVFS 1993:21	b)
Kolhydrater (beräknade)	28	%		SLVFS 1993:21	b)*
Kemisk syreförbrukning, COD-Cr	280000	mg/l	10%	Spectroquant	b)

Utförande laboratorium/underleverantör:
a) Eurofins Food & Agro (Lidköping), SWEDEN
b) Eurofins Environment Sweden AB (Lidköping), SWEDEN

Kopia till:
Eva Thorin (eva.thorin@mdh.se)

Ingrid Westman-Lemstål, Rapportansvarig

Denna rapport är elektroniskt signerad.

Förklaringar

AR-003v35

Laboratoriet/laboratorierna är ackrediterade av respektive lands ackrediteringsorgan. Ej ackrediterade analyser är markerade med *

Mätosäkerheten, om inget annat anges, redovisas som utvidgad mätosäkerhet med täckningsfaktor 2. Undantag relaterat till analyser utförda utanför Sverige kan förekomma. Ytterligare upplysningar samt mätosäkerhet och detektionsnivåer för mikrobiologiska analyser lämnas på begäran.

Denna rapport får endast återges i sin helhet, om inte utförande laboratorium i förväg skriftligen godkänt annat. Resultaten relaterar endast till det insända provet.

Sida 1 av 1

Eurofins Environment Sweden AB
(Lidköping)
Box 887
Sjöhagsg. 3
SE-53119 Lidköping

Tlf: +46 10 490 8110
Fax: +46 10 490 8390

Mälardalens Högskola
Johan Lindmark
Box 833
Box 1020
721 23 VÄSTERÅS

AR-14-SL-099626-01

EUSELI2-00181247

Kundnummer: SL7627680

Uppdragsmärkn.
14795

Analysrapport

Provnummer:	177-2014-07040466	Provtagare	Johan Lindmark
Provbeskrivning:		Provtagningsdatum	2014-06-25
Matris:	Övrigt fast material		
Provet ankom:	2014-07-04		
Utskriftsdatum:	2014-07-28		
Provmärkning:	Kjeldahl-N NH4N ID:RK062SN		

Analys	Resultat	Enhet	Mäto.	Metod/ref	
Torrsubstans	24.3	%	10%	SS EN 12880	b)
Kväve Kjeldahl	9100	mg/kg	10%	EN 13342	a)
Kväve Kjeldahl	3.8	% Ts	10%	Beräknad från analyserad halt	b)
Ammoniumkväve	4400	mg/kg	10%	STANDARD METHODS 1998, 4500 mod	a)
Ammoniumkväve	1.8	% Ts	10%	Beräknad från analyserad halt	b)

Utförande laboratorium/underleverantör:
a) Eurofins Food & Agro (Lidköping), SWEDEN
b) Eurofins Environment Sweden AB (Lidköping), SWEDEN

Kopia till:
Eva Thorin (eva.thorin@mdh.se)

Ingrid Westman-Lemstål, Rapportansvarig

Denna rapport är elektroniskt signerad.

Förklaringar

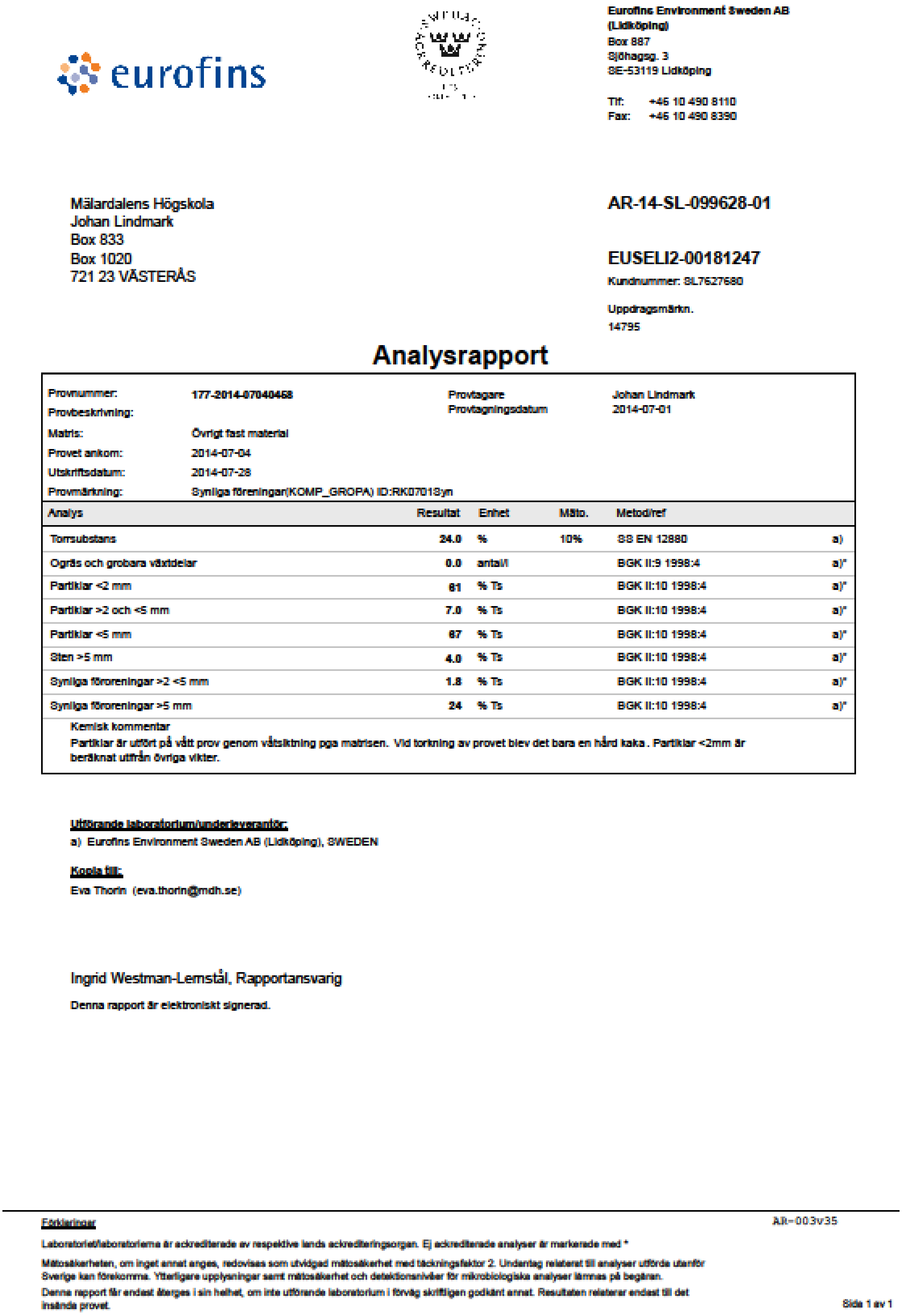
AR-003v35

Laboratoriet/laboratorierna är ackrediterade av respektive lands ackrediteringsorgan. Ej ackrediterade analyser är markerade med *

Mätosäkerheten, om inget annat anges, redovisas som utvidgad mätosäkerhet med täckningsfaktor 2. Undantag relaterat till analyser utförda utanför Sverige kan förekomma. Ytterligare upplysningar samt mätosäkerhet och detektionsnivåer för mikrobiologiska analyser lämnas på begäran.

Denna rapport får endast återges i sin helhet, om inte utförande laboratorium i förväg skriftligen godkänt annat. Resultaten relaterar endast till det insända provet.

Sida 1 av 1



Eurofins Environment Sweden AB (Lidköping)
Box 887
Sjöhagsg. 3
SE-53119 Lidköping

Tlf: +46 10 490 8110
Fax: +46 10 490 8390

Mälardalens Högskola
Johan Lindmark
Box 833
Box 1020
721 23 VÄSTERÅS

AR-14-SL-099628-01

EUSELI2-00181247

Kundnummer: SL7627680

Uppdragsmärkn.
14795

Analysrapport

Provnummer:	177-2014-07040468	Provtagare	Johan Lindmark
Provbeskrivning:		Provtagningsdatum	2014-07-01
Matris:	Övrigt fast material		
Provet ankom:	2014-07-04		
Utskriftsdatum:	2014-07-28		
Provmärkning:	Synliga föreningar(KOMP_GROPA) ID:RK0701Syn		

Analys	Resultat	Enhet	Mäto.	Metod/ref	
Torrsubstans	24.0	%	10%	SS EN 12880	a)
Ogräs och grobara växtdelar	0.0	antal/l		BGK II:9 1998:4	a)*
Partiklar <2 mm	81	% Ts		BGK II:10 1998:4	a)*
Partiklar >2 och <5 mm	7.0	% Ts		BGK II:10 1998:4	a)*
Partiklar <5 mm	87	% Ts		BGK II:10 1998:4	a)*
Sten >5 mm	4.0	% Ts		BGK II:10 1998:4	a)*
Synliga föroreningar >2 <5 mm	1.8	% Ts		BGK II:10 1998:4	a)*
Synliga föroreningar >5 mm	24	% Ts		BGK II:10 1998:4	a)*

Kemisk kommentar
Partiklar är utfört på vått prov genom våtsiktning pga matrisen. Vid torkning av provet blev det bara en hård kaka . Partiklar <2mm är beräknat utifrån övriga vikter.

Utförande laboratorium/underleverantör:
a) Eurofins Environment Sweden AB (Lidköping), SWEDEN

Kopia till:
Eva Thorin (eva.thorin@mdh.se)

Ingrid Westman-Lemstål, Rapportansvarig

Denna rapport är elektroniskt signerad.

Förklaringar

AR-003v35

Laboratoriet/laboratorierna är ackrediterade av respektive lands ackrediteringsorgan. Ej ackrediterade analyser är markerade med *

Mätosäkerheten, om inget annat anges, redovisas som utvidgad mätosäkerhet med täckningsfaktor 2. Undantag relaterat till analyser utförda utanför Sverige kan förekomma. Ytterligare upplysningar samt mätosäkerhet och detektionsnivåer för mikrobiologiska analyser lämnas på begäran.

Denna rapport får endast återges i sin helhet, om inte utförande laboratorium i förväg skriftligen godkänt annat. Resultaten relaterar endast till det insända provet.

Sida 1 av 1

5.2 Newsletter

Sweden

Newsletter 01/2014

Implementing Advanced Concepts for Biological Utilization of Waste

In this issue:

Dry digester pilot arriving in Sweden

Piloting at VAFAB Västerås, Sweden

ABOWE project in short

Activities while piloting in Västerås

Investigating possible business models

Pilot B dry digester

Comparing technologies

Introducing the Ostfalia garage fermenter

Dry digester pilot arriving in Sweden

Wednesday the 9th of April the dry digester pilot plant arrived at VAFAB, the municipal waste company in Västerås, Sweden.

The Swedish project team, together with project members from Germany and Lithuania received the long awaited plant.

Piloting at VAFAB Västerås, Sweden

The dry digester will be operated at VAFAB for six months. The substrate that is being tested is the fine fraction of the residual waste. The fine fraction is obtained by crushing and screening the residual waste (size <40 mm). The residual waste is currently being incinerated but contains organic matter with a high biogas potential that decreases the heating value during incineration.

This waste is complex, containing a mix of hard and soft plastic, paper, metal, glass, and a varying amount of organic material. The purpose of the testing is to determine if it is technically and economically viable to produce biogas from this waste.

ABOWE project in short

ABOWE stands for 'Implementing advanced concepts for biological utilization of waste'. The project is piloting two technologies: a bio-refinery and dry digestion.

Technologies are tested in two mobile pilot plants with waste materials handled by partner companies in the waste sector in Finland, Estonia, Lithuania and Sweden. The overall objective of ABOWE is, based on the outcomes of the pilot tests and stakeholder consultations, to:

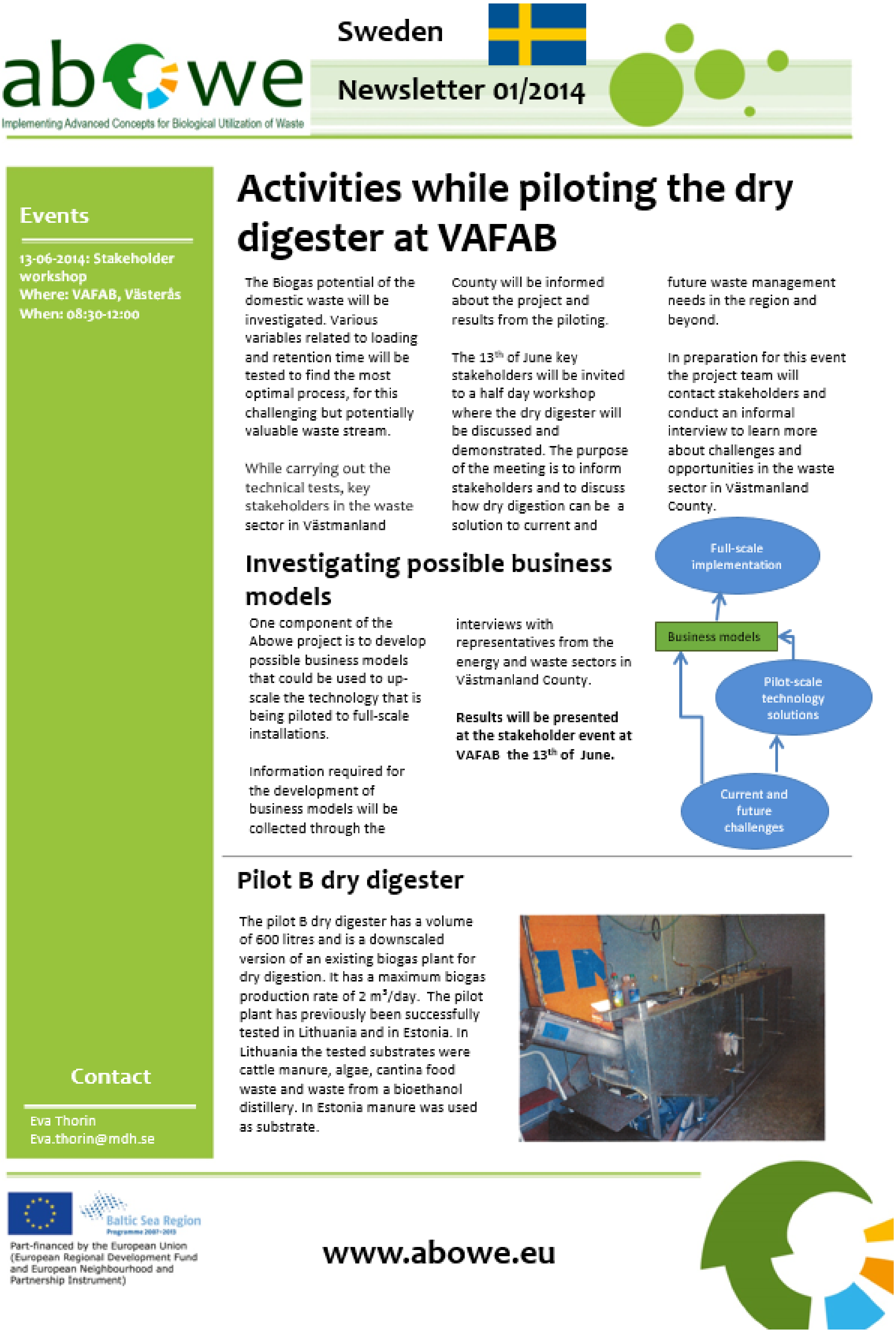
1. Provide evidence that the technologies are viable, and
2. Generate information that can form the basis for investment decisions towards full-scale implementation of either of the two technologies.

Contact

Eva Thorin
Eva.thorin@mdh.se

Baltic Sea Region
Programme 2007-2013
Part-financed by the European Union (European Regional Development Fund and European Neighbourhood and Partnership Instrument)

www.abowe.eu



Implementing Advanced Concepts for Biological Utilization of Waste

Sweden

Newsletter 01/2014

Activities while piloting the dry digester at VAFAB

The Biogas potential of the domestic waste will be investigated. Various variables related to loading and retention time will be tested to find the most optimal process, for this challenging but potentially valuable waste stream.

While carrying out the technical tests, key stakeholders in the waste sector in Västmanland County will be informed about the project and results from the piloting.

The 13th of June key stakeholders will be invited to a half day workshop where the dry digester will be discussed and demonstrated. The purpose of the meeting is to inform stakeholders and to discuss how dry digestion can be a solution to current and future waste management needs in the region and beyond.

In preparation for this event the project team will contact stakeholders and conduct an informal interview to learn more about challenges and opportunities in the waste sector in Västmanland County.

Investigating possible business models

One component of the Abowe project is to develop possible business models that could be used to up-scale the technology that is being piloted to full-scale installations.

Information required for the development of business models will be collected through the interviews with representatives from the energy and waste sectors in Västmanland County.

Results will be presented at the stakeholder event at VAFAB the 13th of June.

Pilot B dry digester

The pilot B dry digester has a volume of 600 litres and is a downscaled version of an existing biogas plant for dry digestion. It has a maximum biogas production rate of 2 m^3/day. The pilot plant has previously been successfully tested in Lithuania and in Estonia. In Lithuania the tested substrates were cattle manure, algae, cantina food waste and waste from a bioethanol distillery. In Estonia manure was used as substrate.

Events

13-06-2014: Stakeholder workshop
Where: VAFAB, Västerås
When: 08:30-12:00

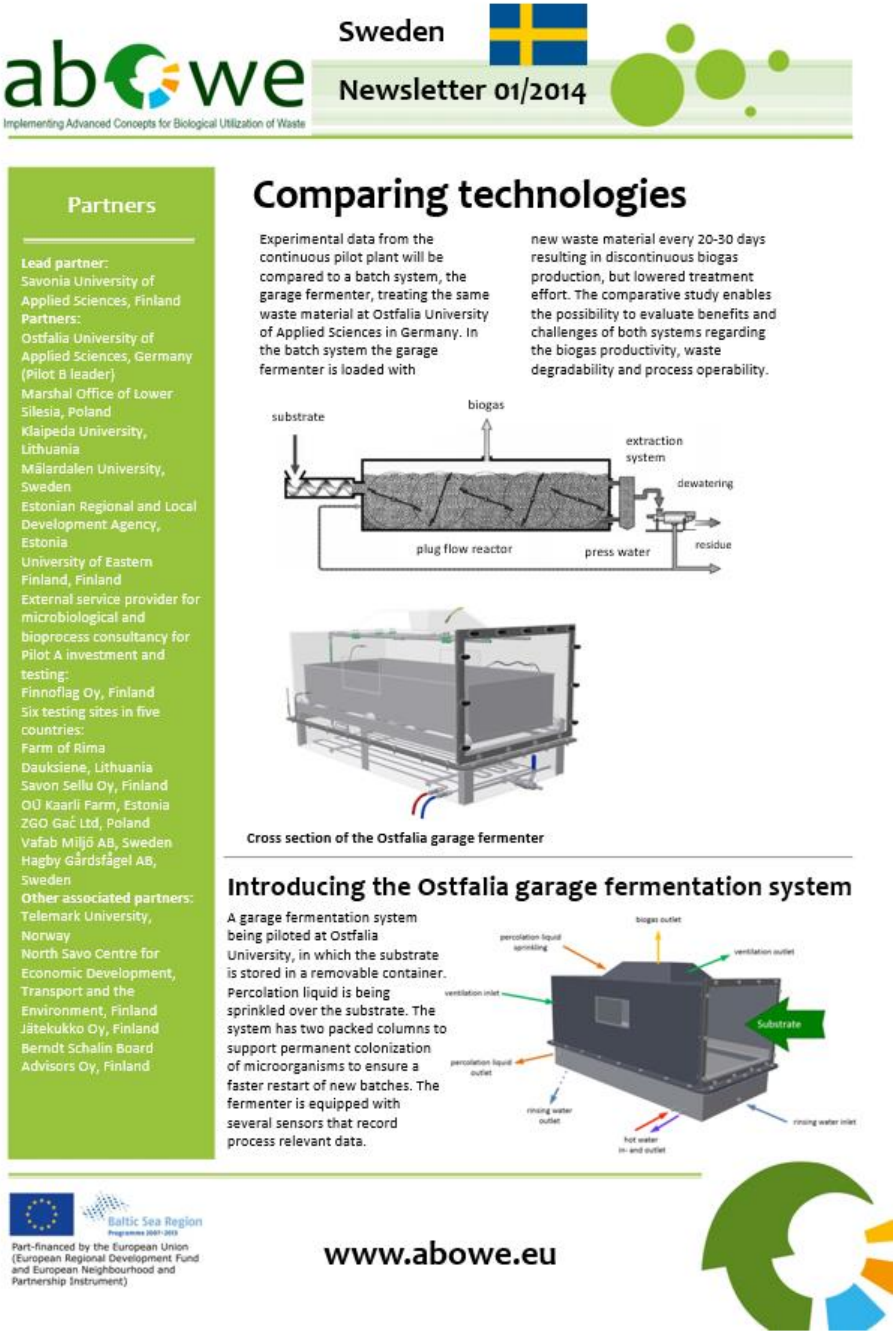
Contact

Eva Thorin
Eva.thorin@mdh.se

Part-financed by the European Union (European Regional Development Fund and European Neighbourhood and Partnership Instrument)

Baltic Sea Region Programme 2007-2013

www.abowe.eu



abowe
Implementing Advanced Concepts for Biological Utilization of Waste

Sweden

Newsletter 01/2014

Comparing technologies

Experimental data from the continuous pilot plant will be compared to a batch system, the garage fermenter, treating the same waste material at Ostfalia University of Applied Sciences in Germany. In the batch system the garage fermenter is loaded with new waste material every 20-30 days resulting in discontinuous biogas production, but lowered treatment effort. The comparative study enables the possibility to evaluate benefits and challenges of both systems regarding the biogas productivity, waste degradability and process operability.

Cross section of the Ostfalia garage fermenter

Introducing the Ostfalia garage fermentation system

A garage fermentation system being piloted at Ostfalia University, in which the substrate is stored in a removable container. Percolation liquid is being sprinkled over the substrate. The system has two packed columns to support permanent colonization of microorganisms to ensure a faster restart of new batches. The fermenter is equipped with several sensors that record process relevant data.

Partners

Lead partner:
Savonia University of Applied Sciences, Finland
Partners:
Ostfalia University of Applied Sciences, Germany (Pilot B leader)
Marshal Office of Lower Silesia, Poland
Klaipeda University, Lithuania
Mälardalen University, Sweden
Estonian Regional and Local Development Agency, Estonia
University of Eastern Finland, Finland
External service provider for microbiological and bioprocess consultancy for Pilot A investment and testing:
Finnoflag Oy, Finland
Six testing sites in five countries:
Farm of Rima Dauksiene, Lithuania
Savon Sellu Oy, Finland
OÜ Kaarli Farm, Estonia
ZGO Gać Ltd, Poland
Vafab Miljö AB, Sweden
Hagby Gårdsfågel AB, Sweden
Other associated partners:
Telemark University, Norway
North Savo Centre for Economic Development, Transport and the Environment, Finland
Jätekukko Oy, Finland
Berndt Schalin Board Advisors Oy, Finland

Baltic Sea Region Programme 2007-2013
Part-financed by the European Union (European Regional Development Fund and European Neighbourhood and Partnership Instrument)

www.abowe.eu

5.3 Poster presentation

abowe
Implementing Advanced Concepts for Biological Utilization of Waste

Ostfalia
University of
Applied Sciences

FUTURE ENERGY

Baltic Sea Region
Programme 2007-2013

Part-financed by the European Union
(European Regional Development Fund)

IMPLEMENTING ADVANCED CONCEPTS FOR BIOLOGICAL UTILIZATION OF WASTE

Dry Digestion

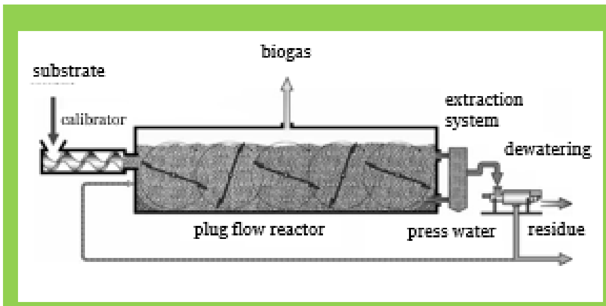
Andreas Behnsen, Tim Freidank, Ostfalia University of Applied Sciences

INTRODUCTION

The substrate´s solids content of the substrate in a dry digestion process is typically between 25% and 40%. It allows biogas production from waste substrates at high efficiency rates.

EXAMPLE

German experiences show, that a dry digestion fermenter with a volume of 1.500 m³ can produce up to two million normal cubic meters of methane yearly. This equals a combined power-and-heat output of more than 1.8 MWh each year.



DIGESTATE

A dry digester produces only little amounts of digestion residues, this is important in case of waste utilization.

Residues can either be used directly as fertilizer or be further processed to compost.

PROJECT PARTNERS

- Savonia University of Applied Sciences (Lead partner)
- University of Eastern Finland
- Ostfalia University of Applied Sciences
- Marshal Office of Lower Silesia
- Klaipeda University
- Mälardalen University
- Estonian Regional and Local Development Agency

abowe
Implementing Advanced Concepts for Biological Utilization of Waste

Ostfalia
University of
Applied Sciences

FUTURE ENERGY

Baltic Sea Region
Programme 2007–2013
Part-financed by the European Union
(European Regional Development Fund)

IMPLEMENTING ADVANCED CONCEPTS FOR BIOLOGICAL UTILIZATION OF WASTE

Garage fermentation system

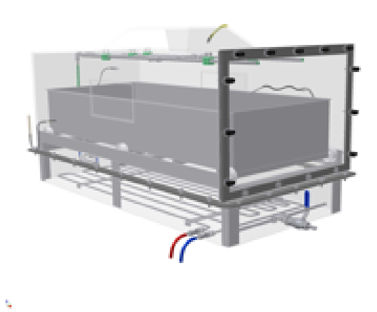
Tim Freidank, Ostfalia University of Applied Sciences

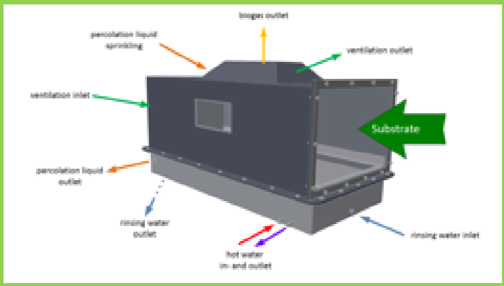
INTRODUCTION

The system includes a garage digester and fixed bed percolation columns for detention of biomass in the percolate.

CONCLUSIONS

During startup as well as during regular operation the process performance is exactly comparable to the process performance of full scale applications. Due to this, the presented system allows the planning and confectioning of full scale percolation processes.





RESULTS

Actually the system has been successfully used for practical process simulation regarding dry digestion of organic waste materials within Ostfalia's scope of works in the research project ABOWE. The presented garage digester is part of the fermentation system. It wasconstructed in the course of studies of Bio- and Environmental Engineering.

Ostfalia Hochschule für angewandte
Wissenschaften
Fakultät Versorgungstechnik
Institut für Biotechnologie und
Umweltforschung
Ansprechpartner Abt. Bioverfahrenstechnik
Prof. Dr. Thorsten Ahrens
Salzdahlumer Straße 46/48, D-38302
Wolfenbüttel
Tel. +49 [illegible], Fax +49
[illegible]
th.ahrens@ostfalia.de
http://www.ostfalia.de

PROJECT PARTNERS

- 🇫🇮 Savonia University of Applied Sciences (Lead partner)
- 🇫🇮 University of Eastern Finland
- 🇩🇪 Ostfalia University of Applied Sciences
- 🇵🇱 Marshal Office of Lower Silesia
- 🇱🇹 Klaipeda University
- 🇸🇪 Mälardalen University
- 🇪🇪 Estonian Regional and Local Development Agency

Part-financed by the European Union
(European Regional Development Fund)

IMPLEMENTING ADVANCED CONCEPTS FOR BIOLOGICAL UTILIZATION OF WASTE

Pilot B on the Way to Sweden

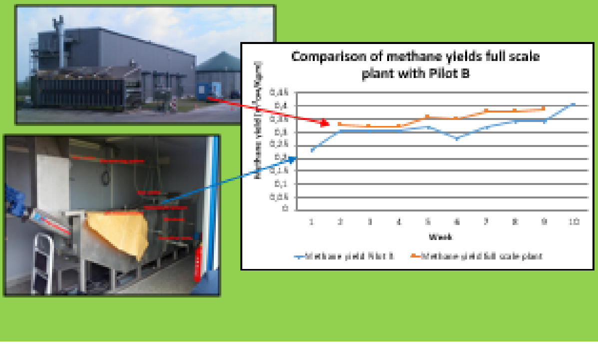
Andreas Behnsen, Tim Freidank, Ostfalia University of Applied Sciences

LITHUANIA

First stop was in Lithuania at a small farm. The fed substrates were manure, residues from distillery, algae and bio waste. Three scenarios were considered to find the economically and technically best mixture.

ESTONIA

Next stay was in Estonia at a considerably larger farm, where solely manure where considered to compare the results from pilot B with those from large scale biogas plants at farms.



RESULTS

National experts have been very interested in getting to know the technology and operation results of pilot B, which led to fruitful discussions.

The results show, that the performance of pilot B and a full scale plant is comparable.

Ostfalia Hochschule für angewandte Wissenschaften
Fakultät Versorgungstechnik
Institut für Biotechnologie und Umweltforschung
Ansprechpartner Abt. Bioverfahrenstechnik
Prof. Dr. Thorsten Ahrens
Salzdahlumer Straße 46/48, D-38302
Wolfenbüttel
Tel. [illegible], Fax [illegible]
[illegible]
[illegible]
[illegible]

PROJECT PARTNERS

- Savonia University of Applied Sciences (Lead partner)
- University of Eastern Finland
- Ostfalia University of Applied Sciences
- Marshal Office of Lower Silesia
- Klaipeda University
- Mälardalen University
- Estonian Regional and Local Development Agency

abowe
Implementing Advanced Concepts for Biological Utilization of Waste
Ostfalia University of Applied Sciences
FUTURE ENERGY
Baltic Sea Region Programme 2007-2013
Part-financed by the European Union (European Regional Development Fund)

IMPLEMENTING ADVANCED CONCEPTS FOR BIOLOGICAL UTILIZATION OF WASTE

Result flashlights

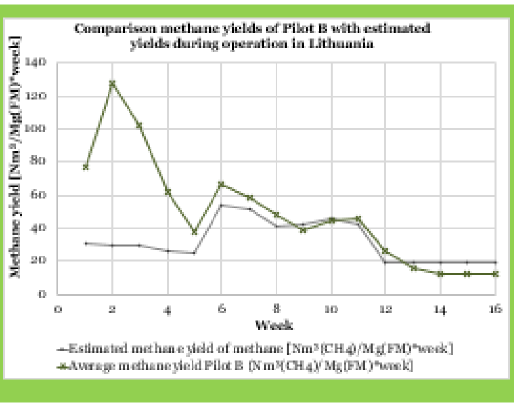
Andreas Behnsen, Tim Freidank, Ostfalia University

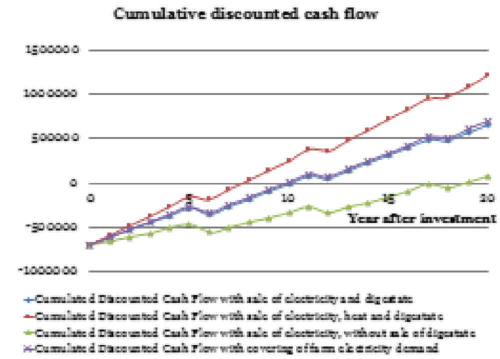
Technical performance

Basis for the estimation of the methane yield were calculations on the basis of lab tests at the Ostfalia University.
The high amount of methane produced in the first 4 weeks in Lithuania is a result of previous overfeeding and following batch operation. Obvious and wished is the parallelism of the two curves.

Financial considerations

From an economic point of view the sale of digestate is beside the sale of electricity the limiting factor for the economic feasibility.
Basis for these determinations is the calculation of the cumulative discounted cash flow of different scenarios.





Communication

To bring together the technicians and economists from University with those from the practical side is the big challenge. The experiences show, that pilot B can be a good catalyst to accelerate and substantiate the process of solution finding in the field of biogas production.

Ostfalia Hochschule für angewandte Wissenschaften
Fakultät Versorgungstechnik
Institut für Biotechnologie und Umweltforschung
Ansprechpartner Abt. Bioverfahrenstechnik
Prof. Dr. Thorsten Ahrens
Salzdahlumer Straße 46/48, D-38302 Wolfenbüttel
Tel. +49 [illegible], Fax +49 [illegible]
h.ahrens@ostfalia.de
http://www.ostfalia.de

PROJECT PARTNERS

- Savonia University of Applied Sciences (Lead partner)
- University of Eastern Finland
- Ostfalia University of Applied Sciences
- Marshal Office of Lower Silesia
- Klaipeda University
- Mälardalen University
- Estonian Regional and Local Development Agency