total COD load to the sewage treatment plant was from process wastewater from Stormossen. Because of the high load from Stormossen putting pressure on the local sewage treatment plant, Stormossen built an aerobic wastewater treatment plant on-site in 2005. Since 2005 wastewater from the anaerobic processes is put through a conventional aerobic treatment plant before being discharged to the sewerage system. The sludge produced on site can be recycled directly into the anaerobic digesters.

VISUAL AND LOCAL IMPACT

The Stormossen plant is located a few kilometres out of the city. The site is not visible from the road due to the heavily wooded landscape (Figure 138). Even on-site, the plant is unobtrusive, as the upper level sections of the plant (those on top of the cliff), including the digesters, are engineered into the cliff (Figure 139). Odour was not a problem on the site. Cold temperatures, strong winds, and the isolation of the site from residential areas would minimise the impact of any odour emissions that did occur.

COSTS AND ECONOMICS

The total investment costs from 1988 to 2004 were €7.5 million. Approximately half of this €7.5 million was upfront capital cost. Approximately 20% of the initial cost was paid by the Finnish National Government, with the balance paid by the owning municipalities. As the site was started up in 1990/1991, and has been added to 'bit by bit', as necessity dictated, and finances allowed, the cost has been somewhat higher than it would have been if the site had been built completely from scratch today. This is offset by the fact that the cost has been spread over such a long period. Also, the costs given above are the costs paid at the time, as such no adjustment has been made for inflation or changes in price since the time of purchase. Advances in technology and in the experience of suppliers would both bring down project costs.

In the regions served by the Stormossen plant people have the choice of putting their waste in a landfill bin or in recyclates bins. People pay nothing for recyclables or hazardous wastes. They pay more per kg for wastes in their 'landfill' bin than per kg in their 'kitchen waste' bin, to try and encourage more 'kitchen waste' (and packaging/combustibles *etc*.) is collected, and less is landfilled. For example, the gate fee paid to Stormossen for wastes from 'landfill' bins is around €130/tonne without tax. The costs for landfilling are high due to the limited available space. The gate fee paid for 'kitchen wastes' is around €84/tonne without tax, which is similar to the Stormossen MBT plant's running costs (Akers, Personal Communication, 2006).

CHALLENGES

The plant initially experienced major problems with a floating layer of wastes that had passed through the pre-treatment stages. The floating layer, consisting of polystyrene, corks, and other floating wastes would accumulate at the top of the reactor, and would sometimes form a thick impermeable layer through which no gas or liquid could pass. This floating layer would reduce the working volume of the reactor over time, and eventually the reactor would need to be shut down and the layer removed. Floating wastes are now removed by a screw-press added between the mixer and the digester, and heavy material is removed from the bottom of the mix separator.

When the sewage sludge digester was opened up for maintenance after 15 years of operation, it was found that 300m^3 of sand and glass had been deposited in the reactor, from when sewage sludge and biowaste were treated together in the digester used for sewage sludge today (prior to 1994). Due to the digesters being underground, this sand/glass had to be removed manually. The installation of the screw-press to remove the 'heavies' after the mix separator means that all sand, glass, small stones *etc*. are now being removed prior to digestion.

Some sections of the plant that were originally made from concrete needed to be re-engineered in stainless steel, due to corrosion. There were some areas in the inside of the reactor that were made from concrete, these remained free from corrosion. Abrasive material in the waste meant that special pumps needed to be used at certain stages of the process.

At present the plant periodically receives more waste than its designed capacity. Therefore, the excess is currently windrow composted before being landfilled (Figure 149 and Figure 150). The limiting step in the process is the pre-treatment stage, which is operating at capacity. Stormossen plan to build another process line to increase capacity (of the pre-treatment) in the near future.

Figure 150 Windrow composting of kitchen waste at Stormossen

Figure 150 shows kitchen waste being windrow composted at Stormossen. As can be seen, vermin can be a problem as the system is not enclosed.

DISCUSSION AND CONCLUSIONS

The changes in Vaasa since the mid-1980s have resulted in a near-sustainable waste-treatment system. The original aim of reducing waste sent to landfill site by 70% had been exceeded significantly. By 1997, over 90% of household waste was recycled or burnt, with just 9.5% sent to the town's new, smaller landfill (Fujita Research website, accessed June 2006). Each tonne of household waste was treated as follows in 1999:

- 450 kg processed into pellets and burnt in the local paper mill (producing 2400 kWh energy and 45 kg of ashes for disposal).
- 450 kg treated at Stormossen biological plant (producing 200 kg of soil improver and 450 kWh of electricity from biogas).
- 50 kg ferrous metals for recycling.
- 50 kg of waste for disposal.

The mass balance above was from the Fujita Research website (accessed June 2006), and represents data from 1999. The case in 2006 is that of the 'kitchen waste' arriving on-site, 14% (by mass) is classed as 'rejects' and is landfilled, 50% is recovered as RDF and used as a fuel to substitute fossil fuel use, 1% is metals that are recycled and 35% is treated anaerobically (Akers, 2006). The change in reported mass balances represents a change in the overall volume and content of 'kitchen wastes' arriving on-site, in particular, slightly more packaging and less organics in 2006 than in 1999. In both 1999 and 2006 the system has a high percentage of recycling and re-use. From 1996, the Stormossen plant has also been treating construction and industrial waste. This means that (as of 1997) 90% of all waste from Vaasa is recycled (Fujita Research website, accessed June 2006).

The 70 – 100 m^3 of biogas per tonne of incoming 'kitchen waste' does not represent a good biogas yield from a thermophilic AD process. Either the organic content (% VS) of the incoming total solids content is very low (information that was not available), or the full biogas potential of the biowaste was not being realised. If the full biogas potential of the biowaste was not being realised it could be due to the reactor process design, for example, it could be due to the potentially inadequate mixing, as previously suggested, or due to the particle size of the incoming waste being too large. The above observations are speculation, and can not be backed up without further data or analysis. The Stormossen biowastes digester has extra capacity and would like to accept organic industrial wastes to boost biogas production, but there are not many food producers in the area.

When asked if there was anything he thought should have been done differently, with the benefit of hindsight, the site foreman referred to the plant layout. The fact that the plant was built half on top of a cliff and half on the bottom, made process modifications and maintenance very difficult (including the use of explosives to cut tunnels into the cliff face). This was particularly true for the anaerobic digesters, which were engineered into the cliff, and were as such completely inaccessible apart from the top few metres. It is unclear what the original thinking behind the unorthodox layout was, but it is clear that it would have been better to build the site on one level, to facilitate changes and expansions, and to allow easier access to parts of the process such as the digesters.

Apart from when modifications or improvements are being made to the plant, downtime is minimal. Whatever downtime there is is mainly attributed to the pre-treatment stages rather than the anaerobic digesters (Lithen, Personal Communication, 2006). The plant is scheduled to close for essential maintenance for one week in July every year. The wastes reception area is big enough to cope with this backlog. This is an important fact to consider when planning new projects.

Fifteen years ago, when the plant was being built, other Finnish regions had the opinion that AD was not a good organic wastes treatment option, and chose composting plants instead. Now, with energy prices as they are and rising, other Finnish regions are reconsidering their options and examining the possibilities of implementing an AD based system (Akers, Personal Communication, 2006). The 'Vaasa Project' has showed that waste treatment can be much more sustainable than it is in the majority of the developed world. The project was completed with little government support (the Finnish government contributed just 20% to the cost of the developments). However after many years of operation the plant has proved to be an economic success and CiTec (the company responsible for developing the Stormossen plant) have installed similar systems in several other countries including Sweden, Netherlands, Italy and Japan. The plant has successfully, reliably and economically treated the organic fraction of municipal solid wastes by anaerobic digestion for 16 years. Plant economics improve year by year as gate fees and energy prices rise. All in all, the team at Stormossen are justifiably proud of their process, their forward thinking and their ability to adapt over time. They are confident that they are doing as much as they can towards treating the regions waste in the best possible way.

5.1.8 Västerås (Växtkraft) Biogas Plant

INTRODUCTION

The Växtkraft biogas plant is situated adjacent to the other installations at the waste treatment plant at Gryta, in the northern outskirts of Västerås (Figure 153 and Figure 154). Västerås (in Västmanland county), is Sweden's sixth biggest city and has around 140,000 inhabitants in the extended area. The Växtkraft biogas plant has a total throughput of 23,000 tpa, comprising of 14,000 tpa of source separated municipal kitchen waste, 4000 tpa of grease trap removal sludge and 5000 tpa of specially grown energy crops. The plant was planned and built, and is operated by Svensk Växtkraft, which was a company set up specifically to oversee the project. Svensk Växtkraft is owned by a consortium made up of Vafab-Miljö (the Solid-Waste Company owned by the municipalities in Västmanland), LRF (the National Federation of Swedish Farmers), Mälarenergi (the local energy company) and seventeen individual farmers close to the city of Västerås. The arrangement is shown in Figure 151.

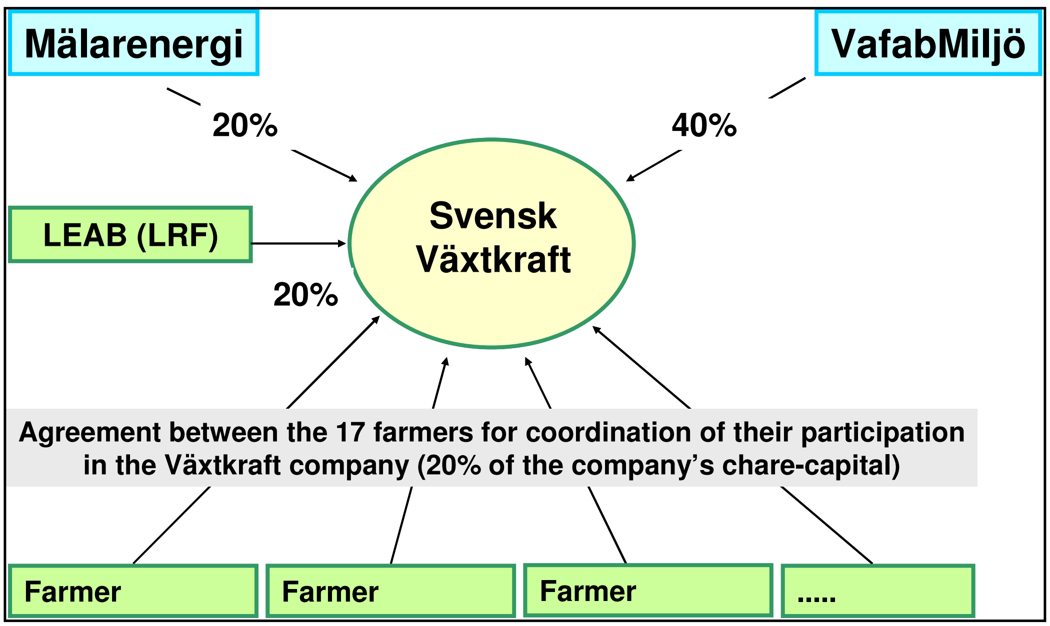

Figure 151 Chart showing ownership of the Växtkraft Biogas Plant (Persson, 2006)

The concept of the system (as presented by Per-Erik Persson, Chief Executive of Svensk Växtkraft AB, at the Agropti Gas workshop, May 2006) is shown in Figure 152.

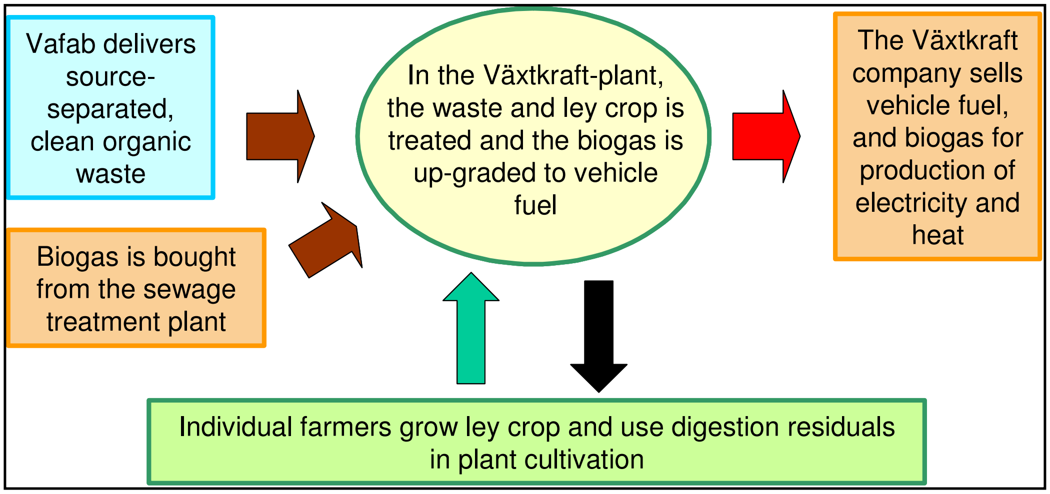

Figure 152 Overall simplification of system (Persson, 2006)

Figure 153 shows the location of Växtkraft plant in relation to the city of Västerås and the fields belonging to the participating farmers, on which the ley crop on which the digester is co-fed is grown.

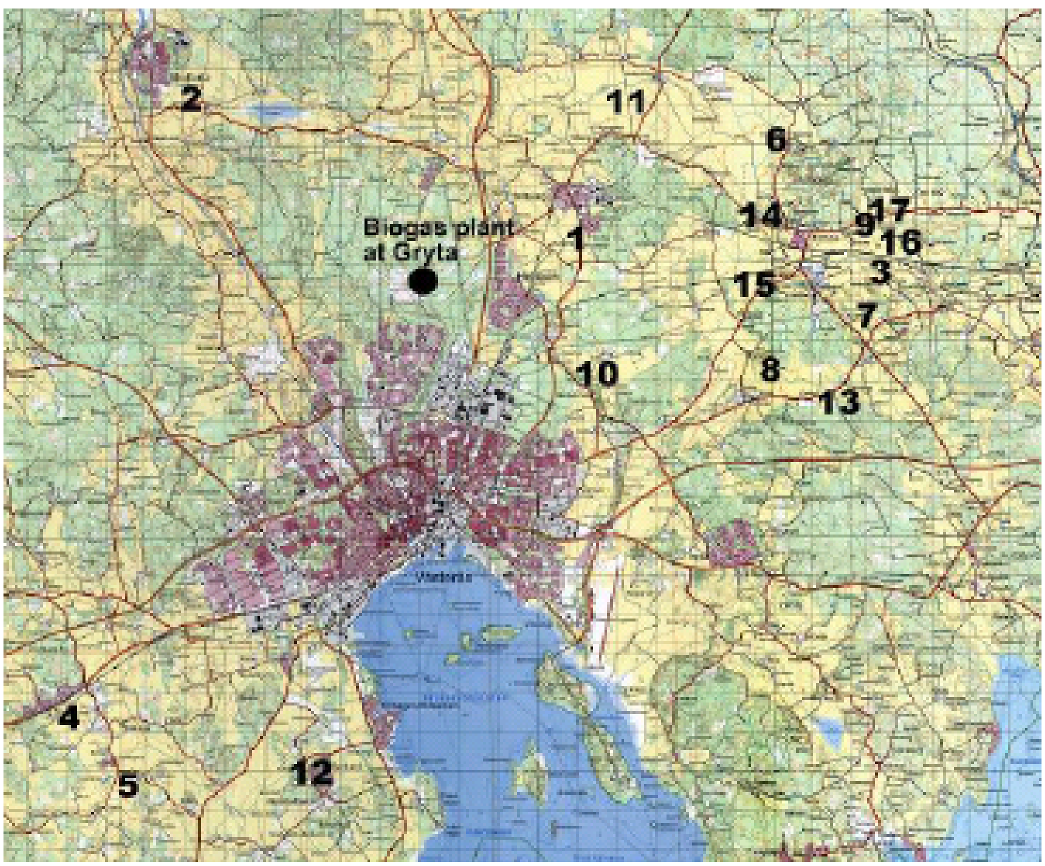

Figure 153 Location of Växtkraft Biogas Plant in relation to the city of Västerås and the participating farmers (Agropti Gas Promotional Information)

It can be seen that the plant is approximately 8 km from the city centre. As can be seen, all of the participating farmers contracted to grow ley have their fields located within 15 km of the site, with most being closer. The average distance from farm to plant is around 8 km. Figure 154 shows the location of the plant in relation to the sewage treatment works (from which biogas is also collected and upgraded), and the bus depot. The biogas from the centrally located sewage treatment works is piped up to Gryta, where it is added to the biogas produced from the Växtkraft plant and upgraded. The upgraded biogas is the piped (under a 4 bar pressure) back to the centrally located bus depot, where it is stored and used to re-fuel the city's bus fleet. The biogas bus depot and fleet is discussed in more detail in Section 2.6.1.8.2.

Figure 154 Location of the production sites for biogas and filling stations for vehicles in Västerås (Agropti Gas Promotional Information)

As with many other sewage sludge digesters in Sweden, it is possible to harvest all of the biogas produced, as most processes are heated by district heating schemes. In the UK, the biogas produced in most sewage sludge digesters is converted to electricity and heat, which is then used (almost completely) on site. The land requirement for the whole plant (including the biogas plant, the gas upgrading plant, the silage storage area and internal roads) is 22,411 m^2 (Persson, Personal Communication, 2006). The land requirement for the biogas plant is 12,000 m^2, which breaks down to include 2320 m^2 for the main building, and 5915 m^2 for internal roads and driving areas (Persson, Personal Communication, 2006).

AGROPTI–GAS RESEARCH SCHEME

In 2003, the Växtkraft project became a central part of the Agropti-Gas Research Scheme (www.agroptigas.com) which is an EU demonstration project within the 5th framework program (FP5). Aside from receiving extra European Funding, becoming part of the Agropti-Gas Research Scheme involved incorporating national and international partners into the project. The partners co-operate in demonstration, evaluation and dissemination of the project. Agropti-Gas is divided into the following parts:

- Demonstration part including purchasing, building and start up the systems described in this publication.
- Analyses of the socio-economic effects.
- Analyses of the handling systems for ley crop and digestion residuals.
- Evaluation of the technical and biological processes.
- Dissemination of results.

Partners in the Agropti-Gas project and their responsibilities are:

- **Svensk Växtkraft** is responsible for the practical demonstration part of the project.
- **JTI** (Swedish institute of Agricultural Engineering) is responsible for the socio-economic analyses and the analyses of the handling of ley crop and digestion residuals.
- **SDU** (University of Southern Denmark) responsible for the dissemination of the results.
- **FAL** (Federal Agricultural Research Centre, Germany) is responsible for the technical and biological evaluation of the processes.
- **BAI** (Bulgarian Association of Investors) is responsible for the information about the project in the eastern European countries.
- **LRF** (The National Federation of Swedish Farmers).
- **Municipality of Växjö** is responsible for project coordination.
- **VLAB** (The Public Bus Company), contracted to buy biogas and provide and maintain vehicles that use it.

As noted above, the owners of Svensk Växtkraft are key players in the project, and their responsibilities are shown in Table 49.

Table 49 Owners of Svensk Växtkraft and their responsibilities

Company	Responsibility
Vafab Miljö AB (The Public Waste Company)	Environmentally sound handling of biowaste Sustainable utilisation of the biowaste (plant nutrients, humus and energy).
Mälarenergi AB (The Public Energy Company)	Efficient energy utilization of biogas from the sewage treatment plant. Establishment of energy efficient systems.
Local Farmers	Cultivation of ley crops. Organic farming. Additional incomes – contracting.
LRF (The Swedish Farmers Association)	Support of important development projects.

The results from the different parts of the project will be published in full, to enable interested parties across Europe to benefit from the results. The main aims of the Agropti-Gas project are:

1. To demonstrate a process technique with new components to enable co-digestion of easy degradable solid biomasses (waste) with agricultural feedstock.

2. To prove that biogas is competitive as a vehicle fuel, and AD is competitive as a waste management system.

3. To prove that re-circulation of bio-waste as a high quality fertiliser in conventional and organic farming is possible, and to demonstrate the advantages for the farmer to be part of the system.

Pre-conditions to the Agropti-Gas Project included:

- All necessary permits for the erection and operation of the plants needed to be obtained.
- The disposal of digestates needed to be guaranteed in terms of;
    - Agreements with farmers, and
    - Written approvals from the food industry.
- The use of biogas as vehicle fuel needed to be guaranteed.
- The technical and economical risks must needed to be limited to a 'reasonable' level.
- The company owners (of Svensk Växtkraft) needed to approve of all the Agropti Gas Project aims and objectives.

What makes this project unique is that grass and organic municipal waste is co-digested and that the farmers and the municipality have joined and formed a company to undertake the project. The Agropti-Gas Scheme adds to this by further formalising the information dissemination, to the benefit of all interested parties. More information is available on the Agropti-Gas website (www.agroptigas.com).

OBJECTIVES OF THE VÄXTKRAFT PROJECT

The objectives of the Växtkraft project are as follows;

The Waste Perspective

- To handle high quality biowaste and crops in an environmentally sound way.
- To establish a sustainable circulation of plant nutrients and energy between the city and the agricultural sector.

The Agricultural Perspective

- To demonstrate a cost effective system for production of an eco-labelled fertilizer from organic household waste and agricultural feedstock and spread the knowledge to other regions in Europe.
- To contribute to an environmentally sound and sustainable form of farming and to promote employment within the region.
- To extract biogas and plant nutrients from ley crops.
- To reduce the use of biocides and chemical fertilizers and promote organic farming.

The Energy and Transportation Perspective

- To extract and utilize high-grade bioenergy from biowaste and energy crops with no net-contribution of carbon dioxide to the atmosphere.
- To demonstrate a cost effective system for production of biogas vehicle fuel.
- To establish a sustainable market for biogas as vehicle fuel within the region.

The Research and Development (R & D) Perspective

- To constitute a basis for R & D activities.
- To provide opportunities for studies on cultivation systems based on ley crops and organic fertilizers.
- To demonstrate the overall system.

WASTES COLLECTION AND DELIVERY

Kitchen waste has been source separated in the Västerås region since 1999. In the Västerås area households have two main options for their wastes collection.

- Source separation.
- Mixed waste collection.

Another option for kitchen and garden waste is home composting. The source separation option is 'optional' in name, but in reality the pricing of each option leaves little choice, with the mixed waste collection being significantly more expensive. Importantly, it remains a 'choice' rather than an 'instruction', which results in a much higher level of public participation. Because it is voluntary, the risk for mistakes made by unmotivated households is minimized.

The choice of alternative made by a single household is confirmed by a written agreement between the municipality and the household. According to the agreement the households within the source separation scheme commit themselves to source separate the organic household waste in accordance to instructions from the municipality. The agreement also gives the municipality the right to control the quality of the source separated organic waste from the single household. Among the 144,000 households in the region, approximately

90% participate in the source separation scheme, 7% home-compost the biowaste while approximately 3% produce a mixed household waste that is treated by incineration.

In addition to the cleverly worked collection 'options' there is a very high level of public education in Sweden. This public education is ongoing. Two full time campaigners tour the regions schools, and annually visit and educate 10,000 school children aged 9 – 11. These school children are seen as key players in 'taking the message home'. Prior to the implementation of source separation Växtkraft aimed for an 85% personal contact rate. The actual percentage of the population directly visited, and informed face to face of the plans for their kitchen waste was 90%. To ensure that the public do participate, and keep contaminants to a minimum, there are a team of two full-time 'rubbish inspectors'. These inspectors actually check citizens source separation bins. Rather than fining (or otherwise punishing) offenders, offenders are 're-educated', and the reasons behind the source separation are re-explained to them. Another offence will then result in the offending household being 'banned' from the source separation scheme, resulting in the necessary payment of the higher charges for mixed wastes collection. The source separation quality is also controlled by waste hauler, who is able to point the 'inspectors' in the direction of offenders. There are also basic quality monitoring procedures when the waste arrives at the biowastes treatment site. This combination of measures serves to keep the level of contaminants exceptionally low, at less than 0.5%. This level of contamination is much lower than in other organic waste source separation schemes in other countries, and is one of the major reasons why the Växtkraft project has been successful to date. Such was the success of the source separation in the area that, initially, more of a contamination problem was caused by spillages between the various sections of the collection trucks. This technical problem was easily solved at an early stage.

The importance of this public education expenditure was continuously re-iterated. Public participation is key to a quality product, which is fundamental to the survival of the whole project. It was judged that all money spent on public education was worth it in the long run. The extra effort and expenditure at the start were money very well spent. 'If they don't get it right from the start you will need to go back and talk to them again anyway, once your process has already experienced problems due to contamination'. The council provided the households with all of the necessary collection gear for free (or included in their annual fee). This included the ventilated wheelie bin, paper bags and the wire container to hold paper bags. Other points on the collection and public education schemes are;

- It is essential to provide clear and simple rules of source separation.
- To keep the public informed as to 'why' they are source separating, based on the (correct) belief that they are much more likely to participate if they understand reasons behind it.
- Source separation results are reported back to the citizens quarterly, so they can take pride in the results. Citizens who are told they are doing well are more likely to keep doing well.

The collection system for the organic household waste, is an open, ventilated system based on collecting kitchen waste in the kitchen in paper bags placed in a wire rack (Figure 155). The paper used to make the paper bags is water resistant, and so does not go soggy when filled with wet wastes. The paper bags are almost impermeable to odours (Pettersson, Personal Communication, 2006). The use of paper bags permanently remind the households that nothing but biodegradable organic waste should be placed into the bag. To guide households in the source separation, sorting instructions are printed on the bags. The instructions state that: only food leftovers, garden waste, wilted flowers, pot plants and household paper should be placed in the paper bags. Full paper bags are deposited in ventilated plastic bins (Figure 156) until collection.

Figure 155 Paper kitchen wastes collection bag (Växtkraft Promotional Information)

Waste from institutional kitchens is handled in the same way as household wastes. Sludge from grease separators in institutional kitchens and restaurants is collected with slurry tankers and is delivered directly to the plant (Växtkraft Promotional Information).

Farmers who are partners in the company Svensk Växtkraft are also contracted for the cultivation of ley crops to be used for biogas production. Cultivation of ley crop in rotation with food crops helps improve the balance of the soil. Clover ley crop in particular helps to fix nitrogen in the soil and makes soils more fertile. According to the contract the leys shall lie for two or three years and have a high percentage of clover (25% of the seed) due to the intended improvement of the soil structure and the intended value of ley as a preceding crop. The leys shall be part of the normal crop rotation of the farms. According to the present rules for EU subsidies the ley may be cultivated on land that is set aside. The ley is under-sown, either in a cereal crop, or in spring oil-plants. Under-sowing, fertilizing and management are done in accordance with the guidelines given by Svensk Växtkraft. Harvesting is done at the same time of the year as for "normal", large-scale ensiling of ley crop for cattle. At harvest, the crop is wilted and finely chopped with a precision chopper. In order to achieve high efficiency, minimize costs and to obtain a substrate that has the intended properties for digestion, the harvesting is organized by Svensk Växtkraft. However, the practical work of harvesting and ensiling is performed by hired contractors. The crop is preserved as silage in plastic bags. The silage is taken out from the bags by a wheel loader and is transported to the biogas plant continuously throughout the year (Växtkraft Promotional Information). Some photographs of the harvesting and storage of the ley crop are shown below. These photographs were sourced from Växtkraft Promotional Information.

Figure 156 Ventilated kitchen wastes collection bin (Växtkraft Promotional Information)

Figure 157 Harvesting ley-crop (Växtkraft Promotional Information)

Figure 158 Harvesting ley-crop (Växtkraft Promotional Information)

Figure 159 Storing ley-crop on-site (Vaxkraft Promotional Information)

Figure 160 Storing ley-crop on-site (Vaxkraft Promotional Information)

PLANT DESCRIPTION

The Västerås project, which was started up in 2005 is a full scale biowastes treatment plant. Biogas is upgraded and used as a vehicle fuel to fuel the city's bus and municipal refuse fleets. The plant treats approximately 23,000 tpa of the following wastes. The quantity and total solids content of the incoming waste is shown in Table 50.

Table 50 Wastes treated at Västerås

Waste/crop	Throughput in 2005 (tpa)	Total Solids Content (%)
Source separated kitchen waste	14,000	30
Grease trap removal sludge	4000	4
Ley crop	5000	35

The source separated kitchen is from households and from institutional kitchens. It is 'clean', with an average contaminant percentage less than 0.5%. The grease trap removal sludge is from grease separators in institutional kitchens and restaurants. The ley crop is ensilaged and is harvested from a contracted ley acreage of 300 hectares cultivated by farmers who are also part-owners in the plant. The anaerobic digestion and pre-treatment system was provided by Ros Roca. More details about Ros Roca are available in Section 4.1.10 or on the Ros Roca website (www.rosroca.de). A process flow diagram of the Västerås plant is shown in Figure 161.

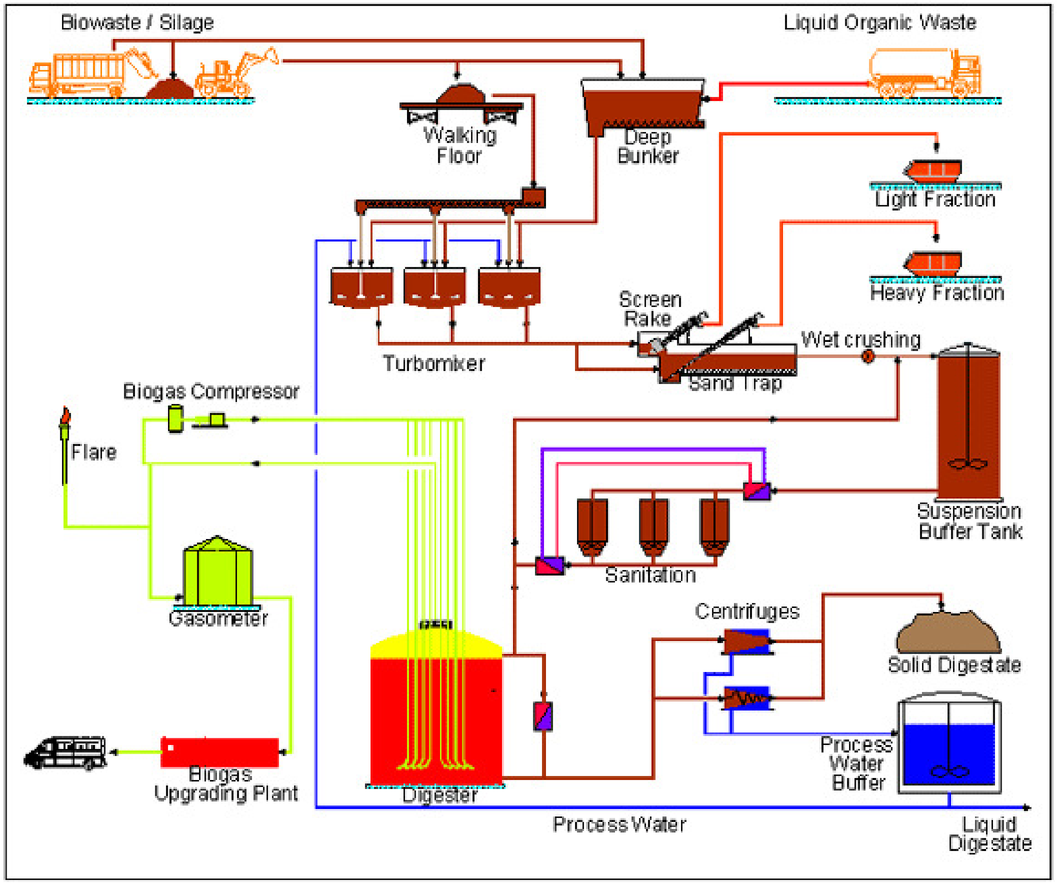

Figure 161 Process flow diagram (Ros Roca website, accessed July 2006)

PRE-TREATMENT

Waste is delivered to a covered wastes reception area, where source separated kitchen waste and ley crop are unloaded directly on to the floor (Figure 162 and Figure 163).

Liquid wastes, such as the grease trap sludge is unloaded directly into a liquid wastes reception bunker (Figure 164). The bunker is discharged automatically with screws and a pump and can be cleaned afterwards.

The first step in the process is a wet pre-treatment. All of the organic waste is mixed with process water in a turbomixer (Figure 165) and a suspension with a solid concentration of up to 15% is produced. It is possible to separate out of the turbomixer impurities like glass, stones, bones by means of a grit system. The turbomixer is then discharged by hydraulic flow to a screening unit which separates floating material like plastic, wood and other non biodegradable structural material.

Figure 162 Waste being unloaded in wastes reception area (Pettersson 2006)

Figure 163 Wastes reception area

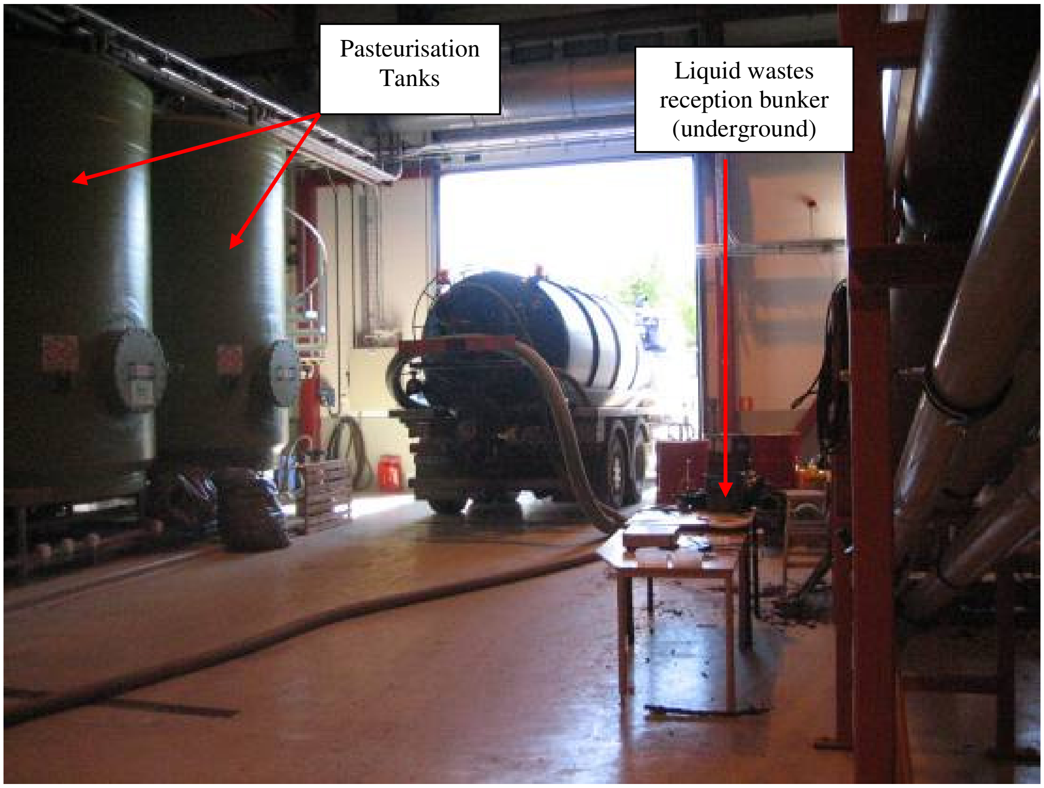

Figure 164 Liquid wastes reception area

Figure 165 Turbomixers

The suspension having passed the screen flows through an aerated sand trap where small inert particles like sand, glass, stones are separated. The result of a very efficient wet pre-treatment is a suspension strongly enriched with biodegradable material and almost free of impurities. The suspension then passes a crushing unit to ensure that only particles with a size of less than 12 mm are charged via a suspension buffer tank to the sanitation process. The sanitation process (70° C for one hour) takes place immediately before the anaerobic digestion. Figure 166 shows the three pasteurisation tanks.

Figure 166 Pasteurisation tanks

The design of the sanitation process makes possible to lead back suspension which was not correctly sanitized to the suspension buffer tank and the suspension can pass the sanitation process again. The sanitation process works under batch conditions in mixed tanks, in such a way as to ensure no short circuiting. The retention time as well as the sanitation temperature are controlled and monitored continuously. The exhaust heat from the co-generation unit is usually used for the sanitation process. After successful sanitation the suspension is charged continuously to the pre-digestion mixing/buffer tank, which is the tall tank narrow in Figure 167, where it is held prior to anaerobic digestion. The concrete structure in the foreground of Figure 167 is the biofilter, while the building on the left is the reception and mechanical treatment building. The shorter, wider tank to the right (just visible over the biofilter) is the digestate storage tank, where digestate is stored after digestion prior to being de-watered and transported to the farms. The anaerobic digester is the large tank at the back.

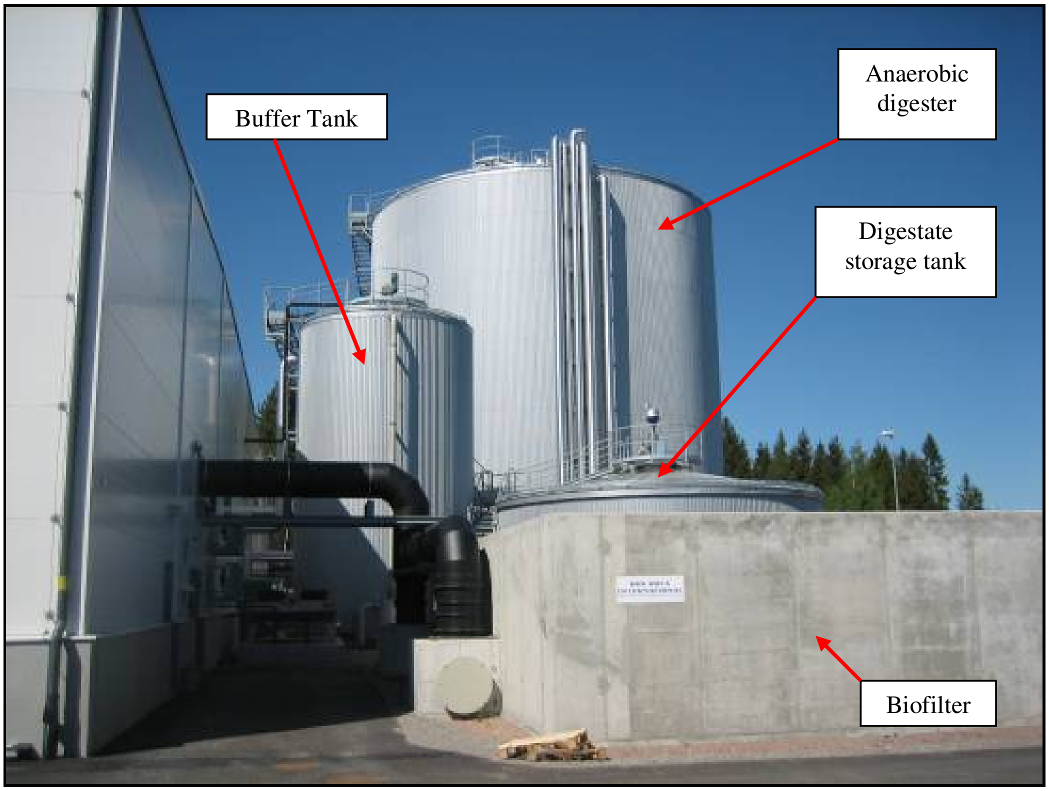

Figure 167 Digestate storage tank, buffer tank, and anaerobic digester at Växtkraft plant

ANAEROBIC DIGESTION

The anaerobic digester, shown in Figure 168, has a volume of 4000 m^3. The retention time of the digester is 20 days (Persson, Personal Communication, 2006). Digestion is mesophilic, and carried out around 37^oC. There are no moving parts in the digester, and mixing is provided by compressed biogas injection.

The digester is fed 6 days per week. Technically, the plant could be fed for seven days per week, but the plant is deliberately not fed on the seventh day so that it 'can clear the backlog' of process intermediates such as volatile fatty acids (Ahrens, 2006). There is some debate about whether this feeding regime is better than a continuously stable pattern, or a system that periodically 'shocks' or pushes the bacterial culture in order to strengthen it and encourage its development. It is assumed that lab scale tests have proven that this system is the optimum for this particular feedstock mixture in this particular digester. Ros Roca state that the digestion process is characterized by a low electricity consumption and a high surplus of electricity which is very important for the economy of the plant. No details of the monitoring regime or the operating pH range were given.

Figure 168 Anaerobic digester at Växtkraft plant

DIGESTATE

Because there is no post-AD treatment other than de-watering the throughput time of the plant is approximately 21 days (excluding the ley crop storage). The digested suspension is de-watered with centrifuges**.** No polymers are used to enhance the de-watering of the digestate. This is a requirement of the Swedish Organic Farming Quality regulations. As the solid digestate is nearly free of impurities, it needs no further treatment. It can be used directly in agriculture or can easily be upgraded to other products (for example, potting soil). The solid digestion residue from the process is of high quality directly after the digestion and certified from the Bundesgütegemeinschaft Kompost e.V. (BGK). The company transports the digestion residuals to the storage facilities on the fields of the participating farmers. The fertilizing potential of the digestion residuals is utilized by using modern spreading techniques. It is up to the farmer how the digestion residuals are used, although he receives guidelines from Växtkraft.

From the biogas plant one liquid and one solid phase of digestion residuals is obtained. The solid phase is handled as "normal" farm manure and is spread with conventional manure spreaders, *i.e.* the residuals must be dry enough to allow stacking. The liquid phase is pumpable and possible to spread with conventional slurry-spreaders. By the separation of the residuals into two phases the plant nutrients are divided too, so that the solid phase can be considered as a phosphorus fertilizer and the liquid phase as a nitrogen fertilizer. Pending the spreading, digestion residuals are mainly stored adjacent to the cultivated acreage. Liquid residuals are stored in covered tanks in order to minimize the ammonia losses during storage. The basic principle for the design and placing of the stores is to minimize the transport distances in connection with spreading. Solid and liquid residuals are distributed between the farmers in proportion to their contracted acreage of ley. The digestion residuals can replace mineral fertilizer on 1200 - 1600 hectares of cereals. The plant produces 4000 tpa of solid digestate (with a dry matter content of 25%) and 13,000 tpa of liquid fertiliser (dry matter content 2%). Liquid digestate (Figure 169) is re-circulated and excess tankered direct to on-farm storage tanks (Figure 171 and Figure 172). Each farm has enough storage capacity for one years worth of liquid fertiliser storage. This is so that the liquid fertiliser can be stored and used at peak growing times (spring and early summer), when its addition will have the most positive impact on plant nutrient uptake and growth rates. There is also less rain in spring and early summer so there will be less nutrient leaching.

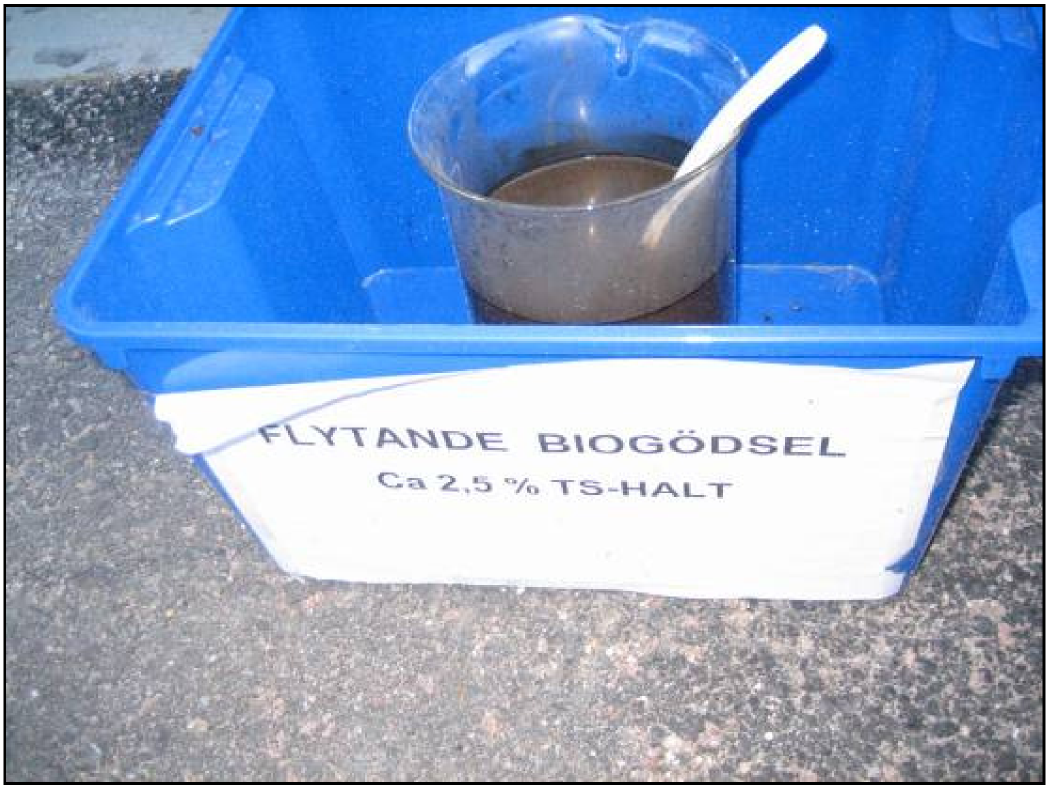

Figure 169 Liquid digestate

Figure 170 Liquid digestate transport from site (Pettersson, 2006)

Figure 171 Liquid digestate transport to storage tanks (Pettersson, 2006)

Figure 172 On-farm liquid digestate storage tank (Pettersson, 2006)

Figure 173 Spreading the liquid digestate (Pettersson, 2006)

The solid digestate (Figure 174) is transported by truck direct to the fields on which it will be applied (Figure 175 and Figure 176). The application of the solid digestate to the land provides NPK and other nutrients, as well as organic matter. Guidelines are provided by the company to each of the participating farmers on the amount of digestate that they can spread on each hectare of their land. The digestate is much better defined, much more regulated and better for the land than manure, which is used throughout Europe anyway (Wahlberg, 2006). All experiences with the soil improver and liquid fertiliser from the full scale process and from the lab and pilot scale projects have been overwhelmingly positive so far (Wahlberg, 2006).

Figure 174 Solid digestate

Figure 175 Truck removing solid digestate container from plant (Pettersson, 2006)

Figure 176 Truck unloading solid digestate container on farmland (Pettersson, 2006)

QUALITY CONTROL OF THE DIGESTATE

Liquid and solid digestates from the biogas plant are accepted as fertilizers in organic farming according to EC regulations. One of the preconditions for the decision to build the plant was that the digestates should be accepted for use in conventional cereal production, according to the rules of Svenskt Sigill and Cerealia and in organic farming according to the rules of the KRAV organisation. The quality control of the digestates is performed according to the rules for certification of compost and digestates, developed by the Swedish Environmental Protection Agency and the Swedish Association of Waste Management. The quality control is carried out in several steps, partly by inspections in connection with the collection and the reception at the plant and partly by analyses of the substrate within the biogas process and the digestates on delivery to the farm. Spot checks are carried out in connection to the collection of the waste in order to ensure that the given sorting instructions are followed. If impurities are found in the biowaste, the household/business is informed. If subsequent spot checks show that the given instructions are still not followed, the household/business in question will be suspended from the source-separation system. At delivery at the biogas plant, impurities (like wrongly sorted bags) are sorted out mechanically in the receiving hall. Furthermore, remaining impurities are separated in the wet pre-treatment step of the biogas plant in which light residuals are separated in a wet screen and heavy residuals in a sand grit trap. The grease trap removal sludge is controlled by checking that the sludge is collected at accepted grease traps and by chemical analyses. Sludge accepted to be charged into the biogas plant undergoes the wet pre-treatment process, mentioned above.

BIOGAS PRODUCTION AND UTILISATION

In lab tests the ley crop silage was shown to produce around 80 m^3 of biogas/tonne. In lab tests the grease waste was shown to produce around 45 m^3 of biogas/tonne. The kitchen waste produces approximately 100 m^3 of biogas/tonne (Ahrens, 2006). This corresponds to an expected biogas production of 550 m^3/hour at full loading capacity, or an average biogas production of 86 m^3/tonne of waste input under the current feeding regime. Average methane content is expected to be 60% (Ahrens, 2006). Figure 177 shows a process flow diagram for the biogas produced.

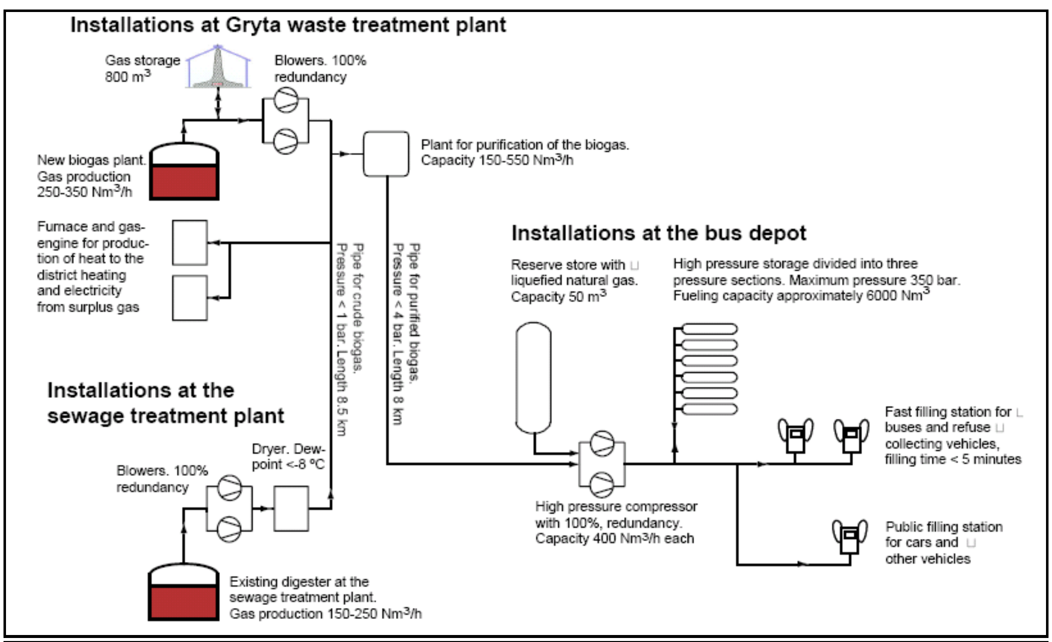

Figure 177 Overall biogas flow diagram (Växtkraft Promotional Information)

As mentioned above, the biogas is upgraded to natural gas quality (97 - 98% methane) and used as vehicle fuel for city buses and refuse collection vehicles. The biogas upgrading procedure will be described below. Prior to upgrading, the biogas must be compressed, and is added to the biogas pumped up from the sewage treatment works and compressed to 10 bar in the compressors shown in Figure 178.

Figure 178 Compressor units (Ahrens, 2006)

After compression, biogas is passed to the gas upgrading building (Figure 179), where a biogas scrubber uses 1560 m^3 of water per day to upgrade 6300 m^3/day of biogas from 65% methane to 97 - 98% methane. The scrubber operates at a pressure of 10 bar. Figure 179 shows the gas upgrading building (in the background), with the pre-digestion mixing/buffer tank on the right. The low concrete structure in front of the biogas upgrading building is the biofilter. Figure 180 shows the inside of the biogas upgrading building. The three columns are the biogas scrubbers, in which the biogas is mixed with water under pressure. The hydrogen sulphide concentration in the biogas before upgrading is around 1000 ppm, and is 0 ppm after. A small amount of hydrogen sulphide is later added to give the upgraded gas an odour. The carbon dioxide percentage in the biogas was 30 – 35% before upgrading, and 2% after.

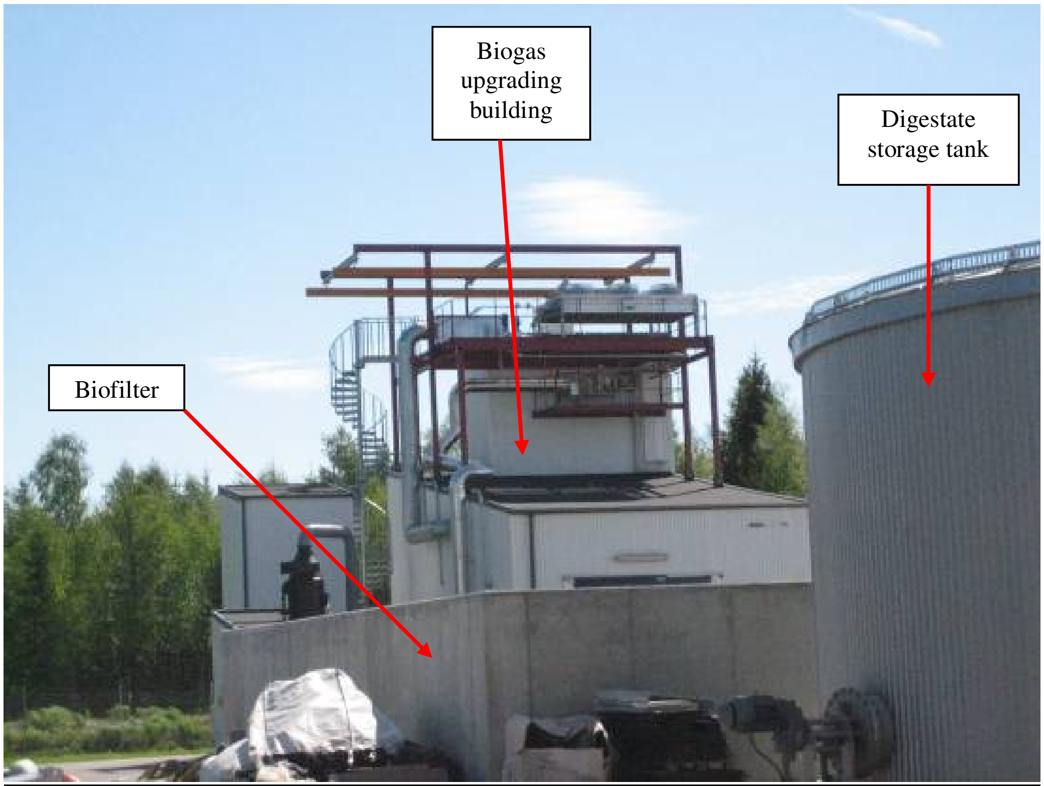

Figure 179 Biogas upgrading building

Figure 180 Inside of biogas upgrading building

After the carbon dioxide and hydrogen sulphide have been removed by scrubbing, the upgraded gas is dried in adsorption driers to remove water vapour, and re-odorised as a safety precaution. A flow diagram of the biogas upgrading system is available in Figure 181.

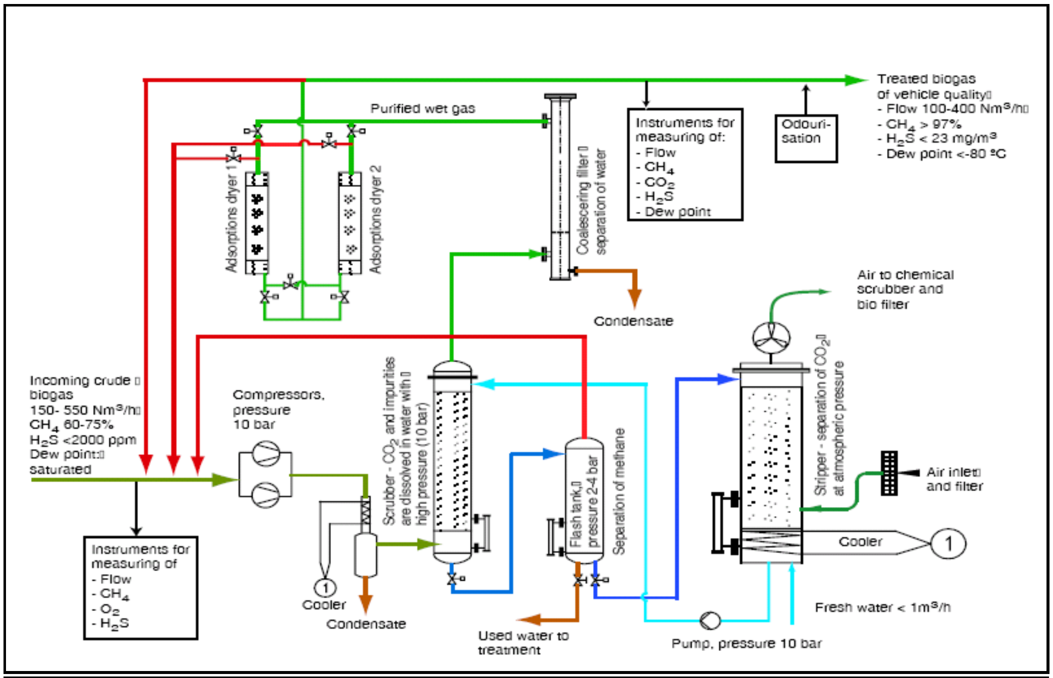

Figure 181 Flow diagram of biogas upgrading (Ahrens, 2006)

As can be seen from Figure 181 the core technology of the gas scrubbing system is the bubbling of biogas through a contra-flow of water at a high pressure (10 bar). The carbon dioxide and hydrogen sulphide, being much more soluble than the methane, dissolve into the water stream and are removed from the gas. Approximately 2% of the methane is also lost in the upgrading system. Trace gases such as Toluene, 1H-pyrazol, tromethamine and butanedinitril are also removed. A full list of the trace gases removed is available in Ahrens (2006). Upgraded biogas is then piped 8.5 km to the bus station in the centre of town (Figure 153 and Figure 154). At the bus station the biogas is further compressed to 330 bar (Figure 182) for storage efficiency and stored on-site (Figure 183). Buses are filled overnight, and one fill-up exceeds their maximum daily range they will not need to be filled again until the end of their working day.

Figure 182 Compressors at Västerås Bus Depot

Figure 183 Biogas storage at Västerås Bus Depot

The biogas pumps from which the buses re-fill are shown in Figure 184.

Figure 184 Biogas fuel pumps

There is also a public biogas filling station served by the same system, located just the other side of the bus station perimeter fence. At the bus depot, a reserve store with liquid natural gas is installed as a back-up in case of a decline in the gas supply. This reserve capacity is necessary, since buses that have been adapted for biogas fuel, can run only on gas, and are therefore totally dependent on daily deliveries of gas. The gas from the two production sites is sufficient to supply all of the city buses (at least 40 buses), 10 refuse collection vehicles and some 500 cars and other light transport vehicles. The use of biogas as a transport fuel is further discussed in Section 2.6.1.8. Only biogas that is needed is upgraded and piped to the bus station. The excess is sold back to the energy company (Mälarenergi), who utilise it in an existing CHP plant for electricity and heat production. The heat produced is led into the district heating system in Västerås. It is anticipated that about 75% of the gas production will be used for vehicle fuel while the rest will be used for CHP production. There is also a biogas flare for emergency maintenance situations, but obviously the flare will be used as seldom as possible.

ENERGY BALANCE

Around 2.9 MWh is input into the plant every day, of which 1.2 MWh is used by the compressors. The plant produces an average of 6290 m^3 of upgraded methane per day. If the biogas was used directly in the CHP plant, rather than upgraded and used as a transport fuel, approximately 24 MWh/day of electricity would be produced, and 44 MWh/day of heat. This means that on balance the plant would produce and excess of electricity of approximately 21 MWh/day (based on the authors calculations). This would correspond to 7665 MWh/a. The plant has a total electrical efficiency rate of 93.4% (Ahrens, 2006).

WATER AND WASTEWATER TREATMENT

The process minimises its water requirements by re-circulating process water for the dilution of the solid waste and the ley crop. No wastewater treatment is required (from the digestion process) as all liquid digestate not re-circulated is used on the farms. The biogas upgrading plant uses 65 m^3 of fresh water/hour to upgrade biogas from 65% methane to 97 – 98% (Ahrens, 2006). This water is treated before being released. No information was available on how or where this wastewater was treated.

EXHAUST AIR TREATMENT

The process is 'closed', with collection and treatment of all exhaust gases in a scrubber and a biofilter, to avoid any odour problems around the plant. The air is pre-heated before it enters the bio filter in order to ensure the intended function of the biofilter in the cold winter conditions.

VISUAL AND LOCAL IMPACT

The biogas-plant is situated adjacent to the other installations at the waste treatment plant at Gryta, in the northern outskirts of Västerås. The whole plant is surrounded by woodland, and can not be seen from outside the complex. With regards to odours, the plant smelt of silage rather than wastes, and therefore portrayed an agricultural image (rather than a wastes treatment image) to visitors. There was no odour nuisance to neighbours due to the siting of the plant on an existing wastes treatment complex. All exhaust air was collected and treated in a scrubber and biofilter in order to avoid any odour problems in the surroundings of the plant.

COSTS AND ECONOMICS

The total capital cost for the biogas plant was in the region of €8.4 million. The contract was a 'turn-key' contract, which means that everything from the initial ground work to the plant running at the levels stated in the contract (Persson, Personal Communication, 2006). The total capital cost for the gas upgrading plant was €1.7 million. The contract was similar to that for the biogas plant, meaning that everything was included, and the contract was not complete until the plant had been running successfully to pre-stipulated performance levels for a stated period of time. The total capital cost for the facilities at the bus depot (high pressure compressors, high pressure gas storage, LNG storage, tank stations for buses and cars, including buildings and internal gas piping *etc.*) cost a total of €1.4 million (Persson, Personal Communication, 2006). The plant was co-funded by EU FP5 program for research and demonstration, by the Swedish government and by the conglomerate of investors described above. The funding was as follows:

- 30% by EU.
- 30% by Swedish Government.
- 40% by the Conglomerate of investors who own the plant.

The 40% share provided by the owning partnership was based on finance from financial institutions, whose reactions to the application varied greatly. The risk perceived by the banks was reduced greatly by the size of the participating companies for example, the energy company (Mälarenergi), wastes and water companies (Vafab-Miljö).

As part of the Agropti Gas project a socio-economic analysis report was carried out (JTI, 2006). To summarise the findings of the socio-economic analysis, the system as it stands is a win-win situation. The results for the annual benefits are summarised below:

- Benefit to the environment was estimated at €91,930.
- Benefit to society was estimated at €275,781.
- Benefit to agriculture was estimated at €72,000.
- **Total Benefit = €439,970**.

Other benefits not factored into these figures include;

- Increased opportunities for rural employment.
- Positive impact on working environments.
- Increased levels of health (as emissions of ammonia and VOCs are reduced, as well as particulates, CO_2 and NO_x reductions from the substituting of diesel as a transport fuel).

A negative impact is the compaction of the soil when spreading the solid digestate or liquid fertiliser. Another area that needs more work was the storage facilities for digestate (solid and liquid), which currently lead to ammonia loss. Conclusions of the socio economic analysis were;

- Project was beneficial on all levels considered.
- Income from biowaste is the largest income.
- Replacement of mineral fertiliser is positive for the agricultural system.
- Substituting diesel with biogas for city buses is environmentally positive.

The full presentation, including how these estimations were calculated is available in JTI (2006).

DISCUSSION AND CONCLUSIONS

The conclusions observed so far have been overwhelmingly positive. There have been benefits observed on all levels considered - agriculturally, energetically, in terms of wastes treatment, in terms of transport and most importantly financially. The positive financial results are a direct consequence of the Swedish Government's taxation and development policies, aimed at promoting renewable energy provision. Government support was key in Sweden. Without top-level Government support, Sweden would not have any biogas plants. Competitiveness depends on the taxation system in your particular country (Nilsson, 2006). It is unknown if similar positive economics would be possible in a similar UK based system. This would require further study based on more detailed economic information than was made available.

Due to its importance in the context of the project, the information contained in the Agropti-Gas Workshop presentation by Carl Magnus Pettersson (Production Manager of the Växtkraft Project), titled 'Lessons Learned' is included in full in Appendix 1. All of the points referred in the slides presented should be studied and taken on board by any decision maker who is considering embarking on a similar project. Key points were extracted and are discussed below.

- **'Identify the important key organisations and involve them in the project in an early planning phase'.**

This is a fundamental key to success. All of the project partners are key to its success in different ways, because of what they can bring to the project.

- '**A company should be formed to make key decisions and manage/realize the project'.**

The key stakeholders should be part owners of the company, so they have active roles. That said, it is important that responsibilities, boundaries and aims are clearly defined.

- '**Make the partners (key organisations) owners of the company**', and
- '**Give the owners active roles in the operation with focus on their specific fields of competence'**. Within this**:**
    - **'it is key that the company does not compete with any of the owning companies'**.

Potential conflicts could arise if these pre-conditions are not met.

It has been said that the farmers are the most important partners in the conglomerate. Indeed the farmers, and their wish to improve their soil was one of the main drivers for the project. The farmers in the region are mainly crop producers, with very little intensive agriculture. As such the soil quality had been observed to be gradually decreasing over a number of years. The farmers wanted to increase the organic and nutrients content in the soil, but with not enough manure to go around they began to search for other alternatives to increase the productivity of the region's stiff clay soil. They looked at the cultivation, cropping, anaerobic digestion (and re-application of the digestate) of ley as a serious soil improvement option. Early studies showed that this would not be economic, therefore they investigated the possibility of taking in municipal biowaste. If the farmers were not on board, the project would simply not be viable. There would be no disposal route for the solid digestate, and therefore the plant would need to pay to have it disposed of. Also, the liquid digestate would need to be treated as wastewater, significantly adding to the capital and running costs of the plant. It was stated that farmers do not benefit greatly financially (at least directly), but their benefit is that they improve their soil quality.

Despite the importance of the farmers, without the wastes and energy companies on-board the project would not have been viable either. Aside from the gate fee from the municipal biowastes being a critical financial input, the sheer size of the energy and waste companies (and their financial clout) meant that the banks took the project seriously and provided the initial finance. These points serve to underline the key concept that a solid partnership between many stakeholders is required.

- '**Get one main contractor for each plant, co-ordinating sub-contractors. This makes life easier for the purchaser'**.

This is an important point that has been re-iterated in personal communications with numerous sources throughout Europe. Co-ordinating contractors for such a diverse plant can be extremely problematic and time consuming.

- '**Reduce the amount of tenderers to a few reliable suppliers, capable of successfully finalising the project. They must have sufficient experience, competence, size and financial strength**'.

Only get tenders from four or five 'major players'. Do not ask for applications from anyone and everyone. Tenders for full plants (or parts of plants) represent huge amounts of work (for those who will submit them, and for those who must evaluate them). The use of suppliers with existing reference plants and a proven track record in the field is highly recommended. It was stated (as it has been referred throughout in this project) that 'corners should never be cut' for short term financial gains. Also extreme care should be taken if considering awarding contracts to an un-proven supplier. The financial strength of the suppliers should always be analysed, as there have been problems in the past of projects running into major difficulties because the suppliers (or some sub-contractors) have gone bust.

A high quality biowaste is essential for the realization of digestate quality standards, which are key to project goals and finances.

- '**A source separated high quality biowaste is achievable but calls for massive efforts, for example information and education activities towards the households**'.

The source separation of biowastes should be established well before the AD plant is scheduled to come online. This provides two main benefits:

1) The population gets used to source separation, and the percentage of contaminants decreases.
2) The exact characterisation in terms of quantity, content and contaminants of the waste stream can be established.

In this case, the source separated biowaste was treated by IVC, purely as an intermediate measure, while the AD process was being planned. In this way there was a viable 'product' to show the public from the start. This also meant that the public did not lose interest in source separation, and let their standards slip, as may have happened had they realised that their source separated biowaste was being incinerated with the residual waste anyway.

- '**Focus on the quality of biowaste, rather than quantity. Restrict the biowaste to food waste**'.

The achievement of a high quality source separation and therefore a high quality biowaste is fundamental for the success of the whole project. In fact, the Swedish lack of contaminants in the waste source separated by the Swedish population provide the primary reason why the project has been successful, as compared to similar schemes in other countries where the quality of source separation was not so good (Denmark, Finland and Germany).

Doubt has been expressed over the possibility that the digestate could possibly meet Swedish Organic Farming Quality Standards, as it is wastes-based. The plant owners (including the farmers) insist it does. If the pre-agreed and contracted quality standards are not met, the farmers are within their rights to refuse to accept the digestate or fertiliser. It may well be that the Organic Farming Regulations differ greatly between Sweden and other European countries. This has not been verified by the authors. The farmers would lose the markets for the crops they produce if they were to apply contaminated digestate. As such, if the quality standards are not met, the digestate will need to be landfilled, as the farmers will not be obliged to accept it. In summary, the key data is shown in Figure 185.

Key data:

Incoming substrates to the biogas plant per year

• Source-separated organic waste from households and institutional kitchens with a dry matter content of 30 %	14 000 tonnes
• Liquid waste (grease trap removal sludge), with a dry matter content of 4 %	4 000 tonnes
• Ley crop from a contracted acreage of 300 hectares with a dry matter contents of 35%	5 000 tonnes

Production per year

• Biogas from the biogas plant	15 000 MWh
• Biogas from the sewage treatment plant	8 000 MWh
• Up-graded biogas to fuel quality	
Energy	23 000 MWh
Equivalent to petrol	2.3 Million litres
• Digestion residuals	
solid part with a dry matter content of 25-30%	6 500 tones
liquid part with a dry matter content of 2-3%	15 000 tonnes

Figure 185 Key data from Växtkraft Project (Växtkraft Promotional Information)

A key concept is the integrated thinking between farmers, the agriculture sector, the waste sector and the energy sector. The political framework must be in place to encourage development. Pettersson (2006) suggested that they would '**do it again, in almost the same way**'. Although the Växtkraft/Västerås project has been successful to date, it was only started up in 2005. Therefore, as yet, there is a lack of an operational track record. The track record over time is the only real way to judge the success of such a project.

5.2 Case studies of systems treating centrally separated OFMSW as part of a MBT plant

5.2.1 Buchen (U-Plus UmweltService AG) MBT Plant

INTRODUCTION

The Buchen MBT plant was built by ISKA GmbH. ISKA GmbH is a subsidiary of U-Plus UmweltService AG, which is one of the biggest waste disposal companies in Germany. The plant is also owned and operated by U-Plus UmweltService AG who have the long term contract to treat municipal residual wastes in the area. Plant capacity is 165,000 tpa. The plant processes the residual waste from approximately 1,180,000 inhabitants in five rural districts in the Buchen Odenwald area (Bad Wurttemburg, Germany). Buchen is situated in a region of Germany where kitchen waste is not source separated, and the Buchen site treated approximately 151,000 tpa of the residual waste stream that also contained kitchen waste from four of the five municipalities, and kitchen and garden waste together from one of the 5 municipalities. Construction was commenced in November 2003 and the plant was started up in June 2005. The ISKA process can be flexibly engineered to meet client requirements, and the modular nature of the system facilitates this. The Buchen site has five percolation lines, with the rest of the plant designed around these. Figure 186 represents an aerial view of the site.

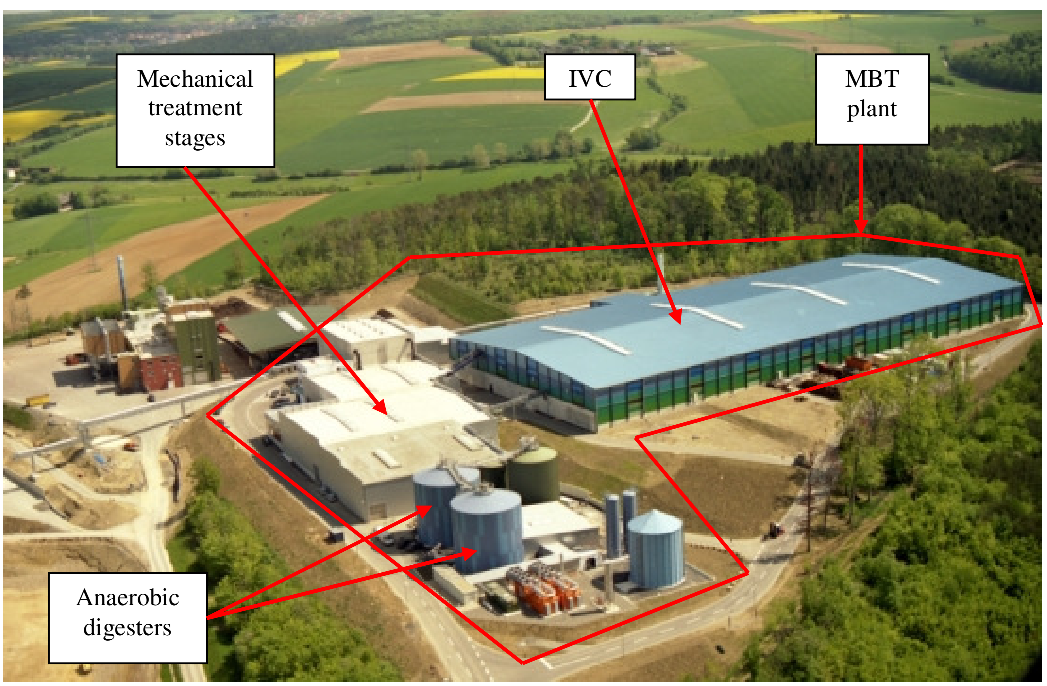

Figure 186 Aerial photograph of Buchen MBT Plant (T-Plus GmbH website, accessed July 2006)

The anaerobic digesters are the two large blue tanks in the foreground and the smaller green tank behind them. The green digester was the digester at the pilot scale plant that previously occupied the site, and is included in the scale-up. Beside the green digester is a rain-water storage tank, and the smaller blue tank for biogas storage. The mechanical separation and percolators are housed in the white buildings, while the large blue warehouse houses the composting hall. The small cluster of buildings in the top left of the screen is a biomass power station. Electrical grid connection and excess heat and water use were co-engineered between both sites for cost and energy efficiency. Immediately to the left of the site is a landfill site (Figure 186), owned by the region, where the biostabilised output is deposited.

The plant occupies and area of 27,000 m^2, of which 14,000 m^2 is taken up by buildings, and 9500 m^2 by the composting hall (Information from ISKA Promotional Information). This corresponds to 6.1 tonnes of waste treated per m^2 of land, or 0.16 m^2 per tonne of waste processed if the plant was operating at its full capacity. The plant employs 16 – 18 staff in two shifts, operating 5 days per week. Although the plant is only manned 5 days per week the percolators, AD and IVC stages of the process run continuously. Figure 187 represents a process flow diagram of the Buchen site. It is sourced from Environmental Expert website [a], accessed February 2006).

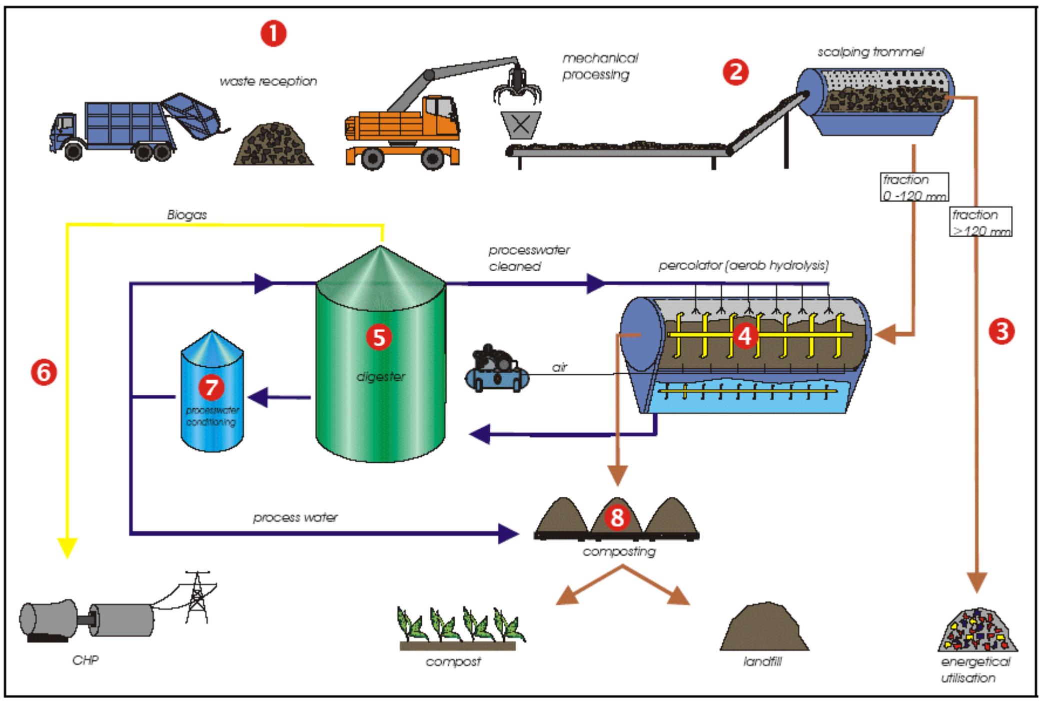

Figure 187 Process flow diagram of Buchen MBT Plant (Environmental Expert website [a], accessed February 2006)

Note
This diagram is slightly inaccurate, as all of the CLO goes to landfill.

PLANT DESCRIPTION

Incoming residual waste is deposited in an enclosed reception hall, and lifted by crane into a coarse (300 mm) slow speed shredder. The purpose of this is more to open bags than to actually shred the waste. The waste is then mechanically sorted, with recyclables such as ferrous metals (3 – 5% of incoming waste) and aluminium being removed for recycling, and the high calorific value wastes such as unrecyclable paper, cardboard and plastics are removed, to be baled and transported to an incinerator for energy recovery. The remaining waste enters percolation drums, where hot water is added to keep temperature around 38°C. In these percolators, described in more detail below, organics are dissolved into the liquid phase. The resulting effluent is sent to anaerobic digesters for wet digestion and energy recovery. The anaerobic digesters are described in more detail later in the case study. The remaining solids, after de-watering, are sent to the in-vessel composting hall for biostabilisation. After biostabilisation in the composting hall, the waste is deposited to the adjacent landfill. Approximately 40% by mass of the incoming waste is sent to landfill. This 40% is fully biostabilised under normal operational circumstances (not observed during our visit, see paragraph below). The process water, after AD, is re-circulated to the percolators and to the IVC process, both of which require water. The whole process is water neutral, with water continuously being introduced with the incoming waste. A small volume of the process water does need to be continuously replaced by fresh water to prevent the concentration of toxins increasing beyond levels potentially harmful to the bacteria. Rain water is collected and stored on site for this purpose. The dilution of the small amounts of wastewater produced with rain water bring effluents produced within standard consent limits for discharge to sewer.

PRE-TREATMENT

After waste reception and shredding, the first mechanical separation stage involves trommel separation, with a mesh size of 120 mm (Figure 188). Oversized fractions go to be baled for RDF, and undersized fractions go via ferrous metal separators (Figure 188) to the percolation tanks.

Figure 188 Inside trommel sieve (1) at Buchen

Figure 189 Ferrous metal separator at Buchen

RDF

Approximately 25% of the incoming waste stream is recovered as RDF. This RDF is currently sent for incineration, and will soon be sent to a newly built EFW plant in Frankfurt, which will have a capacity for 550,000 tpa. The EFW plant has been built in a location where the excess heat will be beneficially used, allowing a more economic gate fee to be charged for wastes received.

PERCOLATION SYSTEM

Percolation in the ISKA system leads to a COD extraction of 200 – 250 kg/t of input dry substance. By extraction of the organic fraction during the percolation process the solid material is stabilised, and the residence time required for the percolated material to reach required stabilisation parameters in the in-vessel composting process can be reduced. Also, by extracting the soluble organics into an easily pumpable, easily treated liquid phase, high rate AD technology can be used.

The percolators (of which there are 5 operating in parallel at Buchen) are horizontal, cylindrical vessels made of steel (Figure 190). The percolators are continuously operating. They are equipped with a central mixer, shown in Figure 191 and Figure 193, with arms extending from the centre to intermittently mix the waste stream, and a hydraulically-powered scraper located over a grate. It is fed with the OFMSW at one end and emptied on the other end after passing through a screw press to de-water the material. The feedstock is alternatively aerated and percolated with hot water. The percolation water is introduced from the top and removed through screens at the bottom of the reactor. A moving floor mechanism pushed the waste through the percolation cylinders at the required rate. Residence time in the percolators is approximately three days, at 38^{o}C. The required temperature (38°C) and moisture content are achieved by the addition of hot water. The percolators must be elevated above the de-gritting and de-watering steps as pumping sand and minerals can be problematic, therefore gravitational flow is preferred. This elevation can be observed in Figure 190. In the percolators, one tonne of grey waste is reduced to a mass of around 363 kg (Beck, 2004).

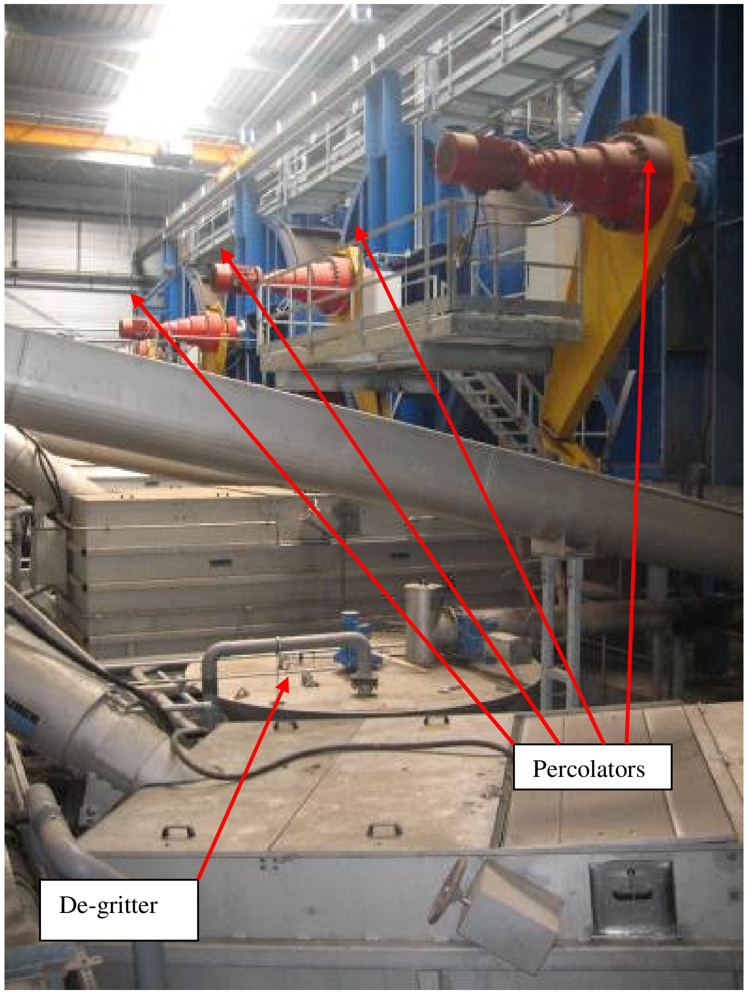

Figure 190 Percolators and de-gritters.

The percolators are the large blue cylinders. The red motor/gear mechanism on the end of the percolators powers the stirring mechanism. The de-gritters can be observed in the foreground, to the left of the percolators. After percolation and de-watering and de-gritting (in a sand cyclone) the liquid phase (with dissolved organics) goes to the anaerobic digesters, and the solid phase goes through another trommel screening process (mesh size 60 mm). Oversized particles go to be baled for RDF, and undersized particles go to the in-vessel composting stage to be completely biostabilised before landfill. Figure 191 and Figure 192 show the inside of a percolator. In Figure 191 the central stirring shaft can be clearly observed, with its stirring arms.

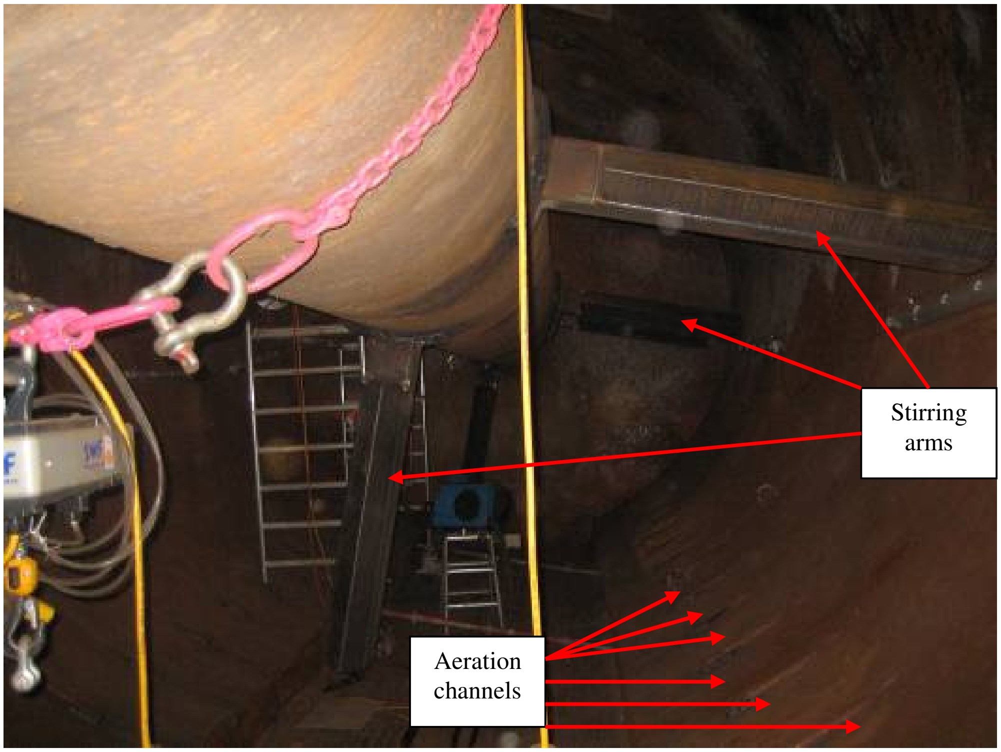

Figure 191 Inside the percolators

Figure 192 shows the aeration channels within the percolators. These aeration channels can also be seen above in Figure 191.

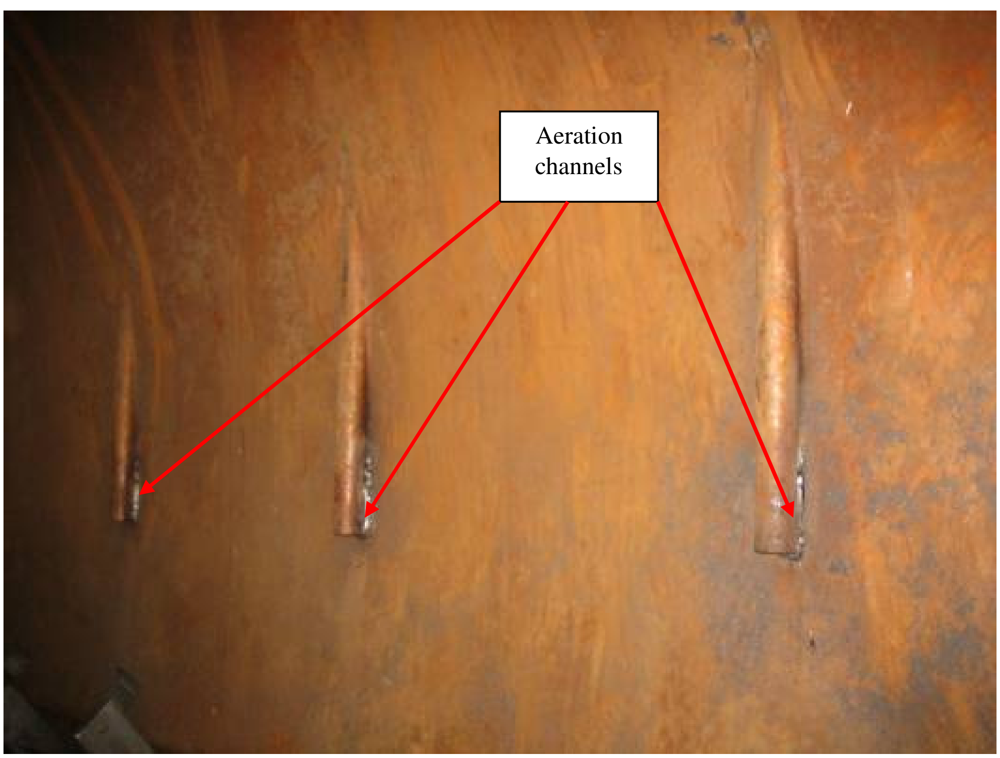

Figure 192 Aeration channels within percolators

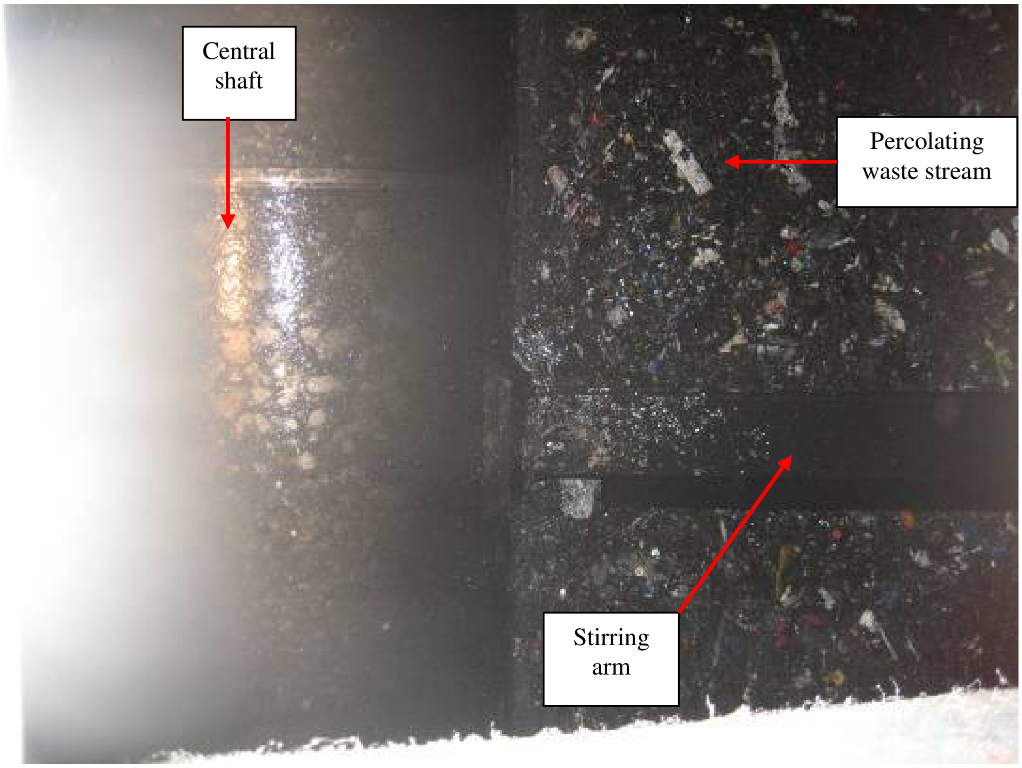

Figure 193 Rotating 'arms', inside percolator, in an operating percolator

Figure 193 shows the inside of an operating percolator (from the top). On the left is the central shaft, and connected to it is a stirring arm.

ANAEROBIC DIGESTION

Digestion of the dissolved organics from the percolation stage is carried out in 3 digesters. Two digesters have a volume of 2000 m^3 and one digester has a volume of 1000 m^3. The digesters were designed by ISKA themselves, and operate in fixed bed/fluidised bed type mode (also known as 'hybrid filter'). The two 2000 m^3 digesters are 14 m tall, the first 4 m of which contains plastic holding material, designed to retain the biomass. Above this, the reactor operates in fluidised bed mode. Biogas is flushed at pressure through the plastic holding material for 2 – 3 minutes every 3 days to 'shake and move' the plastic holding material, so that they do not become so thick with sludge that channelling occurs. Channelling would minimise wastewater/biomass contact and reduce efficiency. Mixing is provided in the fluidised stage above the layer of plastic material by the upflow velocity, as the system is in the liquid phase. The digester has a rake, to remove sludge, which is then sent to the in-vessel composting unit. Retention time in the anaerobic digesters is 4 days. Digester pH is maintained between 6.5 and 8. When pH rises towards 9.0 as ammonia build up, citric acid is dosed manually (sacks of citric acid are emptied) into the exiting end of the percolators until the digester pH is lowered. ISKA deem that expensive control systems are not necessary, and their operator watches trends in on-line gas production and content data, and off-line pH, VFA data trends over the previous 3 - 4 days to control the process. The pumping and piping system between the percolators and the digesters is totally integrated and flexible. It is possible to add any desired volumes from any of the 5 percolators to any of the three digesters. This as a big advantage of the modular design of the ISKA Buchen process, as it adds further flexibility to the system, in that if one percolator is known to be inactive for any reason, its load can be distributed between the three digesters, or if one digester requires maintenance, or is experiencing problems, the load can be diverted to one of the remaining digesters.

Approximately 8,250,000 m^3 of biogas are produced annually, which corresponds to 55 m^3 per tonne of incoming MSW, or 0.5 m^3/kgCOD passing through the anaerobic digestion system. This value of 103 m^3/tonne OFMSW, although low, is comparable to biogas yields in other systems which typically have a higher residence time. The total residence time in the ISKA Buchen system is 7 days (3 in the percolator and 4 in the digester), compared to 15 - 25 days in other AD systems treating OFMSW. The in-vessel composting of the solid fraction takes a further 3 weeks, as the solid fraction has not been digested anaerobically. The average methane percentage was quoted at 65%. It must be pointed out that this methane percentage is higher than that in some other systems, so although the volume of biogas produced is less, the calorific value of it is higher.

BIOGAS UTILISATION

The biogas produced is de-sulphurised, held in a buffer/storage tank and continuously used by a gas engine to produce heat and electricity. The biogas cleaning, storage, piping and CHP use were all subcontracted to the same company (Pro2 AnlagenTechnik GmbH, Willich, Germany, www.pro-2.net). Roughly, the yield from a percolation system accounts for about 70 – 80% of methane produced using other methods with similar feedstocks (Vandevivere *et al*., 2003).

ENERGY PRODUCTION

Overall the Buchen site is usually a net energy exporter, exporting 10 – 15% of the electricity produced to the grid. The majority of the heat produced is used on site. The amount of excess heat produced is small, and there is currently no alternative use for it. 8,250,000 m^3 of biogas would produce approximately 16,100 MWh/a of electricity, and approximately 29,517 MWh/a of heat (based on conversion efficiencies of 30% and 55% respectively). It is calculated that 10 – 15% of the electricity would represent 1610 – 2415 MWh/a of exportable electricity.

POST AD TREATMENT

After leaving the percolator and being separated from the liquid fraction by a press, the recovered solids have a 55% TS content and are dryer than the original fresh material that had a 50% TS content. The organic fraction is still high enough to raise the temperature up to 71 °C during the composting process. As a result, the material is sanitized and is further stabilized. After the three week post-composting process, the solids are further dried to an 80% TS content. If required, this CLO is easy to separate further by sieving it into separate fibre, inert, metal, and plastic fractions.

The IVC plant was supplied by VKW Anlagenbau (Austria). The IVC plant was experiencing problems with process control of the aeration system at the time of the visit (Kutterer, Personal Communication, 2006), but a VKW representative was not present to provide further information. From the IVC system, the compost like output is moved by covered conveyor belt to the landfill site (see dotted red line in Figure 194). Approximately 60,400 tonnes of biostabilised output is landfilled per year at the neighbouring landfill site.

Figure 194 Conveyor belt from IVC to landfill site

WATER AND WASTEWATER TREATMENT

With regards to water use and wastewater production, the system is well planned and engineered. The process water, after AD, is re-circulated to the percolators and to the IVC process, both of which require water. The whole process is water neutral, with water continuously being introduced with the incoming waste. A small volume of the process water does need to be continuously replaced by fresh water to prevent the concentration of toxins. Rain water is collected and stored on site for this purpose. The liquid effluent from the AD plant is treated in a de-nitrification plant followed by an ultra-filtration process, and is either recycled as process water or released into the sewer (Beck, 2004). The dilution of the small amounts of wastewater produced with rain water bring effluents produced within standard consent limits for discharge to sewer.

EXHAUST GAS TREATMENT

All waste air streams are gathered and burnt in a regenerative thermal oxidation (RTO) system. The thermal oxidation treatment is carried out in three lines. Two of these lines are operating at any one time as the other is maintained. Although successful when working well, this form of exhaust air treatment has caused many problems at Buchen, and has proved to be a great expense. It was estimated that half of the entire plants running costs were spent on exhaust air treatment, and that perhaps a different system may be chosen if the plant was to be rebuilt (Kutterer, Personal Communication, 2006). The thermal oxidation of the exhaust gases also uses approximately 30 – 35% of the energy obtained from the biogas, which has significant energetic and financial implications. The exhaust air emissions legislation in the UK is currently less strict than that in Germany.

MASS BALANCE
The mass balance for the system is shown in Figure 195.

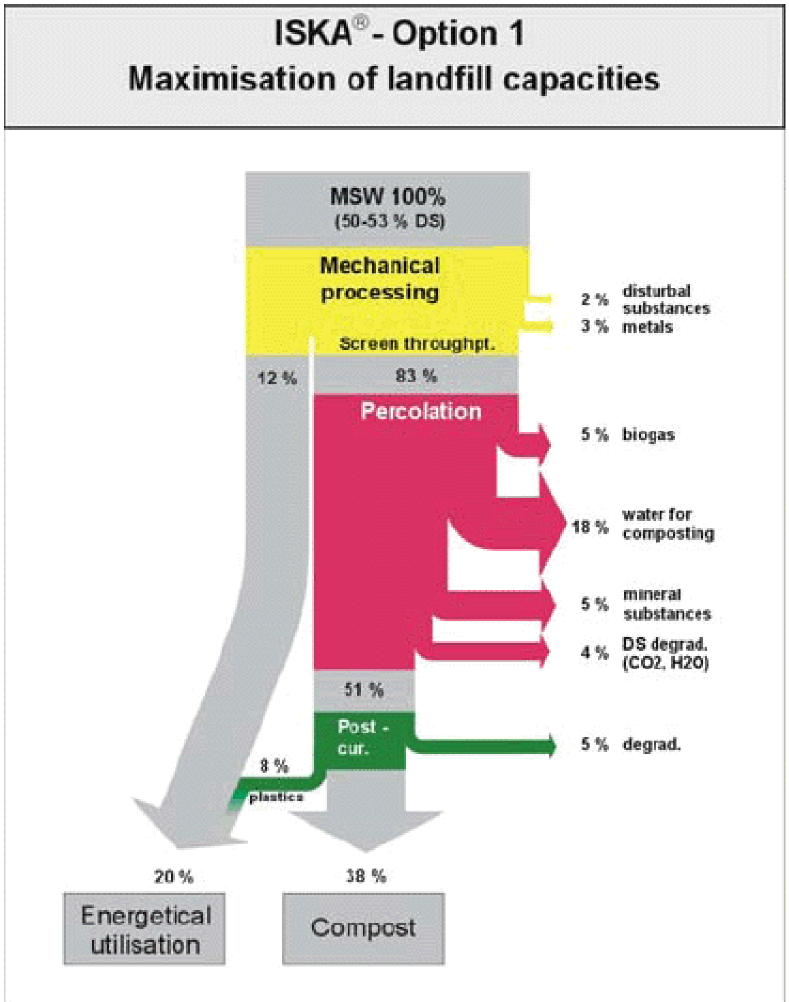

Figure 195 Mass balance of ISKA process (Environmental Expert website [b], accessed June 2006)

It can be seen that the process diverts 60% of the incoming residual waste from landfill under normal circumstances. In the mass balance above, the pink section labelled 'Percolation' incorporates both percolation and anaerobic digestion. It can be seen that 5% of the incoming residual waste (by mass) is converted to biogas. The mass balance is further discussed in Section 6.2.1 and Appendix 2.

VISUAL AND LOCAL IMPACT
The plant was sited in a pleasant rural area, albeit beside an existing landfill site. The plant was built at the highest point on-site, making it visible from far away (Figure 196). The highest points on the plant were the two 2000 m^3 anaerobic digesters at 14m tall. Trees had been planted behind and to one side of the plant to reduce visual impact from these directions (Figure 186).

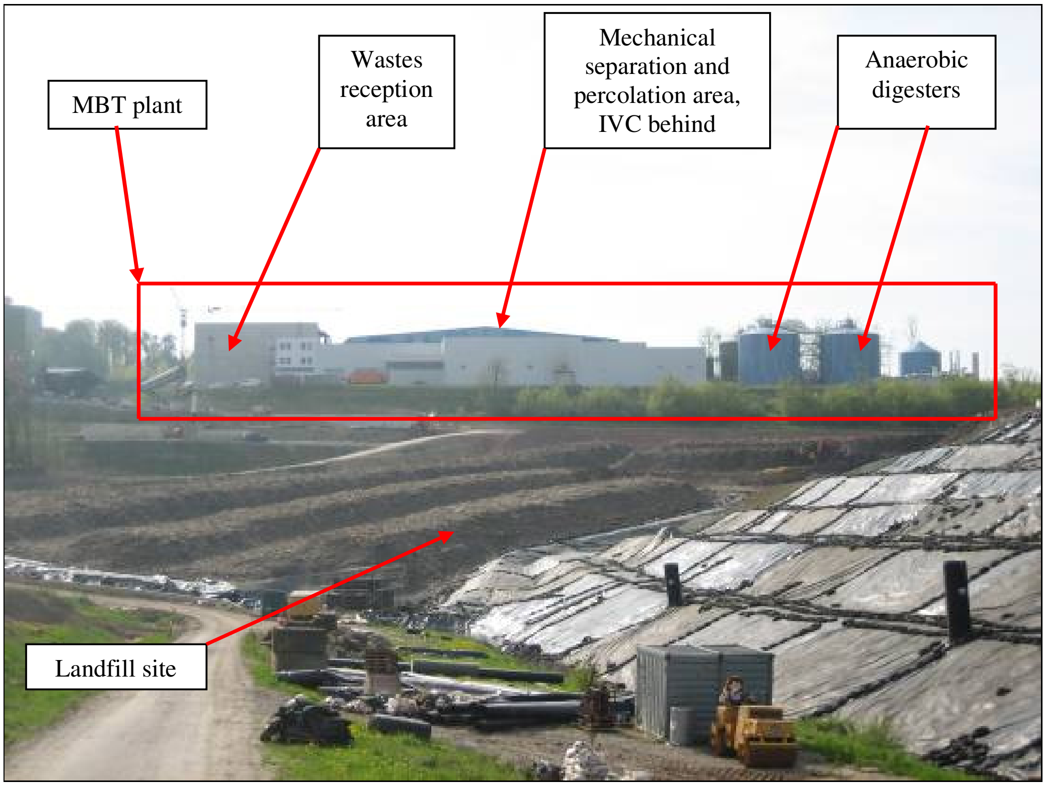

Figure 196 Photograph of Buchen MBT Plant, with landfill site in foreground

Odour and dust/particulates inside the plant were noticeable, indicating that perhaps the odour extraction/fresh air re-circulation system was not ideal. Aside from the high dust levels, housekeeping was very good. The process was not operating at full capacity at the time of our visit, however the process was still accepting its usual waste stream and unstabilised waste was being deposited to landfill. Also, the in-vessel composting plant (provided to ISKA by a sub-contractor) was experiencing problems at the time of our visit. It could be expected that these two factors would lead to odour escape around the site, but on-site, outside the buildings there was no noticeable odour. Considering conditions inside, it can be said that the exhaust gas treatment system was operating well. The plant was not particularly noisy, and its rural location meant that there were few neighbours.

COSTS AND ECONOMICS

The capital cost of the whole MBT plant was approximately €42 million. The landfill site is owned by the region, and ISKA currently pay €53/tonne to dispose of their biostabilised output. Payback time was estimated at 15 years, at current prices, but increased gate fees would reduce this, and increased landfill charges would increase it. A payback time of 15 years may be too high to be considered viable in the UK, where shorter term gains are given more importance.

Buchen receives €100/tonne of waste received. Gate fees to the incinerator are also currently €100/tonne, and approximately 25% of the incoming waste is sent to the incinerator as RDF. The current incinerator is owned by ENBV, ISKA’s parent company. When the new incinerator in Frankfurt comes on-line, gate fees will drop to €50 – 60/tonne. At present 40% of the incoming waste is landfilled, at a cost of €53/tonne. Operating costs were estimated at €35 – 55/tonne (including finance), approximately half of which is spent on exhaust air treatment (Kutterer, Personal Communication, 2006). Exhaust air treatment laws in Germany are particularly tight, and in the UK (at least for now) this would not represent such an expense.

Table 51 Basic plant economics (based on available information)

IN	€	OUT	€
Gate Fee €100 x 151,000 tpa	15,000,000	Operating costs €35 – 55/tonne	5,285,000 to 8,305,000
Recyclates	Undisclosed	Landfill €53 x 60,400 tpa	3,200,000
Renewable energy from biogas	Undisclosed	Incinerator €100 x 37,750 tpa	3,800,000
Total (Minimum)	**15,000,000**	**Total (maximum)**	**12,285,000 to 15,305,000**

The figures in Table 51 are based on available information, and on an incoming waste stream of 151,000 tpa. The more waste is accepted, the more profitable the plant will be. It is expected that future price trends (energy and wastes) will improve plant economics.

<u>CHALLENGES AND CHANGES MADE</u>

At the time of our visit one of the 5 percolators was out of action. As a consequence of this, one fifth of the waste stream entering the percolation stages was being sent direct to the in-vessel composting hall, without percolation. As this waste was not percolated, it contained a much greater proportion of organics, that would otherwise have been dissolved and sent for AD. The effect of not percolating this proportion of the waste stream was that the in-vessel composting stage had a higher organic waste input, greatly increasing residence times and meaning that the waste streams could not be fully biostabilised. Despite one percolator only treating 20% of the waste stream, the plant was operating at only 60% efficiency. Also, essential maintenance/upgrading of the in-vessel composting system was being undertaken at the time of our visit, which also lowered the extent of the biostabilisation. As described above, the in-vessel composting system was supplied to ISKA by a sub-contractor, who is responsible for paying to landfill the excess (non-biostabilised) waste while their process is not operating at its full stipulated capacity. Normally CLO output from the plant for landfill would be completely biostabilised, but at the time of our visit, this was not the case.

The problem with the percolator was that the manufacturing sub-contractor had slightly adapted the design, for ease of transport. The rotating ‘arms’ inside the percolators (Figure 191 and Figure 193) had been screwed on (and off for transport) rather than welded as with previous models. One of these screwed-on arms had become loose and fallen off inside a percolator. The percolators were stopped one by one and the screwed on arms welded on. These are now checked regularly by x-ray. With one of the five percolators not operational, the subsequent organics treatment stages can not cope with the increased throughput. It is clear that this problem will not be repeated in future plants.

As with other MBT plants, string, rope, long sections of wrapping plastic and the insides of cassettes gets wound around all moving parts, such as shredders, conveyor belts (or moving parts inside percolators or digesters if they get that far without being removed). At Buchen (as with other plants) these troublesome items need to be removed from key process points once per week (Figure 197).

Figure 197 Cassettes, rope and other wastes becoming tangled in moving parts of process

The exhaust air treatment has caused many problems at Buchen, and has proved to be a great expense. It was estimated that 30 – 35% of the energy from biogas produced was used by the exhaust gas treatment system, and that perhaps a different system may be chosen if the plant was to be rebuilt.

DISCUSSION AND CONCLUSIONS

The biostabilised output from the ISKA Buchen process mainly contains plastic, but could be further refined (at a cost of around €140/tonne). In Germany, no compost made from residual municipal waste can be certified as quality compost, irrespective of quality, so at Buchen (and the Heilbronn MBT plant in the same region) no effort is made to further treat the compost. In Australia, with the vast areas of arid land, any compost is in great demand and at the Global Renewables UR-3R Facility in Sydney which incorporates ISKA percolation the compost is further treated after the in-vessel composting stage so that it can be used on land, rather than disposed of in landfill. Conditions and legislation in the UK will be closer to the German situation than the Australian. Markets/disposal routes for this material in the UK are being developed, such as land remediation, woodlands creation and as a growth media for energy crops (Lawrence, Personal Communication, 2006).

UK conditions may point towards the thermal recovery/volume reduction of CLO where possible. If this was the preferred option, ISKA could presumably re-engineer their system to meet project specific requirements and legislation.

A payback time of 15 years may be too high to be considered viable in the UK, where shorter term gains are given more importance. From a wastes treatment and recovery perspective the ISKA system at the Buchen site compares well with other MBT configurations (incorporating AD), mainly because of the small area required for such a high throughput. This is possible mainly because of the percolation system. The plant was built to treat a larger capacity than it currently receives. In this way more wastes can be incorporated in the future, as populations and waste arisings increase.

Energetically, the plant is not as favourable as some other configurations. For example not all of the organics are treated anaerobically, therefore potential biogas is lost, and secondly the percolation systems require hot water, and aeration which requires an energy input. It must be mentioned that although the percolation systems require an energy input, they are heated by waste heat produced on-site, so the whole site is usually roughly energy neutral (excluding energy from incineration of extracted RDF). With regards to water use and wastewater production, the system is well planned and engineered.

If a similar system was to be considered in the UK, the up-front mechanical treatment would need to be more robust, and more advanced with regards to the removal of recyclates, as our recyclates would be contained in the residual waste stream (at present). The Global Renewables UR-3R Facility in Sydney (Australia) demonstrates how similar facilities in the UK would be designed, as in Australia recyclates are thrown away with the residual waste as in the UK (although the UK situation is increasingly moving away from ‘black bag’ MSW collection towards the recovery of recyclates).

5.2.2 Heilbronn (U-Plus UmweltService AG) MBT Plant

INTRODUCTION

The Heilbronn MBT plant was built by ISKA GmbH. ISKA GmbH is a subsidiary of U-Plus UmweltService AG, which is one of the biggest waste disposal companies in Germany. The plant is also owned and operated by U-Plus UmweltService AG who have the long term contract to treat municipal residual wastes in the area. Plant capacity is 88,000 tpa, and currently around 80,000 tpa is accepted. The plant processes the residual waste from approximately 625,000 inhabitants in the city of Heilbronn and 2 surrounding rural districts. As with Buchen, Heilbronn is situated in the Bad Wurttemburg region of Germany where kitchen waste is not source separated, and the Heilbronn site treated approximately 80,000 tpa of the residual waste stream that also contained kitchen waste. Construction was started in March 2004 and the plant was started up in June 2005. The ISKA procedure can be flexibly engineered to meet client requirements, and the modular nature of the system facilitates this. This can be demonstrated by comparing the different scales and layouts and costs of the plants at Heilbronn and Buchen. The Heilbronn site has 2 percolation lines, with the rest of the plant designed around these. The Heilbronn plant was built to a smaller scale than the Buchen plant, with much less space available. As such the process is very space efficient. The capital costs were significantly higher than the Buchen plant, per tonne of waste throughput (€338/tonne at Heilbronn compared with €278/tonne at Buchen). Figure 198 represents an aerial view of the site during construction. Strict local conditions were an important factor in the decision to build an ISKA plant. The site is only metres away from an important regional river, and all tanks needed to be ‘double-hulled’ as an extra safety measure before planning was approved. This added to the costs of the project as described below. The stabilised end product is disposed of on an external landfill. Seven employees (per shift) are required to run the plant, which works on 2 shifts, for 6 days per week. At the time of the visit the Heilbronn plant was operating at 130% of designed capacity, to clear a backlog of wastes.

As can be seen in Figure 198 the Heilbronn plant was built in a small site, in an industrial area. Visual impact was not an issue given the industrial surroundings, particularly the cooling tower in the background. The blue cylinders are the percolators, around which the system was built. The construction area immediately to the left of the percolators is the composting hall, and immediately to the right (where the crane is) is the area where the waste reception area and mechanical treatment phases were built. The total area used was 20,000 m^2, of which 8400 m^2 is taken up by buildings, and 5400 m^2 of which is taken up by the composting hall (ISKA Promotional Information). This corresponds to an area of 4.4 tonnes of waste treated per m^2 of land, or 0.227 m^2 per tonne of waste processed if the plant was operating at its full capacity.

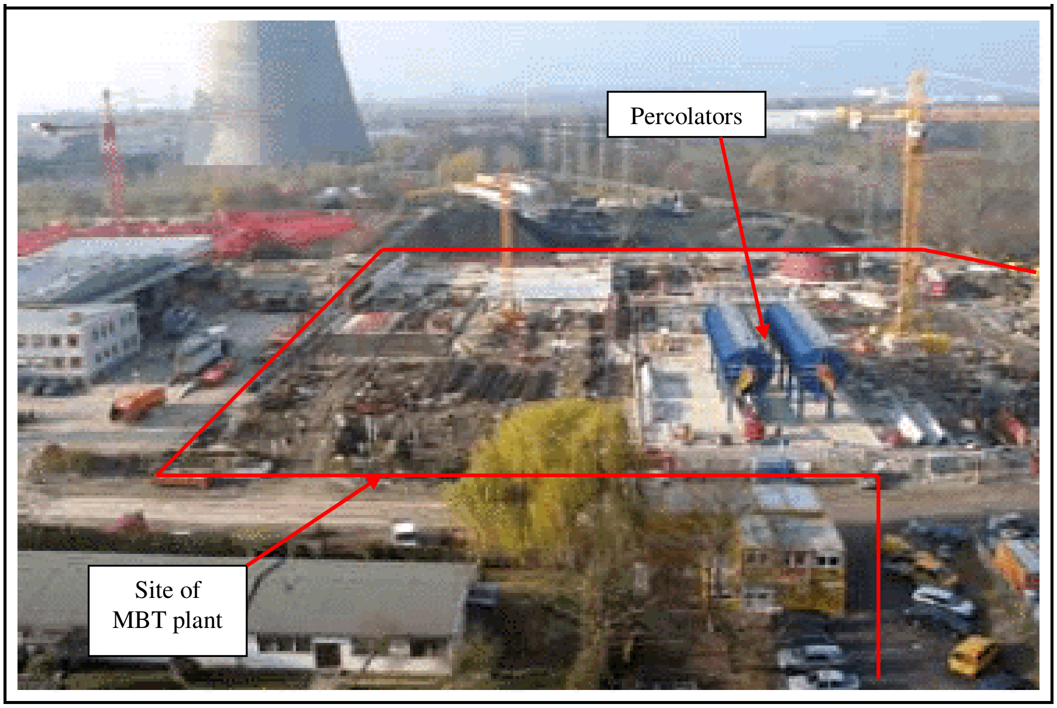

Figure 198 Aerial photograph of Heilbronn Site in construction phase (Environmental Expert website [b], accessed June 2006)

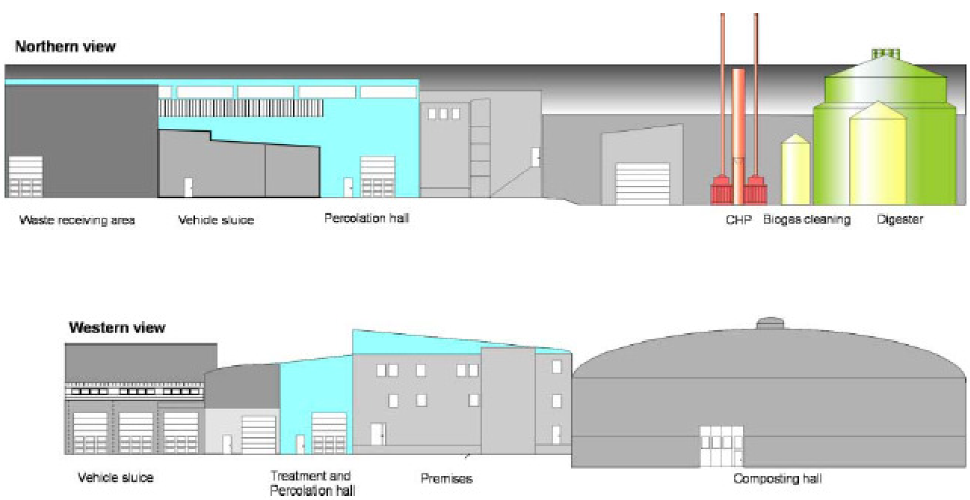

Figure 199 Planned layout at Heilbronn (ISKA Promotional Information)

Other than scale and layout, the Heilbronn system is technically identical to the Buchen system. See the Buchen case study (Section 5.2.1) for a technical process description and discussion. The process flow diagram is the same as the process at Buchen, and is shown in Figure 200.

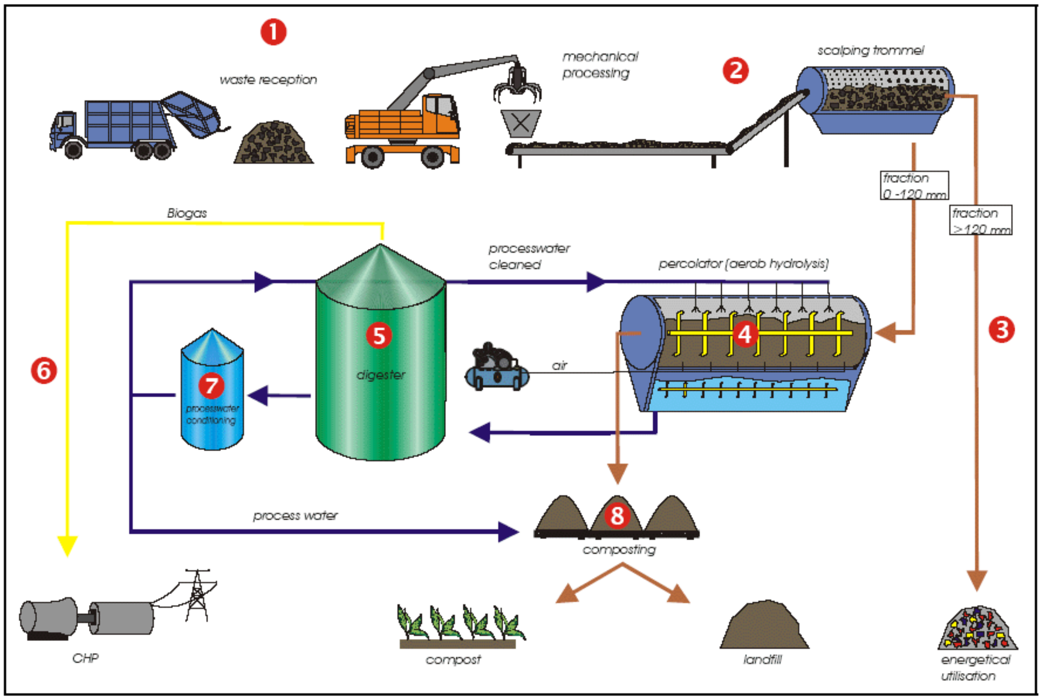

Figure 200 Process flow diagram of Heilbronn MBT Plant (Environmental Expert website [a], accessed February 2006)

Note
This diagram is slightly inaccurate, as all of the CLO goes to landfill.

PRE-TREATMENT

After the weighbridge, lorries reverse into one of the three bays (one open, two behind skips in Figure 201), and empty their loads into the covered wastes reception area. In the top left of Figure 201 is a rain water storage tank. Immediately to the right of the waste reception bays is the mechanical separation hall, while the taller building immediately to the right of this is the composting hall.

In the covered reception area, waste is picked by a crane (Figure 202) and put into a hopper falling into a slow speed shredder. From the slow speed shredder the waste is automatically moved by conveyor to the mechanical separation stages (Figure 203), which commence with the trommel sieves (Figure 204).

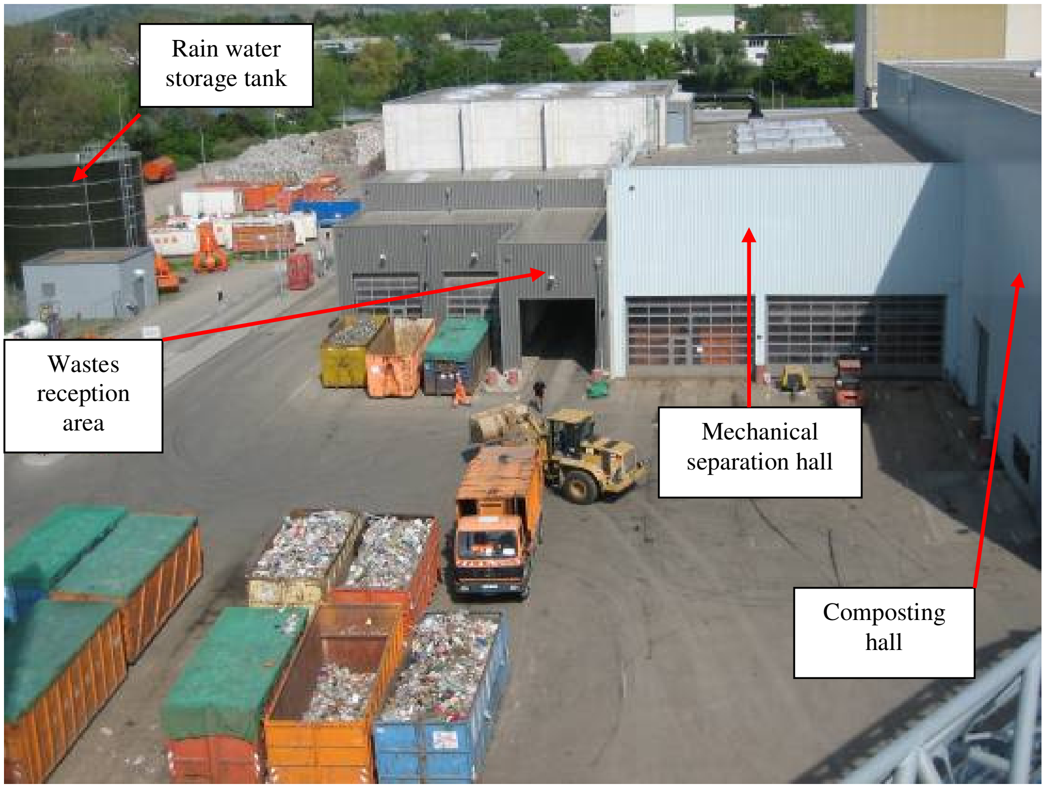

Figure 201 **Wastes reception area (outdoors) at Heilbronn**

Figure 202 **Wastes reception area (indoors) at Heilbronn**

Figure 203 Mechanical separation stages at Heilbronn

Figure 204 Inside trommel sieve at Heilbronn

As with the trommel screen at Buchen, oversize materials are sent via conveyor to be baled and transported to an incinerator. Undersize materials are passed via conveyor to the percolators, which are shown in Figure 205.

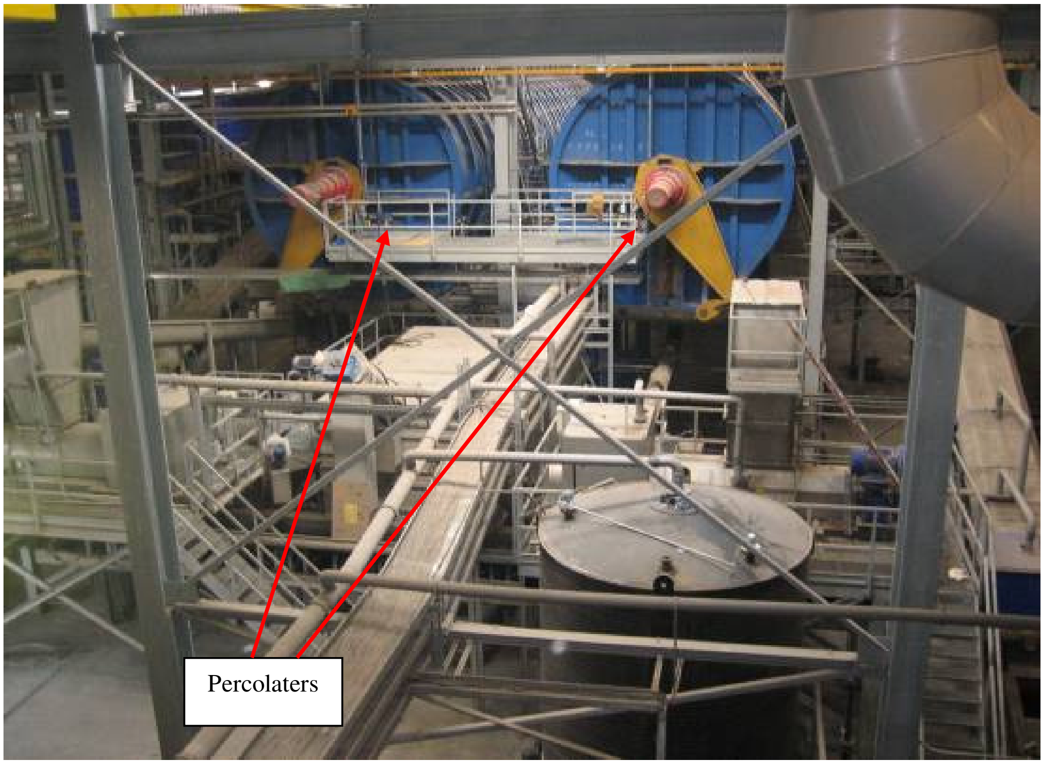

Figure 205 Percolators at Heilbronn

Material moves through the percolator by means of a rake in the base. A screw conveyor discharges the material and it is pressed. After percolation, the percolator liquor is de-gritted and de-watered the solid phase is sent to an in-vessel composting stage, and the liquid phase, containing 2% TS sent for anaerobic digestion.

ANAEROBIC DIGESTER

The anaerobic digester (Figure 206) is designed and operated in the same fashion as those at Buchen. As with the Buchen plant digestion is mesophilic (35 – 40^{o}C). Testing carried out before construction indicated that for this substrate in these hybrid filter reactors, mesophilic digestion was energetically favourable to thermophilic digestion, as any extra biogas production was not sufficient to provide the extra heat required. More details are available in the Buchen case study.

Figure 206 Anaerobic digester at Heilbronn

Note the 'double-hull' on the digester, which it was necessary to add as an extra safety measure before planning was approved. The double hull significantly increased the capital outlay.

POST AD TREATMENT AND DIGESTATE

After passing though the percolators, AD or IVC processes, the solid biostabilised output is loaded on to trucks (at the point shown in Figure 207) and transported to the landfill site, approximately 6 km away.

Figure 207 CLO/biostabilat loading bay at Heilbronn

BIOGAS UTILISATION AND ENERGY PRODUCTION

Approximately 4,000,000 m^3 of biogas is produced per year, which amounts to 50 m^3/tonne of residual waste entering the plant, or approximately 100 m^3 per tonne of organic waste entering the anaerobic digester (only percolator liquor is anaerobically digested). Roughly, the yield from a percolation system accounts for about 70 – 80% of methane produced using other methods with similar feedstocks (Vandevivere *et al.*, 2003). The Heilbronn site is a net user of energy. No energy balance for the system was given. The low level grey structure to the bottom right of the digester (Figure 206) is the CHP unit. The gas storage vessel, biogas de-sulphurisation unit and CHP stack chimney can also be seen to the right of the digester. The overhead piping coming from the CHP unit towards the left of the picture is the exhaust gases from the CHP unit to the regenerative thermal oxidation process. As at Buchen, the gas collection, upgrading, piping and use are all sub-contracted to the same company. In this case the sub-contactor is Pro2 AnlagenTechnik GmbH (Willich, Germany, www.pro-2.net).

EXHAUST GAS TREATMENT

Exhaust gases are treated by thermal oxidation. As at Buchen this represents a major cost and use of heat and electricity.

COSTS AND ECONOMICS

The capital cost of the whole MBT plant was approximately €27 million. The landfill site is owned by the region, and ISKA currently pay €53/tonne to dispose of their biostabilised output. Payback time was estimated at 15 years, at current prices, but increased gate fees would reduce this, and increased landfill charges would increase it. The cost of the project was increased slightly due to the limited space available, and severely due to the proximity of the site to a river. The site also suffers significantly (as compared to the Buchen site) in terms of extra costs due to its smaller throughput (€338/tonne compared to €278/tonne in terms of capital costs). Operating costs were estimated at €35 – 55/tonne (including finance), as at Buchen, approximately half was spent on exhaust air treatment (Kutterer, Personal Communication, 2006). Exhaust air treatment legislation in Germany is particularly stringent, and in the UK this would not represent such an expense. As mentioned in the Buchen case study, the incinerator is also owned by ISKA.

MASS BALANCE

The mass balance for the system is identical to that at Buchen, due to the processes treating the same wastes in the same area with the same process. The mass balance is shown in Figure 208.

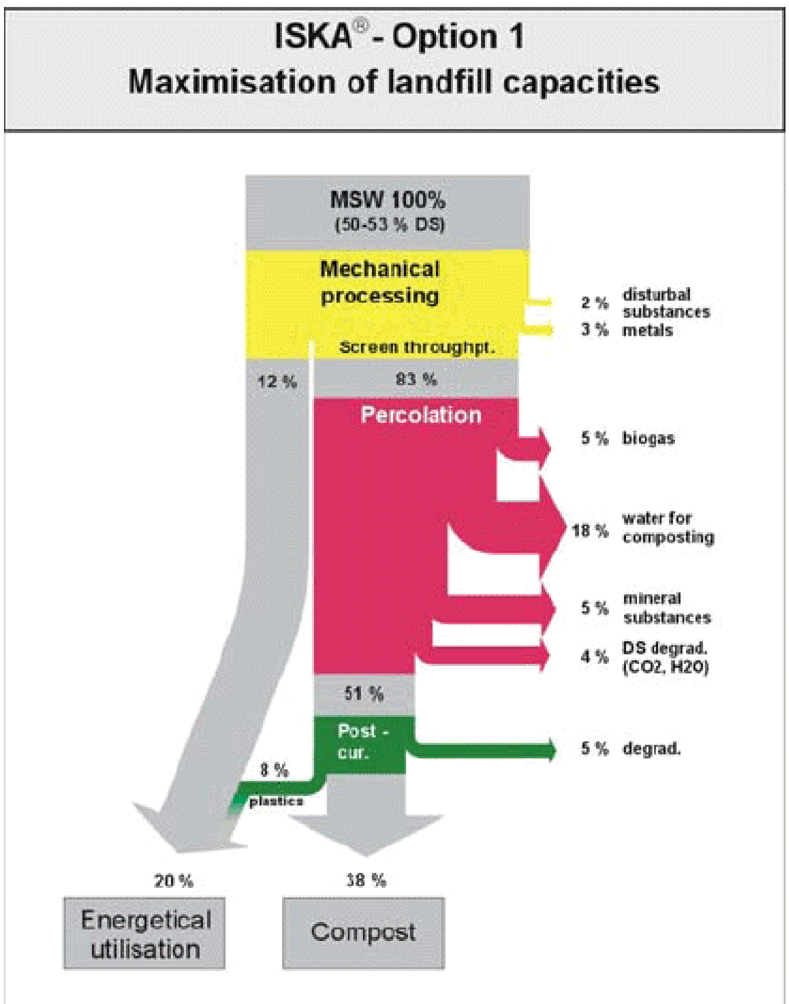

Figure 208 Mass balance of ISKA process (Environmental Expert website [b], accessed June 2006)

It can be seen that the process diverts 60% of the incoming residual waste from landfill under normal circumstances. In the mass balance above, the pink section labelled 'Percolation' incorporates both percolation and anaerobic digestion. It can be seen that 5%

of the incoming residual waste (by mass) is converted to biogas. The mass balance is further discussed in Section 6.2.1 and Appendix 2.

VISUAL AND LOCAL IMPACT

The plant was sited in an industrial area, beside heavy industry including a scrap-yard, and a power station. The highest point on the plant is the CHP chimney, but as can be seen in Figure 209 the whole plant was dwarfed by a nearby power station.

Figure 209 ISKA Plant at Heilbronn (power station in background)

As at Buchen, odour and dust/particulates inside the plant were noticeable, indicating that perhaps the odour extraction/fresh air re-circulation system was not ideal. It should be pointed out that dust/particulates should be expected given the nature of the plant and the waste it is processing. The odour inside the plant buildings was strong at Heilbronn, where due to the space limitations the composting hall is joined on to the mechanical separation stages. Aside from the high dust levels, housekeeping was very good, despite the site operating above capacity to catch up a backlog that had developed. Again, as with Buchen, there was no noticeable odour outside the buildings, indicating that the thermal oxidation exhaust gas treatment system was working well. The plant was not particularly noisy, and its industrial location meant that even if it were, noise would not have been a problem.

CHALLENGES, DISCUSSION AND CONCLUSIONS

From a wastes treatment and recovery perspective the ISKA system at the Heilbronn MBT plant ideally fits local requirements. In terms of cost/throughput, it would have been more economic at a larger scale (such as Buchen), but this was not necessary. In terms of throughput for the space available Heilbronn compares well with other MBT configurations, mainly because of the small area required for such a high throughput. This is possible mainly because percolation system reduces the residence time in both the AD and composting phases.

Energetically, the plant is not as favourable as some other configurations. For example not all of the organics are treated anaerobically, therefore potential biogas is lost, and secondly the percolation systems require hot water and aeration. It must be mentioned that although the percolation systems require energy input, they are heated by waste heat produced on-site, so the whole site is usually roughly energy neutral (excluding energy from incineration of extracted RDF). The thermal oxidation of exhaust gases is also energy intensive. With regards to water use and wastewater production, the system is well planned and engineered.

5.2.3 Heerenveen (SBI Friesland) MBT Plant

INTRODUCTION

The SBI Friesland (Scheidings en Bewerkings Installatie Friesland) site at Heerenveen is owned and operated by SBI Friesland, which is a publicly owned wastes treatment company owned by Afvalsturing Friesland. Afvalsturing Friesland is a part of OMRIN (www.omrin.nl), a regional wastes management company in the northern Netherlands. The anaerobic digesters were originally designed by Grontmij, and started up in 2002. These digesters have been extensively redesigned and improved by SBI Friesland. The SBI Friesland MBT plant receives around 230,000 tpa of residual municipal waste from 650,000 inhabitants from the 31 shareholding municipalities in the province of Friesland. The site also receives industrial and commercial wastes, which accounted for <5% of the total waste accepted in 2006 (Koopmans, Personal Communication, 2006).

Food and kitchen waste, paper, glass (all source separated in the home), hazardous wastes, electrical wastes and bulky wastes are all sent elsewhere. Kitchen and garden wastes are collected together, and are treated elsewhere in an in-vessel composting system. Table 52 shows the average content of the residual MSW received.

Table 52 Average content of residual MSW brought to SBI Friesland site

Type of 'Waste'	Percentage of Residual MSW (%)
Metals	2
High calorifics (paper and plastic)	16
Organic fraction	43
Refuse derived fuel	39

This waste stream is separated into the different fractions mechanically. The metals are recycled, the high calorifics and the remaining rest waste (after removal of heavy inerts such as stones and sand, which are landfilled on site) are sent for energy recovery from incineration. After mechanical separation and pre-treatment the organic fraction is anaerobically digested in a process described below.

PLANT DESCRIPTION

A simplified process flow diagram is shown in Figure 210.

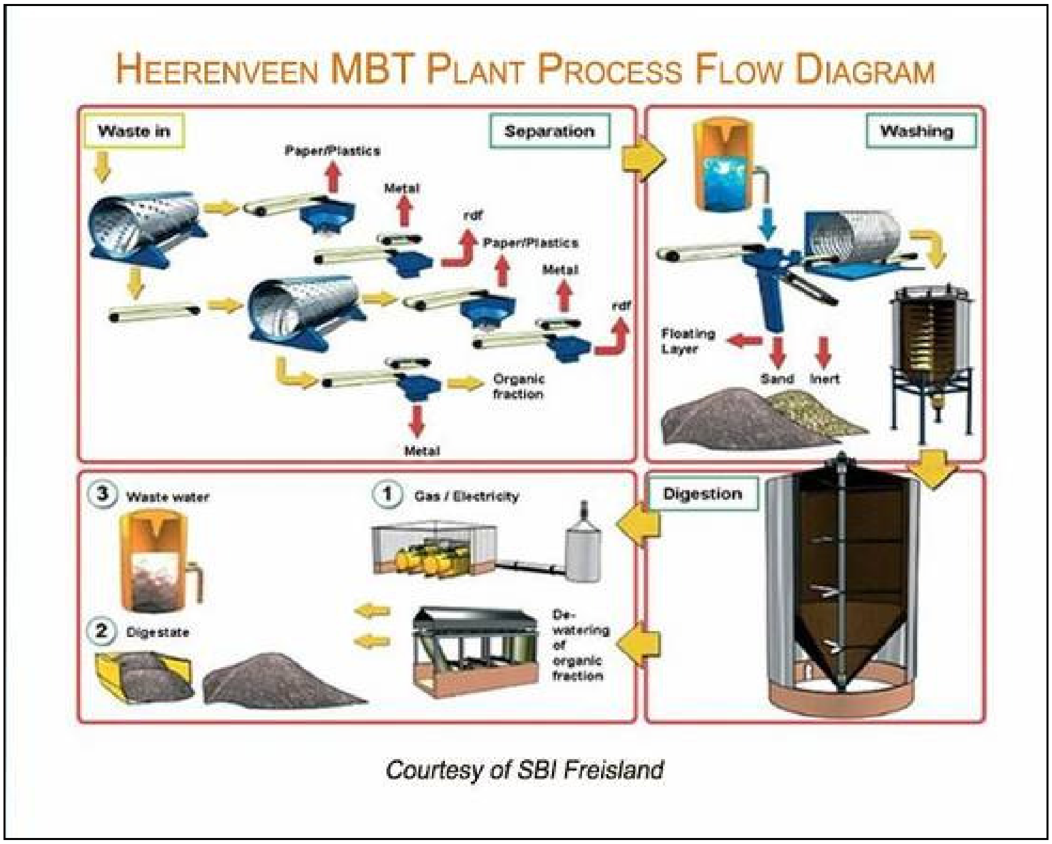

Figure 210 Process flow diagram (Omrin website, accessed November 2005, Courtesy of SBI Friesland)

<u>PRE-TREATMENT</u>

The mechanical separation stage of the process was not visited as part of this project. The following description of the mechanical separation stages relies heavily on information provided in the Juniper MBT Report (2005). The MSW is separated on size by two drum screens (hole sizes 200 mm and 55 mm) and mass (two windshifters). The air blower removes the light waste, *.e.g.* paper and plastics, which are baled and stored on site (Figure 211), until it is removed to be thermally recovered.

Figure 211 Baled paper and plastics awaiting collection

Materials smaller than 55 mm from the drum screen are sent to an inerts-separator, which separates the dense and less dense materials in an upflow stream of water. In this stage coarse inerts (e.g. stones and glass) are removed from the process (Figure 212).

In addition, light floating materials are removed by a rake and added to the RDF. Finer materials caught up in the water stream are sent to a washing drum screen, which separates sand and fine organics from the coarse organics. Coarse organics (4 – 55 mm) are shredded (to <12 mm in 3 dimensions), mixed with hot water until they reach a total solids concentration of 12 – 15% and a temperature of 55^oC and sent to the digester. The sand and fine organics are passed through a hydro-cyclone, which separates them. Sand removed from this process must be landfilled, as it is usually contaminated (uncooked rice being a major contaminant). Fine organics are sent to a sludge centrifuge, where water is removed, before going to the digestion plant. The liquid stream from the centrifuge is recycled for use in the drum sieve.

Because the residual waste stream is so contaminated, plenty of contaminants get through to the anaerobic digester despite the mechanical separation techniques described above. Contaminants include cork, wood, bone, glass, plastics, ceramics. Any reactor volume taken up by inerts (such as cork, wood, glass, plastics, ceramics) is ‘dead space’ that can not be taken up by bacteria or organic waste. The more inerts that enter the reactor, the less efficient the reactor will be. A bigger reactor volume, a higher retention time or a lower OLR will be needed to compensate for the ‘dead space’. The impact of all of these options on reactor economics will be negative.

Figure 212 Coarse inerts removed from organic waste stream

ANAEROBIC DIGESTION

The digester primarily treats the organic fraction of the municipal residual waste, which amounts to approximately 100,000 – 120,000 tpa. It also treats local organic industrial wastes, including wastes from locally based coffee and tobacco companies (around 10% of digester throughput). The plant also has the flexibility (mainly due to its large scale and throughput) to deal with other waste streams when necessity dictates. For example, despite not being regularly processed, the plant can deal with slaughterhouse waste when necessary. A wet, single stage thermophilic anaerobic system is used. Two of the digesters can be observed in Figure 213.

The building on the left in Figure 213 (behind the truck) is the mechanical separation building. An overhead conveyor can be observed going from this building to the building behind the digesters (see dotted red arrow). This overhead conveyor transports the organic fraction, and in the building behind the digesters, where sand (and other inerts) and floating layers are removed, and the remaining organic fraction is pre-treated to the right temperature and total solids content before entering the mixing tanks and the digesters. This building also contains the post-digestion de-watering stages. After mechanical separation and preparation, and prior to digestion, the waste stream is mixed in 3 x 200 m^3 mixing tanks. This is to stabilise the strength, temperature and content of the waste stream, to provide greater uniformity and 'dilute out' any irregularities before the waste is introduced to the reactors. There are three anaerobic reactors, each with a volume of 3000 m^3. Digesters are approximately 25 m tall and 15 m in diameter. Digesters are continuously fed and continuously purged at a rate of 200 m^3/day. The minimum retention time is 15 days. Mixing is provided by continuously stirring, by paddle stirrers on 4 levels. Feed is added to the reactors continuously, to the top of the reactor, at a rate of 200 m^3/day. Around

140 m^3/day (70%) of waste is removed from the top and 60 m^3/day (30%) from the bottom of the reactor. Waste is removed from both the top and the bottom of the digester to ensure that neither sediments nor floating material are allowed to accumulate. Total solids content in the digester is 12 – 15% (Smink, Personal Communication, 2006).

Figure 213 Anaerobic digesters at SBI Friesland

Anaerobic digestion is carried out in the thermophilic range, at 55°C. Thermophilic digestion was implemented in this case due to the faster reaction dynamics, and the subsequently shorter retention time required to digest the organic waste and produce the same amount of biogas. Heating is supplied by the addition of steam/excess heat to the waste entering the digesters. The steam is from the conversion of biogas to electricity. The digesters themselves are not heated, only insulated. Maximum particle size is 12 mm due to the shredding in the mechanical pre-treatment. Temperature, gas production and content are monitored on-line, and daily off-line samples are taken for pH, dry solids content (TS), organic content (VS). Chloride and nitrogen concentrations in the influent and effluent are also monitored daily, to ensure concentrations are kept at levels not toxic to the micro-organisms. An on-line measurement of dry solids (TS) was tried but found to be unreliable. pH is continuously monitored, but maintains itself (between 7.5 – 8.0) without additions. The reactor feeding rate is controlled based on biogas production, with the aim of maintaining output volume and quality as steady as possible (within a 1% fluctuation). Irregular feeding produces peaks and troughs in biogas production, which can lead to problems with biogas utilisation, as there is no gas storage facility at Heerenveen. Hydrogen sulphide concentrations in the reactor (and in the biogas) are kept lower than 250 ppm (usually around 180 ppm) by the addition of 'ferro-sludge', a by-product from a nearby drinking water purification plant. Ferro-sludge with an 8% dry content is added to the waste stream, prior to digestion, at a rate of 100 tonnes per week. SBI pay the sludge transportation costs.

POST AD TREATMENT AND DIGESTATE

After anaerobic digestion, the total solids content of the digestate is 8 – 12%. This is de-watered using belt-presses (Figure 214) and excess heat from the utilisation of the biogas. Water recovered from the de-watering process is recycled back to the drum sieve to be re-used in the mechanical pre-treatment. After de-watering the digestate has a total solids content of 38%.

Figure 214 Belt-presses for de-watering digestate

The final digestate does not meet Dutch standards, and therefore can not be considered as 'recycled', in terms of meeting the Dutch recycling targets. It would not meet UK standards either. Ironically, it would meet the less strict French standards, and it was implied that the compost would be welcome in France if the transport was paid for. If the Dutch legislation were to count compost used in France as recycled, then it would be a realistic economic option for SBI to pay to have compost transported to France for land application. Instead, there were 2 disposal routes for the digestate. The originally preferred option (which is no longer permitted due to a change in German Legislation) was to transport the digestate to a German energy from waste (EfW) installation, where it was used as a secondary fuel to supplement coal combustion for energy production. The calorific value of the digestate was quoted as 4 MJ/tonne. Presently, digestate is no longer transported to Germany, and is sent to an 'immobilisation plant' on site, where it is mixed with ash, sludges and water glass (sodium metasilicate) to produce a permanent landfill cover. In the UK digestate used as a permanent landfill cover counts towards recycling targets (providing the ABPR is met). It is estimated that this digestate costs in the region of €40/tonne to dispose of by the on-site immobilisation route, and that the cost of transporting the digestate to the site in Germany is approximately €20/tonne. Therefore, as long as the gate fee for receiving the waste/digestate at the German site remains less than €20/tonne, this is the most economic disposal option. Environmentally, it is generally preferable to recover energy from the waste where possible, although in this case the transport required will reduce the environmental gain.

BIOGAS UTILISATION AND ENERGY PRODUCTION

Around 55 m^3 of biogas is produced per tonne of residual waste entering the plant (Smink, Personal Communication, 2006). One tonne of OFMSW (<55 mm) entering the digesters produces 100 – 145 m^3 of biogas, with a fairly regular methane content of 62%. Annual biogas production from AD amounts to approximately 11,000,000 m^3. A 5.3 MW gas engine converts the biogas from AD (2/3) and landfill gas (1/3) to electricity and heat. There is no biogas storage facility at Heerenveen, so excess biogas must be flared. For this reason, and for general reactor stability, variations in feed content and strength are avoided where possible. The heat energy produced in the production of electricity is used to pre-heat the reactor influent and to keep the anaerobic digesters at around 55^{o}C. It is also used to heat all buildings on-site, and to dry/de-water the digestate. Overall, approximately 1/3 of the electricity produced from the anaerobic digestion of OFMSW is used on-site (this includes the whole waste treatment site, not only the MBT part), and 2/3 is exported to the Dutch national grid. It is estimated that enough electricity is exported to provide electricity for 14,000 households. As in the UK, it is necessary to sell all of the electricity produced, and buy back what you need. The RDF has a high calorific value and is incinerated for energy recovery. Energy can also be recovered from the bio-stabilised digestate, for which a calorific value of as 4 MJ/tonne was quoted.

WATER AND WASTEWATER TREATMENT

Approximately 12,000 m^3 of fresh water is used on-site per year. This corresponds to 0.04 m^3/tonne of residual waste processed. Process water is re-circulated as much as possible to minimise this usage. Approximately 1 m^3 (or 1 tonne) of wastewater is produced per tonne of organic waste treated by the anaerobic digester. Much of this wastewater is re-used in the wet pre-treatment stage, although it is necessary to continuously replace some wastewater with fresh water to avoid the build up of nitrates and chlorides which could affect digester performance. Some of this replaced wastewater is also re-used in other parts of the process. The total volume of wastewater produced was reported to be 28,575 m^3 per year (Juniper, 2005). This corresponds to 0.094 m^3/tonne of waste processed. There is a wastewater treatment plant on site, to which the anaerobic digestion wastewater is sent (along with wastewater from other parts of the process and landfill leachate). The effluent from this wastewater treatment site is sent to the sewerage system. The wastewater treatment system is shown in Figure 215.

Figure 215 Wastewater treatment plant at SBI Friesland

EXHAUST GAS TREATMENT

All waste gases are sent to a biofilter prior to being released to atmosphere, to reduce risk of bio-aerosol and dust emissions and minimize odour.

VISUAL AND LOCAL IMPACT

The Wastes Treatment Park is outside the city, in an industrial area. The tallest structures on-site are the digesters, at 25 m tall. As the plant is in an industrial area, visual impact is not an issue. The site is adjacent to the landfill site, and also has wastewater treatment plant and the biogas utilisation plant on-site, as well as RDF baling and storage facilities and office buildings. There was a distance of around 500 metres between the road and the plant, which was not used. SBI Friesland had plenty of available land and footprint minimisation was not a priority in the design of the plant. No specific data on the total land-take of the plant was available. No odours were apparent when on-site outside the buildings, although the wastes reception area and mechanical pre-treatment building were not included in the tour. As the plant has no composting site, odours were minimised significantly.

MASS BALANCE

The mass balance in terms of the percentages of outputs was shown in Juniper (2005), these percentage outputs have been shown in terms of the tonnes per annum of ‘output’ they represent and are shown in Table 53.

Table 53 SBI Friesland plant outputs

Products	Tonnes per annum	End Use
Biogas	18,000	Electricity and Heat production
Ferrous metals	4600	Recycled
Coarse inerts	13,000	May be recycled, but may be landfilled
Fine inerts (sand)	14,000	May be recycled, but may be landfilled
RDF	89,000	Sent for incineration as secondary fuel
Rake fraction	9000	Sent for incineration as secondary fuel
Paper and light plastics	39,000	Used as a co-fuel in cement kilns and CHP plants
Digestate	45,000	Sent for landfill after 'immobilisation', to be used as landfill permanent cover
Wastewater	15,000	Treated and discharged

(Koopmans, Personal Communication, 2006)

The wastewater percentage was quoted as 14%, but 9% extra water was added in. Therefore to balance the outputs at 100% it was necessary to subtract the extra water input from the wastewater. The mass balance is discussed in Section 6.2.1 and Appendix 2.

COSTS AND ECONOMICS

The total capital cost for the MBT plant was estimated to be in the region of €38 million (£25 million) as of 2002 (Smink, Personal Communication, 2006). The plant was built at the site of the existing landfill, and infrastructural facilities such as road links, offices, biogas utilisation facilities, grid connection and the wastewater treatment plant already existed. Despite the offices, biogas utilisation facilities and wastewater treatment facilities needing upgrading, a considerable cost saving (on the capital cost) could have been achieved.

The operating cost of the plant were not made available. The gate fee depends more on the costs/incomes from the remaining products (*e.g.* recyclables, digestate) than on the operational costs (Smink, Personal Communication, 2006).

The high calorific waste is suited to energy recovery from incineration, and as such is more valuable (or costs less to the company) to send for incineration than the rest waste fraction (which SBI must pay for, per tonne, to be accepted at the incinerator). Therefore SBI are constantly striving to try and increase the amount of high calorific wastes that can be recovered from the 'rest waste' fraction.

It costs in the region of €115/tonne to transport and incinerate the rest waste, and around €95/tonne to anaerobically digest the organic fraction. Therefore at present the anaerobic digestion of the organic fraction (40% of 300,000 tpa = 120,000 tpa), which would otherwise need to be incinerated, saves the company around €2,400,000 per year (120,000 tpa x €20/tonne). It is assumed that the renewable energy incomes from AD and incineration are included in these figures.

CHALLENGES AND CHANGES MADE

Since originally starting up the anaerobic operation in 2002, SBI Friesland have experienced major operational problems, and made significant modifications and improvements to their process.

- A major problem experienced was a floating layer of waste (corks, wood, polystyrene, plastics *etc*). In the original design, this floating layer was periodically swept from the reactor liquid, onto a 'beach' and into an exit pipe (200 mm diameter) towards the top of the reactor. It was found that this pipe blocked every 2 weeks. When this happened, with no exit for the floating impurities, and with more contaminants continuously introduced with the inflow, the floating layer got bigger and bigger until it occupied more than 1/3 of the reactor volume. Also, this floating layer of debris dried out, due to the biogas passing through it, and became 'so thick that you could walk on it' (Smink, Personal Communication, 2006). As no solution was available on the market, SBI solved the problems themselves. The roof was taken off the reactor (which was very expensive) and a flanged roof added for quick removal and easier access in case of further problems. The 200 mm pipe was replace with a 400 mm pipe, and a valve installed near its entrance. When a blockage occurred, this valve would be closed, and the liquid level raised towards the top of the reactor. When the valve was released, any blockage was 'flushed out' by the pressure of the liquid escaping.

- In the original design the reactor was purged (digestate/waste removed) only at the bottom of the reactor. After these changes, the digesters were purged at the top (70%) and bottom (30%) so as floating non-digestible layer could be removed as well as dense impurities/sludge layer at the bottom of the reactor. Many other processes that can not remove dense impurities (such as sand) from the bottom of the digester have experienced problems with sedimentation.

- Another problem was that the main pre-treatment technique was a drum sieve, with waste <55 mm (in 2 dimensions) passed through to the reactor. This created problems with waste such as strips of plastic, the insides of cassettes, sticks and bones from food waste. These wastes would all help 'bind' the floating layer together, increasing its solidity. Strips of plastic, string, the insides of cassettes or anything less than 55 mm in two dimensions but not three could become fouled in the reactors moving mixing paddles, and wind around them. This reduced the efficiency of the mixing, as well as increasing the 'dead space' in the reactor.

- A shredder was added after the drum sieves, and waste entering the reactor is now <12 mm in 3 dimensions. This had a positive effect on the floating layer removal problem, as although the impurities/layer is still there, it is in smaller pieces and therefore less likely to cause a blockage. Many shredders were tried, and many found to be insufficient for the job, but eventually a suitable shredder was found. This shredder is in continuous operation but is currently physically located out of the process line. This is the case with much of the Heerenveen site, with temporary conveyor belts carrying waste streams to the location of the next sorting equipment. They have found the technical solutions for their problems, but still need to physically put the solutions back 'in line'.

- There were major problems with the wet pre-treatment system in the original design, the design of which was adapted from water treatment technology and not previously tested on OFMSW. These problems further added to the problems in the reactor, as more floating waste was getting through. The original design included technologies to separate waste by straining, sinking, flotation and filtering, all connected in series. Therefore any problem with one section overflowed to the next, and ended up in the reactor. The pre-treatment system was redesigned to include a centrifuge, and a series of loops introduced so that the system was no longer in series.

The pre-treatment system and digesters have been in continuous operation since May 2004, with 0% downtime (Smink, Personal Communication, 2006), and SBI are confident that their solutions have eradicated all problems they had previously encountered. After a period of almost 2 years the new modified process can be considered successful and proven.

DISCUSSION AND CONCLUSIONS

Despite kitchen waste being separately collected and treated, it is possible that the residual waste stream contains meat products and therefore (in the UK) ABPR criteria would need to be met if the product was to be used as a landfill cover in the UK. Also, the Heerenveen plant is equipped to deal with slaughterhouse waste, which it must be prepared to accept as and when necessity dictates, although slaughterhouse waste is not regularly processed. The thermophilic nature of the digestion means that raising the digestion temperature from 55^oC to 57^oC would ensure compliance. (provided it could be guaranteed that the waste stays in the digester for a minimum of five hours). If the digestate was all sent for incineration (as is a proportion of the digestate here) then it would not be necessary to meet the UK ABPR.

The wet digestion system means that the process uses a lot of fresh water, approximately 12,000 m^3/a, or 0.04 m^3/tonne of residual waste processed) and therefore produces a lot of wastewater. Large volumes of wastewater are recycled, minimising freshwater use, and the rest is treated in an existing wastewater treatment system.

As the mass balance shows, a total of 73 - 89% of the residual waste is diverted from landfill. This depends on the volume of digestate that is accepted for thermal energy recovery. If daily landfill cover were to count as a beneficial use, then only 11% of the incoming waste would be landfilled (coarse and fine inerts). In addition, the biogas produced covers all on-site electricity and heat requirements (for the whole wastes treatment park (not just the MBT plant) and annually exports enough electricity to power 14,000 Dutch homes. Thermal energy is also recovered from the RDF, and energy (4 MJ/tonne) can also be recovered from the digestate (provided a user can be found).

By May 2004, all the problems were technically solved, and the anaerobic digestion process (including pre-treatment stages) has enjoyed continuous, trouble-free operation since then (almost 2 years). SBI Friesland are confident they have dealt with their issues and solved their problems.

5.2.4 Mons (ITRADEC) MBT Plant

INTRODUCTION

The ITRADEC MBT Plant (Mons, Belgium) accepts approximately 80,000 tpa of residual municipal wastes. The plant is owned and operated by ITRADEC (Intercommunale de Traitement de Dechets). ITRADEC is the regional municipally owned waste handling company (more information is available on www.itradec.be). The MBT Plant accepts 80,000 tpa of residual waste from a population of approximately 463,000 in 23 municipalities in the Mons-Borinage and Centre regions in Belgium. This is the equivalent of 172 kg per person per year. The Belgian experience has shown that the introduction of source separation leads to a significant decrease in the average amount of residual waste produced per person. Belgium introduced source separation approximately ten years ago, and in the first years that source separation was introduced the average mass of residual waste collected per person was 350 kg/a. Recyclates are separately collected and sent elsewhere for processing or recovery. Kitchen waste is not collected separately, and is included in the residual waste stream. Garden wastes are either home composted or must be taken to centralised collection points, from where they are composted. For garden waste disposal and treatment the residents must pay a fee. The MBT system was chosen in 1995, and the decision to choose a Valorga-based system was made based on the experience and reputation of Valorga, and the cost. Construction of the plant commenced in 1997, and the plant started accepting waste in the year 2000. The planning and the management of the building of the new site was carried out by ITRADEC, with the individual areas of expertise sub-contracted to companies with specific areas of expertise. Since construction, ITRADEC have run the plant. The anaerobic digester was planned, constructed and started-up by Valorga. An aerial photograph of the ITRADEC (Mons) MBT plant is shown in Figure 216. A process flow diagram is shown in Figure 217. The total area of the site is 170,000 m^2, of which only 70,000 m^2 is used by the plant.

Figure 216 ITRADEC Plant (Mons) aerial photograph

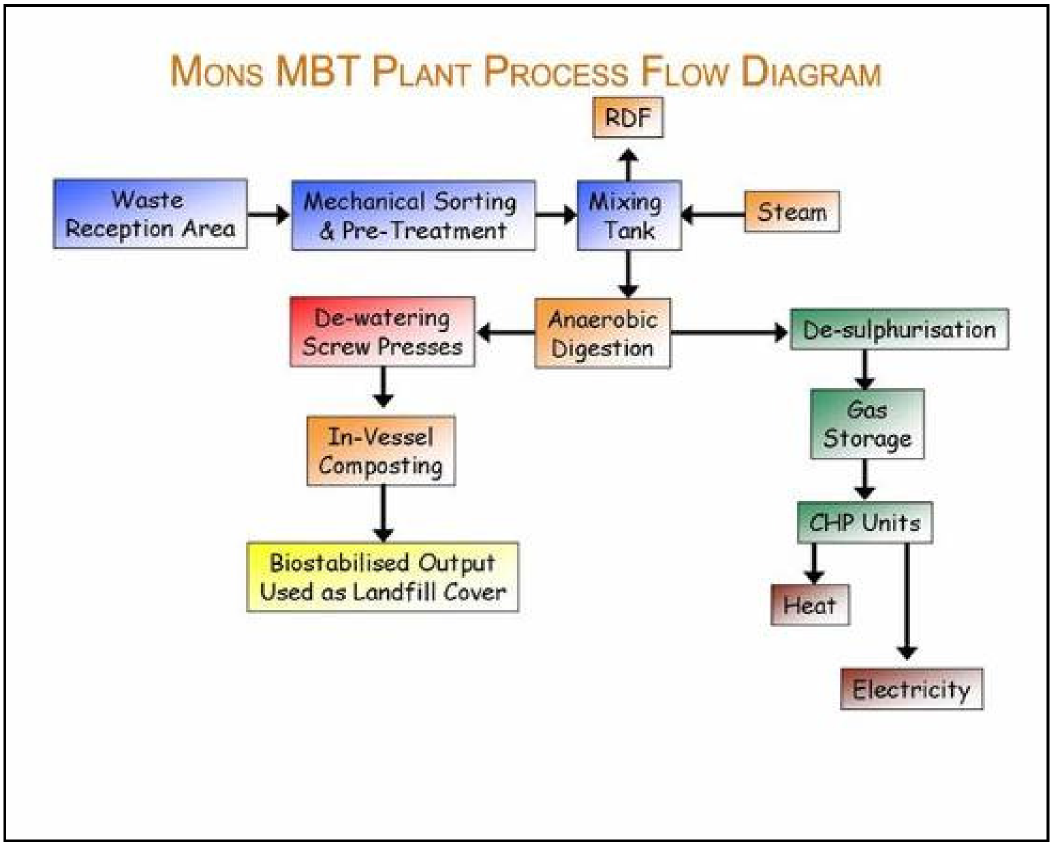

Figure 217 ITRADEC MBT plant process flow diagram

ITRADEC has 50 employees in total, of which 35 work on the plant. The plant operates five days a week (Monday to Friday), from 06:00 to 21:00. The plant employees work in two shifts. No waste is accepted over weekends, and the digester is not fed over the weekend. On Saturday mornings digestate is removed from the digester.

PLANT DESCRIPTION

PRE-TREATMENT

After being weighed on the weighbridge, the waste is emptied from the collection vehicles into a wastes reception pit, from where a manually operated crane loads waste into one of three identical process lines.

The three process lines are identical, and a process line will be described below. The first step in the process line is a trommel sieve (Figure 219), with a hole size of 60 mm. Oversize particles go via conveyor (Figure 220) to a shredder. Undersize materials from the first trommel sieve are not shredded, so as not to release the heavy metal contaminants from *e.g.* batteries, and to minimise the size of the shredder needed), and pass through a ferro-separator before being passed to the second trommel sieve. From the shredder, the oversized material is returned to the second, smaller trommel sieve (Figure 219), which has a hole size of 30 mm.

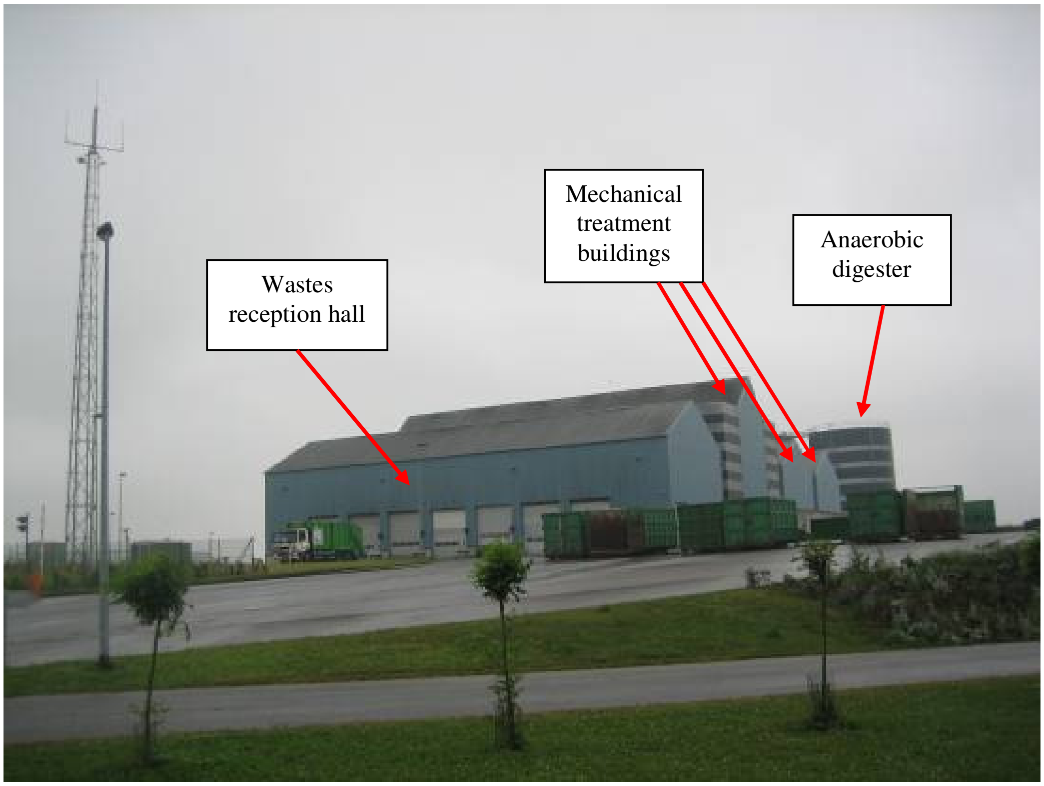

Figure 218 Waste reception hall

Figure 219 Trommel sieves

In Figure 219 the first trommel sieve can be observed on the left, with the second (smaller) trommel sieve on the right.

Figure 220 Waste stream from first trommel sieve to shredder

Figure 221 Inside trommel sieves

Waste that passes through the second trommel sieve (<30 mm) is passed to a mixing unit where it is mixed with re-circulated digestate, process water and steam to the right temperature (42°C) and total solids content (35% TS). The oversize material is used as RDF, and is sent to a skip to await removal (Figure 222).

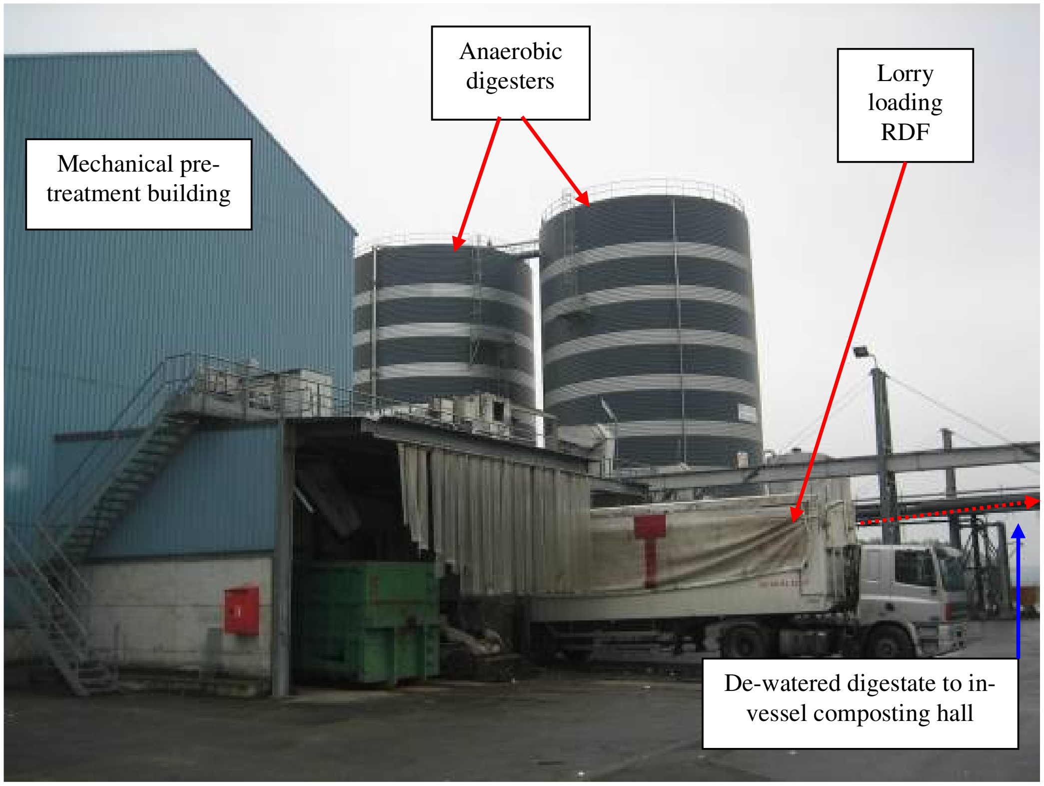

Figure 222 RDF loading bay, with digesters in background

Figure 222 shows a truck loading up with RDF after the mechanical separation (mechanical separation building is the blue building on the left). The anaerobic digesters can be seen in the background, as can the overhead conveyor belt transporting de-watered digestate (dotted red line) to the composting hall. Prior to digestion the OFMSW waste stream has a content of 50% TS. The waste stream is mixed with re-circulated digestate and process water to seed the waste with the anaerobic bacteria, and to reduce the total solids content to 35%. Because of the trommel sieves and the shredder, the maximum particle size entering the digester is 30 mm.

<u>ANAEROBIC DIGESTION</u>

The capacity of the AD plant (within the MBT system) is 60,000 tpa. Currently only one of the two 3800 m^3 reactors is required to treat the incoming OFMSW. The plant hopes to win contracts for organic industrial or commercial wastes in the near future, to maximise the income potential of this spare capacity. The two identical anaerobic digesters were provided by Valorga and are shown in Figure 222 and Figure 223.

Figure 223 Anaerobic digesters

Each digester operates according to the patented Valorga system, which is described fully in the Valorga website (www.valorgainternational.fr). A diagram of the reactor interior is also shown on the Valorga website. Digestion is dry, with a total solids content of 35% in the reactor and an average retention time of 30 days. The minimum retention time can be guaranteed at 14 days due to the internal design of the reactor. Heating is provided by mixing the incoming waste with digestate, with re-circulated process water and with steam to a temperature of 42^{o}C. This temperature prior to entering the digester is enough to ensure a (supposedly) homegenous temperature of 40^{o}C. In cold weather conditions, it is sometimes necessary to use more steam. Mixing in the reactor is provided by sparging with pressurised biogas. Biogas is pressurised to 5 bar in a pressurisation unit beside each digester (Figure 224) and injected into the bottom of the reactor to mix the process. Different sections of the digester are mixed in turn to provide the optimum mixing efficiency at the minimum cost.

Off-line samples are taken daily at various points in the plant for TS and VS analysis. In the digester(s), gas production and content are measured on-line, as are temperature and liquid levels. Off-line samples are taken daily to monitor pH, VFA content and bicarbonate alkalinity (BA). There is a lab on-site where these samples are analysed. The digester operates steadily in a pH range of 7.8 – 8.0. No chemical additions are required to maintain this. VFA content is usually in the region of 3 – 10 g/l, depending on the time the sample was taken in relation to the time of feeding. If the pH is abnormally low, or the VFAs abnormally high, feeding is stopped until the process regulates itself. This daily off-line monitoring (rather than weekly as at many other sites) could partly explain why the gas production is high. The digester is not fed over the weekend, and on Saturday mornings digestate is removed from the digester, and moved to the composting hall. Sedimentation of sand or other small inerts is not a problem in the digester (Urbain, Personal Communication, 2006), due to the high TS percentage at which the process operates (34% TS). Sand is removed after digestion in a centrifuge. Anaerobic operation has been continuous since the plant started-up in 2000, and it can be said that the system is reliable.

Figure 224 Biogas pressurisation unit

<u>POST AD COMPOSTING</u>

After AD, a small proportion of the digestate is re-circulated to mix with the waste stream prior to digestion. The remainder of the digestate is de-watered in two screw-presses (Figure 225). A flocculant is added to aid de-watering. A portion of the liquid fraction is re-circulated to dilute the incoming waste to 35% TS, and the rest is sent to a wastewater treatment plant (off-site) to be treated.

The de-watered digestate, now 50 - 60% TS is transported by an overhead conveyor belt (see dotted red line in Figure 222 and Figure 223) to the composting hall. The composting hall consists of a covered windrow system, with 4 windrow lines (Figure 226).

Entering the composting hall the de-watered digestate is mixed with 10% fresh garden waste. The addition of this 10% garden waste boosts the volatile organic content of the waste, so that an immediate temperature rise can be observed, rather than the more gradual rise with the digestate alone. Without the addition of this fresh garden waste it was found that not enough organic material remained in the digestate to provide a fast and effective composting process. The addition of this extra organic matter means that the composting process works faster, and treatment time can be reduced by a couple of days.

Figure 225 Screw press

Figure 226 Composting hall

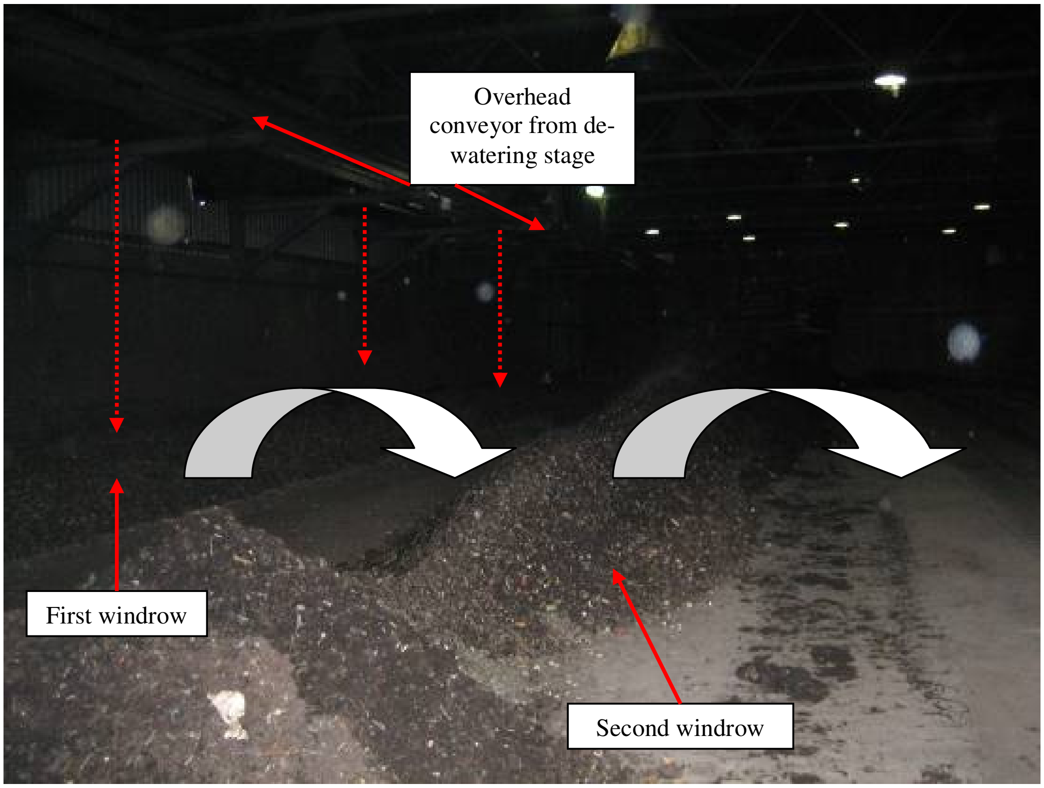

Figure 227 Windrows in composting Hall

Each windrow line is aerated automatically from below. The conveyor belt automatically lays the first windrow (as indicated by the dotted red arrows), and thereafter the compost is moved by a human-operated windrow turner from the first row to the second, to the third (as indicated by the white arrows), and then to the fourth. After the fourth windrow, the compost is loaded onto another conveyor leading to a trommel sieve, to remove plastics and reduce the particle size before the CLO is stored in the compost storage hall (Figure 228). The small plastic particles removed by this trommel sieve can be added to the RDF stream to be sent to the cement kiln, or landfilled.

From the storage hall the CLO is picked up and transported to the landfill site. The compost is left on each windrow for 3 – 4 days, and the turning (from one row to the next) provides the extra aeration required for full biostabilisation.

Figure 228 Compost storage hall

WATER USE AND WASTEWATER TREATMENT

The anaerobic digestion system and composting systems together use approximately 5500 m^3 of fresh water per year to treat the 18,000 tpa of organic waste arriving from the mechanical separation stages of the plant. This corresponds to 0.31 m^3/tonne of OFMSW processed. This water usage is primarily for steam and for daily washing of the plant. As mentioned above, a small proportion of the wastewater is re-circulated to dilute the waste stream to the right total solids content prior to digestion. The whole plant produces 9000 m^3 of wastewater per year, which is treated elsewhere. This corresponds to 0.11 m^3/tonne of residual waste processed. Wastewater is aerobically treated off-site, for which ITRADEC pay €20/m^3 (plus €5/m^3 for transport. The introduction of an on-site wastewater treatment plant could improve plant economics.

FINAL SOLID PRODUCTS

The ITRADEC process produces around 20,000 tpa of CLO. Due to the MSW based nature of this CLO it does not meet any quality standards and can not be used on agricultural land. A picture of this CLO is shown in Figure 229. As can be seen, the CLO contains many small pieces of plastic and other contaminants.

Figure 229 Compost like output

As this CLO is not a quality product, it is still considered a waste. It is currently used as daily landfill cover. As the CLO is used as a landfill cover (rather than actually being landfilled) ITRADEC do not have to pay landfill charges and landfill tax to dispose of the CLO in this way. After this use has been exhausted (at the end of the landfill's lifespan) it is anticipated that this CLO can be used in the reclamation of industrial or contaminated land. This CLO use as a daily landfill cover would not count as a beneficial use in the UK (and therefore would not count towards recycling targets). As mentioned, ITRADEC do not pay for this material to be landfilled, but pay for the transport of the material to the landfill site (over 60km away). Inerts such as stones and sand are landfilled, as is the RDF that is not utilised by the cement kilns. The process also produces around 40,000 tpa of RDF. There is a lack of incineration capacity in Belgium and the portion of this RDF that cannot be utilised thermally (by a nearby cement kiln) must be landfilled. Whether it is combusted or landfilled, ITRADEC pays for each tonne of RDF leaving the site. The incineration of the RDF (by the cement industry) is the most preferable option economically and environmentally (in terms of fossil fuel avoidance), and ITRADEC would like to dispose of all their RDF in this way, if the capacity were available. Until another RDF user can be found (which is a priority), ITRADEC are forced to landfill the proportion of the combustible fraction that can not be thermally utilised.

BIOGAS UTILISATION

A proportion of the biogas is used for internally mixing the digester contents. The remaining gas passes through a buffer storage tank (Figure 230) before being de-sulphurised (Figure 231) and used in four gas engines, each with a capacity of 500 kWh. At times of lower gas production, fewer gas engines are used. Before the de-sulphurisation stage was introduced, the hydrogen sulphide in the biogas corroded the gas engines within two years.

If the digesters were at full capacity it is estimated that 7,000,000 m^3 of biogas/year would be produced, with an energy equivalent of 3,500,000 litres of fuel (ITRADEC Promotional Information), or 7700 MWh of electricity (Urbain, Personal Communication, 2006). This is equivalent to a biogas production of 117 m^3/tonne of incoming organic waste (or 87.5 m^3/tonne of incoming residual waste). The anaerobic reactors are running well below capacity. And the actual biogas production has been an average of 80,000 m^3/week (or 4,160,000 m^3/a). Biogas production was quoted as being on average 148 m^3/tonne of OFMSW entering the reactor. A biogas production of 4,160,000 m^3/year at a capacity of 80,000 tpa would give a biogas production of 52 m^3/tonne of residual waste being processed in the plant. Assuming that 80,000 tpa of residual waste is entering the plant, and 30% of this is organic, then a total gas production of approximately 3,522,000 m^3/a could be expected. The average methane content is 56%, although this changes depending on the stage of the feeding process. In 2005, 4500 MWh of electricity was produced. On average, the plant is a net energy producer, but in effect, due to the feeding regime (the digester is fed through the day, therefore most of the gas production is towards the end of the day and at night) and working hours (the plant, with all of the energy intensive mechanical separation processes only operates through the day) the plant exports most of its electricity during the night, and must buy back a portion during the day. Significant amounts of heat are produced as a by-product of electricity generation. The heat produced covers all on-site requirements, after which a considerable excess remains. A biogas yield of 148 m^3/tonne is high for OFMSW. This high yield is thought to be for three main reasons:

1). The residual waste contains all kitchen waste, but no garden waste. Kitchen waste has the higher energy potential of the two waste streams.
2). Because the digesters were built over-sized, and are operating nowhere near capacity, the retention time in the digesters can be kept very high. It is currently around 30 days. By keeping the highest possible retention time, the maximum possible biogas production can be achieved.
3). As off-line samples are taken and analysed daily (rather than weekly as at some other plants), the data trends can be observed and controlling steps taken (if necessary) daily. This closer monitoring and control could optimise digester performance.

Figure 230 Biogas buffer/storage tank

Figure 231 Gas de-sulpurisation units

ENERGY PRODUCTION

The biogas produced has an electrical energy equivalent to 275 kWh electricity/tonne of waste. The electrical conversion efficiency is approximately 32%. Total electricity potential is 7700 MWh electricity. Actual electricity production is 4500 MWh/electricity. Energy recovery from the incineration of RDF represents further energy recovery but is not further considered in this work.

Although the site exports in the region of 4500 MWh/a of electricity, it buys back a similar amount for on-site use. In terms of the specific electricity excess, no figures were given, but the plant usually produces slightly more electricity than it uses (Urbain, Personal Communication, 2006). Other MBT plants produce significantly more electricity than they use, and although no figure was given for the Mons plant, the electricity excess seems low when compared with that of other similar plants. Possible reasons for this include the possibility that the incoming waste contains less organic material than other plants, or that more organic material is lost in the pre-treatment stages, or that the mechanical separation stages are more energy intensive. There is also a significant amount of heat energy that is not used on site that could be exported if the site were to have any neighbouring industries that could use it.

EXHAUST GAS TREATMENT

Odour was suppressed at points throughout the plant (including the wastes reception pit) by the periodic spraying of an 'odour control aromatic oil'. Odour was initially a problem, especially in the summer. The plant operators have learnt from their early experiences and nowadays odour is greatly reduced by the addition of the aromatic oils, and by ensuring that the wastes reception pit is completely emptied and cleaned weekly. Exhaust gases are treated in a biofilter unit. No more details of this unit were available.

RESIDUAL WASTE COMPOSITON

The residual waste that arrives on-site is separated into 4 main fractions:

- Organic 30%
- Ferrous metal 2 – 3%
- Mineral Fraction 15%
- Combustibles 50%

The organic fraction, as described above is digested anaerobically and composted for use as a landfill cover. The ferrous metal content is sold to ferrous metal recycling company, the mineral fraction is landfilled and the combustible fraction (which contains paper, plastics and textiles) is accepted by a cement kiln or landfilled. The mass balance is further discussed in Appendix 2.

VISUAL AND LOCAL IMPACT

The plant was built around 7 km outside the town, beside a major motorway. There are many rural residences nearby, with the closest at a distance of 500 m. The proximity of these residences exacerbates the importance of odour minimisation. Initially, the neighbouring residents complained regularly about the smell. With experience, ITRADEC have been able to minimise this odour escape, and there have been no more complaints. However, some odour was detectable on the plant (outside the buildings), even with the strong winds. Odours were detected outside the wastes reception area, outside the anaerobic digesters and outside the covered composting hall. The doors of the composting hall (usually the worst and strongest smelling part of any plant) were left wide open which would not help the odour emissions, although a digger was turning the windrows. A composting system that was more ‘in-vessel’ (therefore contained) rather than ‘covered windrow’ would minimise odours from the composting process, but would also increase the capital costs of the project. As for the visual impact, the area was flat, and the digesters 27 metres tall, so the plant was visible from a long distance.

COSTS AND ECONOMICS

The total capital cost of the anaerobic digesters (for a capacity of 60,000 tpa) and the post-AD composting system was €16 million. The mechanical sorting plant cost approximately €20 million. The total cost of the plant was €36 million (in 1998). The plant was 82% funded by central government. The central government also funds incineration projects at 85%. The ITRADEC MBT process is cheaper than incineration, but more expensive than landfill (Urbain, Personal Communication, 2006). Operating cost per tonne of incoming waste is €100. As the site is 100% publicly owned, the exact costs are passed on to the public, and the site gets a gate fee of €100/tonne from the municipalities. Wastewater treatment costs €25/m^3 and 30% of the operating costs of the plant concern valorisation, *i.e.* sending the RDF to the cement kiln. It costs ITRADEC €70/tonne (including all taxes, but not including transport) to landfill waste. Therefore the plant is more expensive than landfilling by €30/tonne at present. Government plans to increase the landfill tax over the coming years to around €100/tonne or above, will close this gap. Also, the European Landfill Directive demands that no biodegradable waste should be landfilled. Each megawatt-hour of green electricity produced earns 1 green certificate, which can be traded for €90/certificate (June 2006). When this certificate is taken into account, the plant can produce electricity at the same price as the large scale electricity producers. As the plant is 100% publicly owned, the company is assured that it receive municipal residual waste. Therefore waste contract uncertainty was not a barrier to the realisation of the plant. It was pointed out that the Valorga plant in Amiens (France) has been successfully privately operated for 16 years, so the process is viable from a commercial point of view as well as from a municipality-run point of view.

CHALLENGES

The major problem at the moment is trying to find an industry to accept the RDF as a fuel. If a taker for the remainder of the RDF (that is not taken by the cement kiln) could be found, landfill diversion would be maximised and plant economics greatly improved. It was reported that the Valorga plant had given the operators ‘no problems’ (Urbain, Personal Communication, 2006).

DISCUSSION AND CONCLUSIONS

The total throughput time of the plant is around 60 days. The time in the mechanical sorting is less than 1 day, time in the digesters is on average 30 days. Post AD composting takes between two and four weeks. This represents a slow throughput of wastes compared with other processes (see Section 6.2.8). Nevertheless, the ITRADEC plant treats 80,000 tpa of residual waste on a relatively small site (170,000 m^2, of which only 70,000 m^2 is used).

As ITRADEC is municipally owned, wastes contracts are not an issue. Given this scenario, decisions to make large investments in plants that will benefit the whole community environmentally and financially can be made more easily and with greater confidence. If the company owning or running the plant was privately owned, the potential danger of losing wastes contracts would be a very important parameter, and could potentially limit investment and development.

The housekeeping and odour control at the plant were somewhat less well organised than observed at other similar plants. The percentage of the residual waste stream that is landfilled is approximately 27% (including the CLO used as daily landfill cover, but excluding RDF which is not incinerated but could be if incinerator capacity was available). Only inert material is landfilled. It must be remembered that the residual waste stream consists of only those sections of the waste stream that are not recycled, re-used or disposed of as hazardous waste. In real terms therefore, the actual percentage of the waste stream being landfilled is considerably lower.

All in all the ITRADEC MBT plant, having run successfully and without interruption since 2002, can be considered a reliable and economic option for the processing of residual wastes.

5.2.5 Pohlsche Heide (AML) MBT Plant

INTRODUCTION

The Pohlsche Heide MBT plant and wastes treatment centre is located at a landfill site between the towns of Hille and Minden, on the northern boundary of the Minden-Lübbecke district. The Pohlsche Heide Waste Disposal Centre is owned by AML (Abfallentsorgungsbetrieb des Kreises Minden-Lübbecke) which is the council-owned waste treatment company for the Minden-Lübbecke region. The site is operated by GVOA mbH & Co. KG, which is also primarily owned by Minden Lübbecke Council and employs 60 people. The mechanical separation equipment and the tunnel-composting facility was provided by Horstmann, the anaerobic digester by OWS Dranco Ltd, and the gas cleaning equipment by HAASE. The facility is located next to a landfill site, with a recycling facility, windrow composting plant and a wastewater treatment plant on the same site. Prior to the construction of the MBT plant the residual municipal waste from the region was landfilled without treatment. The MBT plant accepts 40,000 tpa of residual MSW from 320,000 inhabitants in the Minden-Lübbecke region. It also accepts around 40,000 tpa of commercial wastes, around 12,500 tpa of sewage sludge from the water treatment works on-site, and around 7500 tpa of other sludges. Therefore in total the plant accepts 100,000 tpa of wastes.

In August 1999 detailed plans for the project were submitted to the local authority in Detmold. The MBT plant was approved for construction in May 2002. Construction began in September 2002, and the plant was brought into trial operation in January 2005. The MBT plant has been in continuous operation, treating the designed waste capacity since June 2005. An aerial photograph of the site is shown in Figure 232. Figure 233 shows the plant from the entrance. More information on the plant is available on the Pohlsche Heide website (www.pohlsche-heide.de). Unfortunately most of this information is in German. Some financial figures about gate fees are available. The site also contains a webcam of the MBT plant, which is updated hourly.

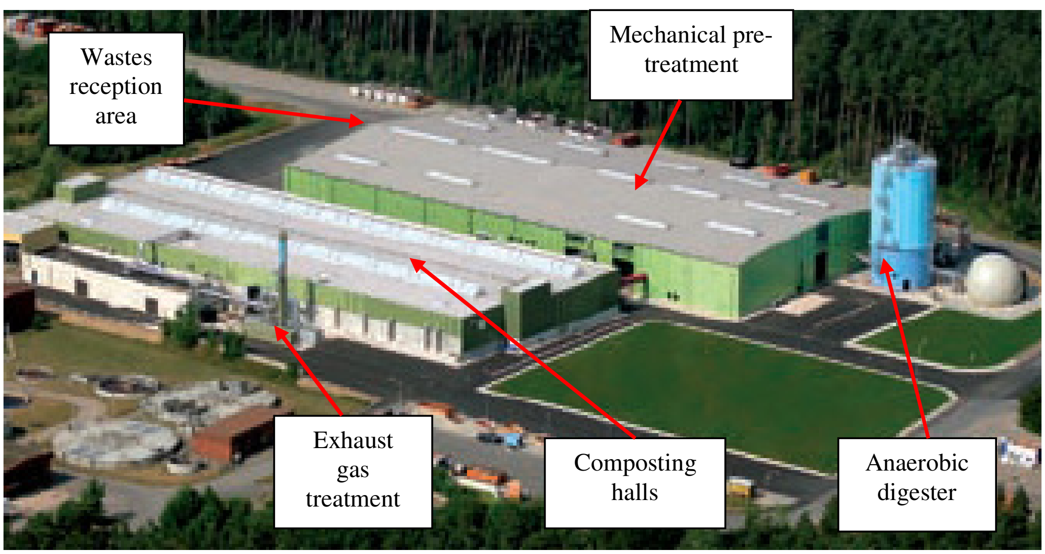

Figure 232 Aerial photograph of MBT plant (Pohlsche-Heide website, accessed November 2005)

The top building contains the wastes reception area (left), the mechanical separation stages (middle) and the biogas engines (right, beside digester). The smaller green building towards the bottom of the photograph is the composting hall. The wastewater treatment plant, which was part of the existing landfill site can be seen in the bottom left.

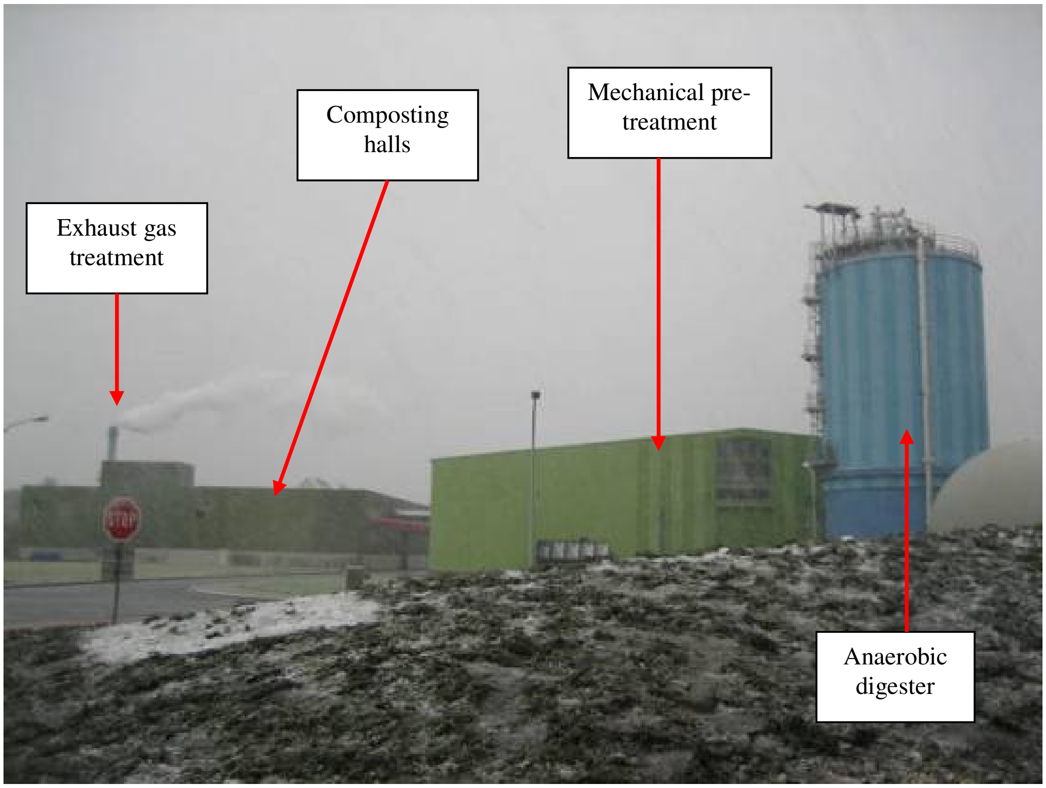

Figure 233 MBT Plant at Pohlsche-Heide

The gas storage bell and anaerobic digester can be observed on the right of Figure 233. The green building to the left contains the unloading bay (at the far end), and the mechanical separation stages. The building on the left (connected to the other building by overhead conveyors) is the composting hall. The composting hall building also contains the exhaust gas treatment facilities (see chimney). A diagram of the process concept can be observed in Figure 234, and a process flow diagram can be observed in Figure 235. Both Figure 234 and Figure 235 are sourced from the IBA website (accessed July 2006).

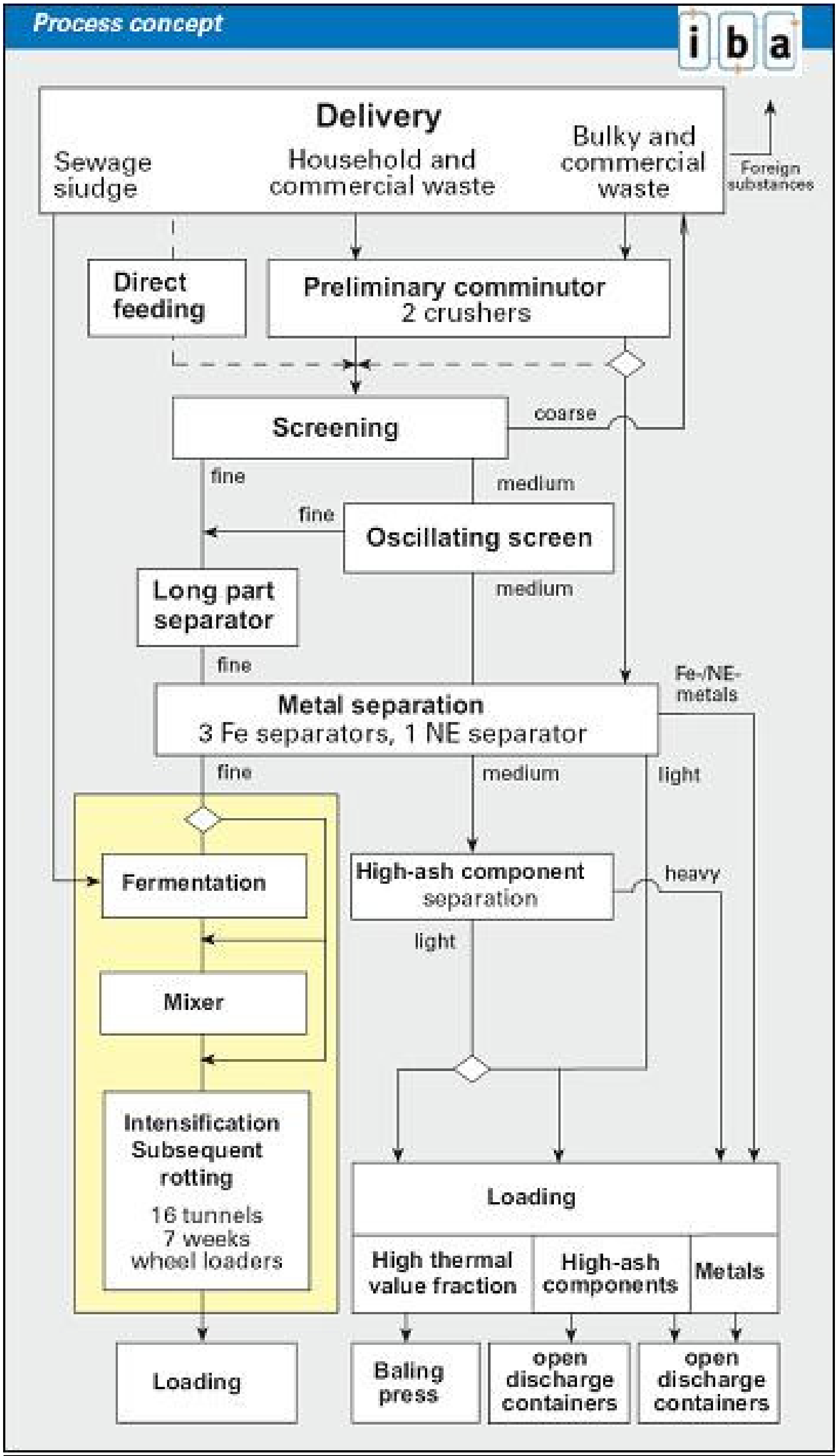

Figure 234 Process concept (IBA website, accessed July 2006)

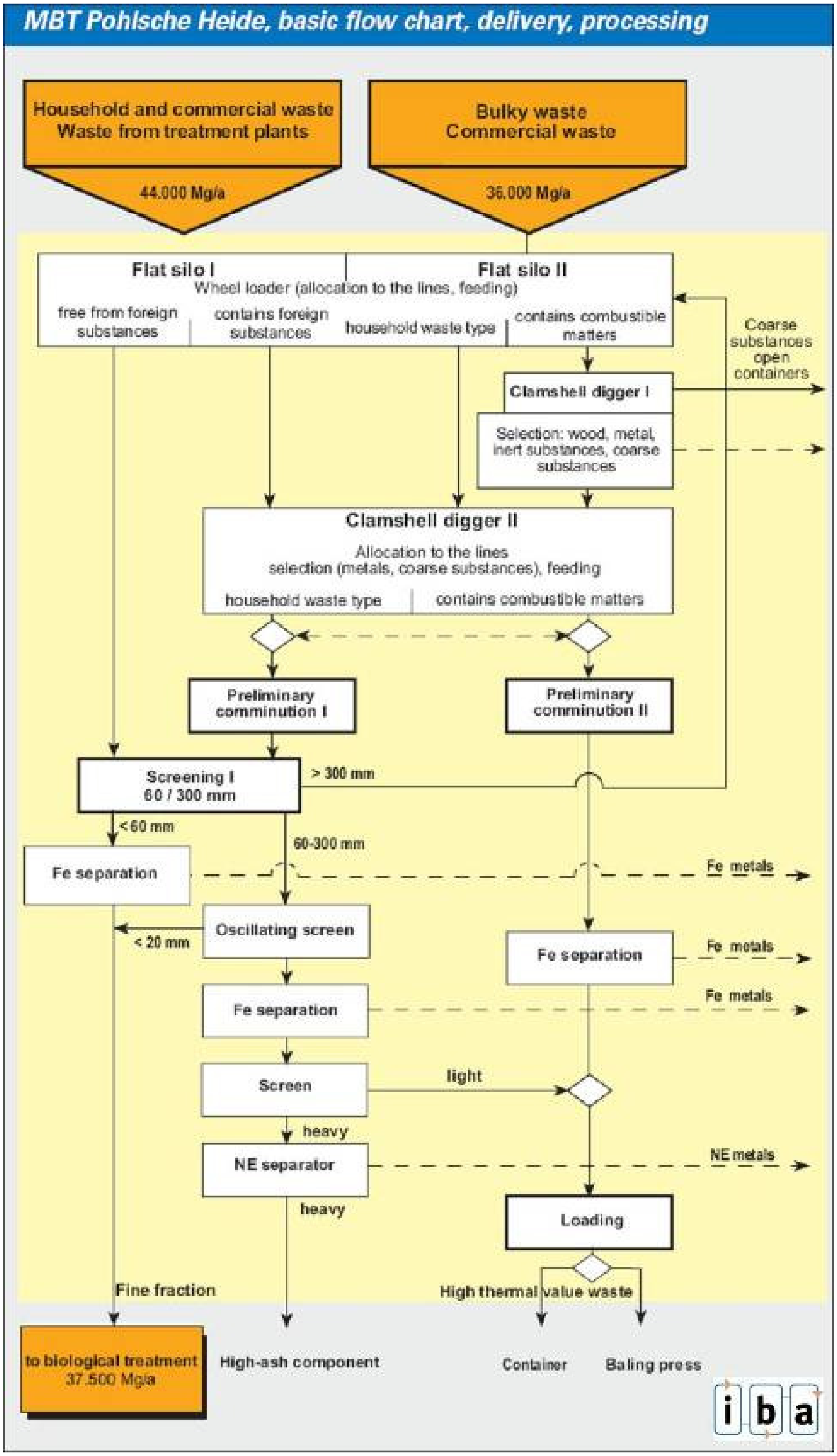

Figure 235 Process flow diagram (IBA website, accessed July 2006)

WASTES RECEPTION AND PRE-TREATMENT

The reception area is in the form of a standard covered warehouse (Figure 236) with fresh air re-circulation to minimise dust and bio-aerosols. Lorries drive in, unload their residual municipal waste (or commercial waste) directly to the floor (Figure 236) and drive out. Doors are kept closed when not in use, although during the day deliveries are fairly constant.

Figure 236 Wastes reception area

The waste is manoeuvred around the reception are floor by JCB diggers, and lifted into a shredder by picking-cranes (Figure 236). All the incoming waste is shredded, and passed on to a conveyor belt. All recyclable materials such as wood, metals and plastics are separated from the waste stream and sent for recycling. Of the remaining waste stream particles <100 mm are sent for biological treatment, while particles >100 mm are sent for energy recovery by thermal treatment. Separation techniques used include air classification (to separate heavy wastes from RDF), magnetic separation techniques (to remove recyclable ferrous metals) and vibrating trommel sieves to separate the waste stream by particle size. As with every MSW stream, problems were caused by long slivers of plastic (*e.g.* the inside of video tapes, strips from fertiliser sacks *etc.*) that wound around moving parts and needed to be periodically removed. Figure 236 shows some of the conveyors between different stages of the mechanical separation. Figure 238 shows the 'light fraction' being wind separated from the heavier wastes. This 'light fraction' will go to be baled as RDF and sent off-site for energy recovery.

Figure 237 Conveyors between mechanical separation stages

Figure 238 'Light fraction' separation by wind sifting

Organic materials (along with small impurities that have passed through the mechanical separation stages) are then sent for biological treatment.

ANAEROBIC DIGESTION

The biological treatment is carried out in two stages. The first stage is anaerobic digestion in a Dranco reactor (Figure 239), and the second is tunnel composting (Horstmann GmbH) to achieve complete biostabilisation. The anaerobic digester was supplied by OWS Dranco Ltd. The Dranco process consists of a dry thermophilic, one-phase anaerobic digester. Annual throughput is around 48,000 tpa and digester volume is 2500 m^3.

Figure 239 Dranco digester at Pohlsche-Heide

The green building on the left contains the gas engines and the mechanical treatment stages. The gas storage bell can be seen on the right. After the mechanical separation stages the waste stream has a maximum particle size of 60 mm. It contains mainly organics but also a significant amount of shredded card and plastic. Before its introduction to the reactor, steam is injected into the waste stream. This steam is renewably produced on-site as a by-product from the production of electricity from the biogas. It is estimated that approximately 3 or 4% of the total biogas produced is used to make this steam. Steam injection ensures the correct moisture content (45% TS in the input in this case), and raises the temperature of the reactor influent prior to its introduction into the reactor. The Dranco process operates between 55 and 59^{o}C. This particular digester is operated at as close to 55^{o}C as possible. This steam-injection to the inflowing waste stream is sufficient to maintain the reactor within the desired temperature range without further heating. The waste is mixed with a recycled portion of the reactor contents (removed at the bottom of the reactor) at a ratio of 1/3 fresh feed to 2/3 recyclate, and pumped back to the top of the reactor for re-introduction. In newly built Dranco reactors such as this one the inflow piping to the top of the reactor is inside the reactor vessel, rather than outside as in the Salzburg plant. This reduces heat loss, but could cause extra problems in the case of pipe corrosion/blockage etc. Similar to all other Dranco processes, a Putzmeister pump (Putzmeister, Germany) is used. These pumps, designed for heavy duty use in the cement industry, are used to pump feed to the top of the reactor, where it is introduced. Once pumped in to the top of the reactor, there is no internal mixing apart from the downward flow of the waste due to gravity. There is no internal or external heating, with the thermophilic operating temperature being solely controlled by steam addition to the influent stream. An advantage of this mixing system is that there are no moving parts inside the reactor, so no danger of blockage or malfunction leading to downtime. With more internal flow-pattern data it could possibly be argued that better waste/biomass contact could be achieved with more mixing, provided by an additional mixing system. An advantage of this heating system is that the steam from the production of electricity is re-used. The organic loading rate is in the range of 5 – 8 kgVS/m^3 reactor/day. The waste entering the reactor has an average total solids content of 45%. A C:N ratio was not given. Retention time is 21 days. For more information on the Dranco process see the OWS Dranco website (www.ows.be/dranco.htm).

The anaerobic digester does not receive all of the organic waste stream, only around 70 - 80% of the OFMSW. This set-up forfeits the biogas available in the other 20 - 30% of the waste stream, but means that de-watering of the digestate is not required. Wastewater treatment costs and the costs associated with connecting the site to the grid to export the renewable electricity are also saved, as the site uses all of the energy it produces, and does not produce any wastewater.

POST AD TREATMENT

The second biological treatment stage is the tunnel composting stage, provided by Horstmann. The tunnel composting stage contains 39 tunnels, each measuring 26 m *x* 6 m *x* 5.3 m. In the first few weeks an intensive de-gassing of the material takes place. In this stage anaerobic conditions are replaced with aerobic conditions over a period of a few weeks. Including the AD digestate, 65% of the residual waste is treated in the tunnel composting stage. In a mixing and homogenization vessel, the digestate is mixed with the other 20% of the organic waste stream, sent directly for aerobic decomposition from the mechanical treatment and moistened (with water recovered from another part of the process) if necessary. These composting tunnels are managed with an automatic entry system and a manually operated wheeled loader as discharge equipment. Composting occurs ‘in-vessel’ in a concrete tunnel system with automatic control of aeration, temperature and moisture content. The composting takes place computer-aided and personnel-free. It was not possible to see these tunnels, but the waste entering the tunnel-composting system is shown in Figure 240.

Figure 240 Waste entering tunnel composting system

The material remains in the composting tunnels for about 7 weeks. Usual retention time in Horstmann tunnels is around 10 weeks, but this organic waste has already been anaerobically digested, which minimises the organic decomposition required. During this period waste is moved from one tunnel to another other several times. This aerates the waste. The biostabilised output conforms to the standard values of German law, and can be landfilled. Horstmann claim the tunnel composting process raises the temperature to 70 °C in the tunnels, resulting in the hygienisation of the material. The Horstmann tunnel composting system, as with other tunnel composting systems, is modular, and can therefore be easily scaled as desired.

DIGESTATE

After tunnel composting the material is fully biostabilised. Therefore it can no longer release any contaminants after it is landfilled. As a consequence the aftercare of the landfill is significantly lowered. The waste landfilled after recyclables recovery and biological treatment represents around 1/3 of the combined input to the plant. Therefore, even after source separation of recyclables and kitchen waste in the home, around 2/3 of the residual waste can be successfully diverted from landfill using this MBT system. The biostabilised output is stored on separate part of the Pohlsche Heide landfill site. This ensures that the storage properties of the decomposed output can be monitored. It is deposited highly compacted to minimize space requirements and the build-up of leachate.

BIOGAS UTILISATION AND ENERGY PRODUCTION

Around 115 – 120 m^3 of biogas are produced per tonne of waste treated in the Dranco digester. This biogas is estimated to be 50 – 60% methane. The total annual throughput of the Dranco reactor is 48,000 tpa. This equates to 57.5 – 72 m^3 of methane per tonne of residual waste entering the MBT plant. Assuming a conversion efficiency of 30% for electricity and 55% for heat, this methane could produce 8287 – 10,376 MWh/a of electricity and 15,192 – 19,023 MWh/a of renewable heat.

Biogas is stored in a 600 m^3 steel bell (Figure 239 and Figure 239). Around 3 – 4% of the biogas produced is used to produce steam for the heating of the influent of the Dranco reactor. The rest is sent to the existing CHP unit on the landfill site (200 – 300 m away) for conversion to electricity and heat. The electricity and heat produced are used to supply all on-site requirements. The biogas produced in the AD stage covers the energy requirements of the plant, both in terms of electricity and heat. The presence of the anaerobic reactor as well as the composting tunnels leads to reduced emissions compared to a single-stage aerobic method without anaerobic digestion. The tunnel composting process is a net energy user. Each composting tunnel has a ventilation unit with approximately 45 kWh installed capacity. These units are used 24 hours a day, but not always at full capacity.

EXHAUST GAS TREATMENT

The Pohlsche Heide MBT plant was conceived as an in-vessel plant. Polluted exhaust-air flows (building air-conditioning, wastes reception area air, composting area exhaust-air) is intercepted and fed to a multi-stage exhaust-air scrubber consisting of a cooler, a washer, a humidifier, a closed biofilter and an exhaust gas chimney fitted with emission monitoring sensors. The exhaust air treatment system was supplied by HAASE. An overview of the exhaust air treatment system can be observed in Figure 241.

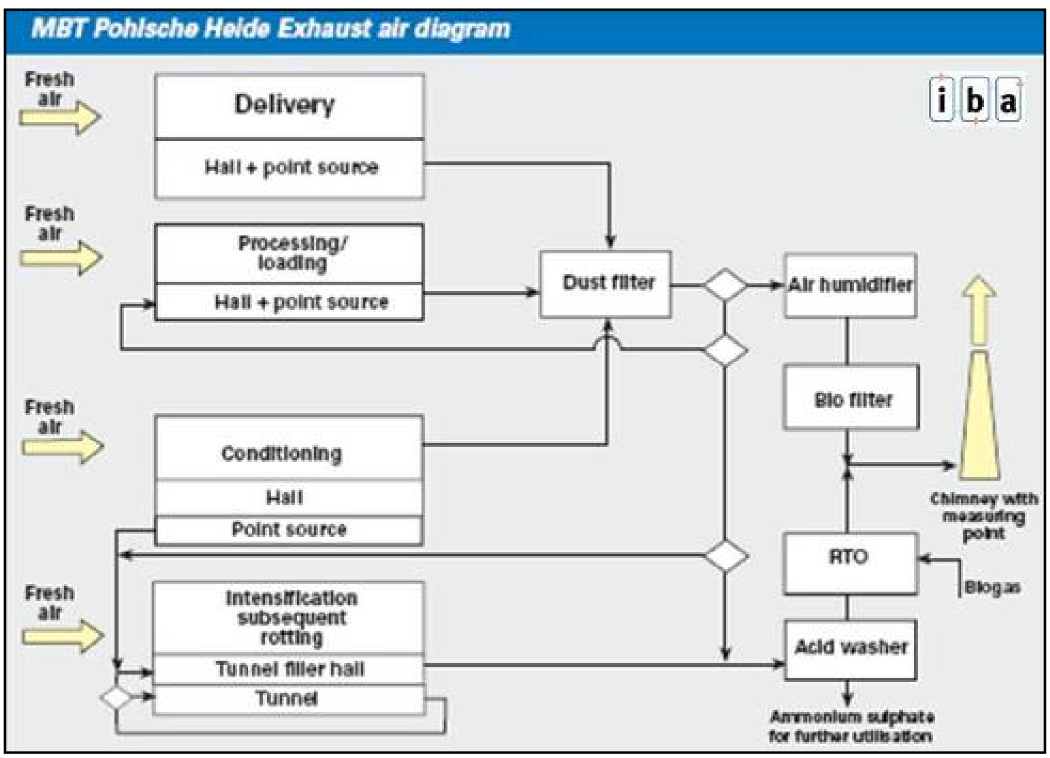

Figure 241 Exhaust gas treatment system overview (IBA website, accessed July 2006)

This system ensures that the requirements of TA-Luft (the German regulations covering air cleanliness) are reliably maintained. Exhaust air from the first few weeks of the tunnel composting process, which can smell particularly bad, is cleaned using regenerative thermal oxidation (RTO) before being added to the rest of the exhaust gas stream for treatment. This RTO involves the exhaust gas being passed through ceramic material heated to 1100^{o}C. The composting systems had a strong odour, despite being in-vessel, but this is normal and the odour at this site was perhaps less offensive than on other composting sites visited.

Figure 242 Exhaust gas treatment

Noise and odour emissions from the MBT plant lie well below the statutory limits.

<u>WATER AND WATEWATER TREATMENT</u>

The MBT plant only generates a small amount of residual wastewater because the concept provides for using any wastewater in the process itself. The water used in the biological process evaporates and is dissipated with the exhaust-air. Water evaporated from the tunnel composting stages is recovered, and converted to steam, which is used to pre-heat and add moisture to the inflow of the Dranco system. The digestate from the Dranco system is produced in exactly the right quantity that when mixed with the residual OFMSW stream that was not digested, contains a water content perfect for tunnel composting. It was estimated by a Horstmann representative on site (Dippert, Personal Communication, 2005) that only around 6000 tpa of water is needed by the MBT process. This corresponds to

0.06 m^3/tonne of incoming wastes. This is a low water requirement, although as well as residual MSW the plant accepts sewage sludge (12,500 tpa), commercial wastes (40,000 tpa) and other sludges 7500 tpa). These other waste streams may contain a high water content. Very little wastewater is produced (exact volume and content was not disclosed) and therefore very little wastewater treatment is required. Wastewater produced is treated in the wastewater treatment plant that already existed on-site to treat landfill leachate (Figure 243 and Figure 232).

Figure 243 Wastewater treatment plant

VISUAL AND LOCAL IMPACT

The plant was built on the site of an existing landfill site, and is completely surrounded on all sides by woodland (Figure 232). As the plant was surrounded on all four sides by forestry trees, with the access road passing through the forest the site was not visible until you were inside. The total surface area of the Pohlsche-Heide Waste Disposal Centre is 270,000 m^2 including the landfill and wastewater treatment plants. The area of the MBT plant was quoted as 30,000 m^2 (IBA website, accessed July 2006). The highest points on site are the anaerobic digester and the gas exhaust chimney, at approximately 30 m (Figure 233). The plant was landscaped well, and was invisible from public roads.

COSTS AND ECONOMICS

The MBT plant cost a total of €26 million. It was estimated by a Dranco representative on-site (Six, Personal Communication, 2005) that the Dranco reactor and the biogas cleaning and utilisation equipment cost approximately €6.4 million of this. Operational costs (excluding RDF disposal) were stated as €60 per tonne, with the gate fee received being €125 - 145 per tonne. The low water usage and wastewater treatment requirement contributes to keeping the operational cost down. As the plant covers the vast majority of its energy requirements, energy costs will be low, although as no energy is exported, there is no income for this.

MASS BALANCE

The flow of materials entering the plant can be observed in Table 54, and the materials leaving the plant can be observed in Table 55.

Table 54 Wastes treated at Pohlsche Heide MBT Plant

Input Waste	Amount (tpa)
Municipal residual waste	40,000
Commercial waste	40,000
Sewage sludge	12,500
Other sludges	7,500
Total	**100,000**

Table 55 Approximate mass balance of the output

Output	Amount (tpa)
Recovered metals	2500
Biostabilised output	33,500
RDF	32,500
Digestion losses	6700
Composting losses	16,500
Miscellaneous	8300
Total	**100,000**

The mass balance information is discussed in Section 6.2.1 and Appendix 2.

CHALLENGES AND DISCUSSION

This system is newly commissioned and has operated continuously without interruption since June 2005. The percentage of the residual waste diverted from landfill is 66.5%. Without the exact details of what the 40,000 tpa of commercial wastes were, it is difficult to speculate on the efficiency of the process in this context. All of the waste landfilled is fully biostabilised. From a water use point of view, the plant is efficient, and the concept is very strong. Energetically, the plant does not compare so well, as other MBT plants treating residual wastes export significant amount of the renewable energy they produce. The system is designed to minimise water addition and wastewater treatment, and for these reasons not all of the organic waste is digested in the Dranco reactor. Therefore from an energy production point of view the plant does not produce as much biogas as it would if it were to digest the whole organic waste stream anaerobically. In this case the savings made on de-watering, wastewater treatment and electricity grid connection must have outweighed the potential income from electricity if the whole organic waste stream had been digested. From this point of view this concept is different from any others reviewed in this report.

5.2.6 Saschenhagen (AWS) MBT Plant

INTRODUCTION

The Saschenhagen MBT plant (near Schaumberg, Germany) accepts 55,000 tpa of residual MSW from a population of approximately 440,000 (around 125 kg per person per year), and 25,000 – 30,000 tpa of commercial wastes from the surrounding area. The facility is located on the grounds of a landfill site, with a commercial waste sorting facility, a public recycling/drop-off facility, a wood waste treatment plant, a windrow composting plant, and a wastewater treatment plant also on the same site. The site and waste facilities are owned and operated by AWS (Abfallwirtschaftsgesellschaft Landkreis Schaumberg mbH). Upgrading of the site from a basic landfill site began in 1993, with the addition of a basic mechanical processing plant. The biological stage of the MBT plant, consisting of two-stage wet mesophilic anaerobic digestion (followed by an aerobic maturation stage) was not yet completely on-line at the time of the visit, but was gearing up to increase throughput to 100% of the design capacity. All of the plants on site were supplied and commissioned (as far as possible) by HORSTMANN GmbH & Co. KG Division Recyclingtechnik. HORSTMANN GmbH & Co KG is a leading supplier of MBT processes and has supplied many turnkey plants. HORSTMANN are also key suppliers of mechanical sorting and processing equipment. Their core biological technology has been Horstmann tunnel composting systems, which are very well established throughout Europe (at least 14 reference sites, with more being commissioned) either as a stand-alone biological treatment within MBT plants or as a further treatment after anaerobic digestion. The AD part of such plants has usually been sub-contracted. This site represents the first wet anaerobic digestion system built by HORSTMANN themselves. More information on HORSTMANN is available on the company website (www.horstmann-group.com). The aims (and main drivers for plant construction) were:

- Reduction in waste volume or weight.
- Reduction and treatment of organic fraction.
- Production of energy.

The main driver was landfill diversion, especially the treatment of the organic fraction of the residual waste stream before landfilling. No photographs were permitted inside the mechanical pre-treatment building.

PLANT DESCRIPTION

PRE-TREATMENT

After delivery, the waste is subject to intensive mechanical separation to remove recyclables and collect RDF. The remaining organic fractions of MSW and commercial waste (which are processed in a similar fashion on different process-lines), are trommel-sieved to a particle size less than 60 mm and sent via conveyor belt to the biological stage. If the organic particles are oversize (>60 mm) they are shredded and then trommel-sieved again). The shredded organic waste (with many inorganic impurities) is pulped (mixed with water and mashed) to a solids content of 10% TS so that it is pumpable (Figure 244). The pulp is pumped via a sand separation unit to hydrolysis tanks. Throughput to the biological treatment stages is 40,000 tpa. The flow of the waste into and through the pulper/mixer and towards the sand separation unit is shown by the dotted red line in Figure 244.

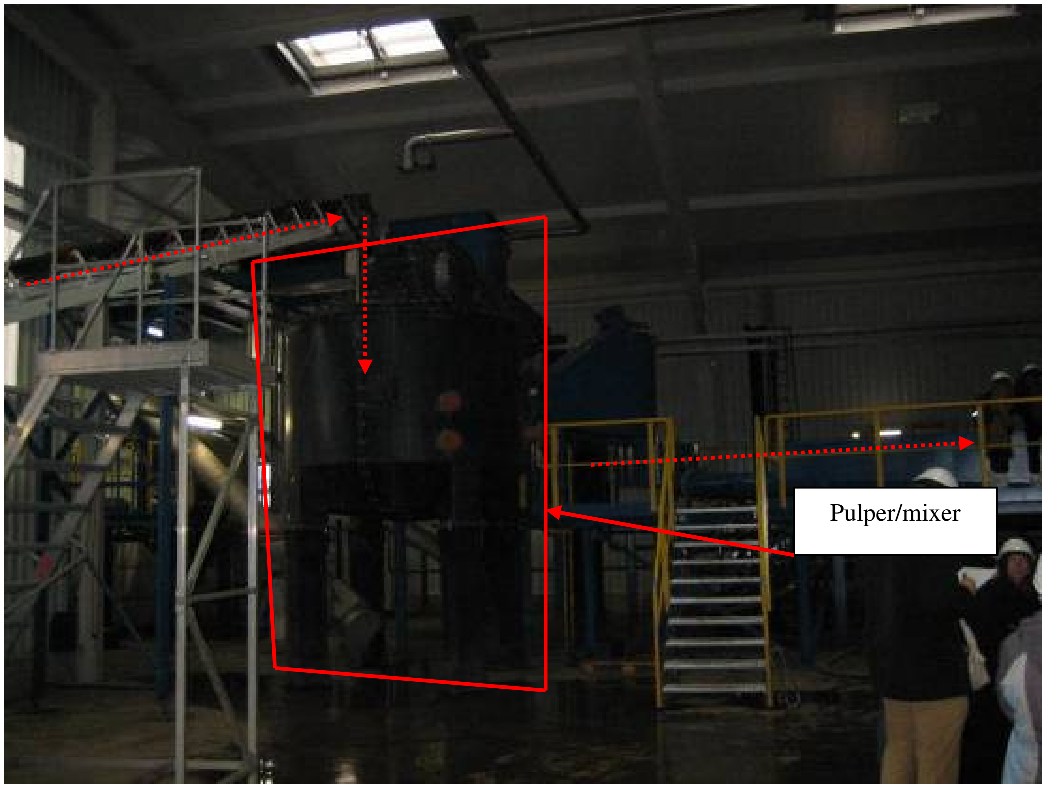

Figure 244 Pulper/mixer at Saschenhagen

ANAEROBIC DIGESTION

In the two 1000 m^3 hydrolysis tanks (Figure 245), remaining heavy materials are settled out and removed, as are remaining floating materials. Retention time in these tanks is 4 – 5 days, and the temperature is 20 – 25°C (Kuhlmann, Personal Communication, 2006). The first stages of the anaerobic digestion process occur in the hydrolysis tanks, with complex organics (such as fats, proteins and carbohydrates) being hydrolysed (broken down) into smaller, more digestible organic polymers (such as sugars, long chain fatty acids and amino acids). Between the hydrolysis tanks and the anaerobic reactors there are two mixing tanks, each with a volume of 400 m^3. The waste stream from each process line is mixed into one stream at this stage. Therefore the entire waste stream becomes one again, and is thoroughly mixed to ensure an equal and uniform feed (in terms of temperature, % TS, organic strength and content) is fed to each of the four anaerobic digesters (volume 2000 m^3 each). Maximum particle size in the slurried waste stream entering the digesters is 16 mm. Heating is provided using hot water/steam from the CHP plant.

Figure 245 Hydrolysis tanks

There is also a 1000 m^3 process water storage tank, in which harvested rainwater is stored. This rainwater is added at the pulping stage, or in the mixing stage to realise the preferred total solids content (10% TS). The hydrolysed, mixed waste flow (still at 10% TS) is pumped continuously to the anaerobic digesters. Temperature is raised to the operating temperature prior to the waste entering the digesters. Digestion is carried out at 37^{o}C in the mesophilic temperature range. Retention time for the whole digestion process is 21 days. Working back from the volumes of the tanks, and assuming continuous influent and effluent with no recycle the retention times must be in the region of 4 days in the hydrolysis tanks, 2 days in the mixing tanks and 15.5 days in the digesters. If extra water is added to the process at any stage (except prior to the hydrolysis tanks) these figures would change.

Figure 246 Anaerobic digester at Saschenhagen (one of four)

Temperature, gas production and content, liquid levels and gas pressure are measured continuously on-line. Liquid influent and effluent samples are taken once per day for laboratory analysis.

POST AD TREATMENT

After anaerobic digestion, and de-watering the waste stream is aerobically treated to remove the remaining organics. Aerobic treatment of the waste flow enables full biostabilisation of the waste stream. Retention time in the 'liquid maturation stage' is 5 - 14 days (HORSTMANN Promotional Information). Five days is a short residence time for a post-digestion aerobic treatment facility. It is assumed that because the aerobic treatment is in the liquid phase rather than the solid phase (as in composting), the waste would have more mixing and more contact with air and therefore the organics could degrade faster. After digestion and aerobic polishing the waste stream is biologically stable and free from unpleasant smells (Saschenhagen Promotional Information). After the waste is biostabilised it must be de-watered to more than 65% dry solids (the legal limit for landfilled waste in Germany). The waste stream is de-watered mechanically and using heat from the CHP unit. Sand (removed from the waste stream removed prior to the biological stages) is re-introduced at this stage, which further increases the dry solids percentage of the solid fraction and minimises expenditure on de-watering. Resulting process water is collected, and re-used where possible.

DIGESTATE

Approximately 33,000 tpa of CLO remains after the digestion, aerobic treatment and de-watering of the waste stream. This represents 82.5% of the mass of waste put into the biological treatment system. Therefore the percentage landfill diversion of the whole MSW stream (55,000 tpa) provided by the biological treatment system (AD and aerobic treatment) is around 13%. When the total mass balance is considered (rather than only the organic fraction) it can be sent that 40% of the total residual MSW is diverted from landfill. Furthermore, if the entire waste stream entering the plant is considered (total input is 80,000 – 90,000 tpa) then 59 - 63% can be considered to be diverted from landfill. Without further details of the contents of the 25,000 – 35,000 tpa of incoming commercial wastes it is not possible to comment on this figure. The digestate is completely biostabilised and meets the German legislation allowing it to be landfilled. There would be no chance of a market being found for a 'compost' based on MSW, especially considering the ever increasing volumes of better quality compost being produced from garden waste (and kitchen waste) throughout Europe.

BIOGAS UTILISATION

HORSTMANN are expecting to produce between 160 and 200 m^3 of biogas per tonne of waste put through the digesters. This expected range of biogas production is in the upper range compared to other figures observed for similar feedstocks. Despite the fact that HORSTMANN are digesting organics in a two-stage digestion system, this range of biogas production is perhaps ambitious (unless some of the commercial wastes being received are high energy food production wastes). This expected gas production would represent a range of 6,400,000 – 8,000,000 m^3 of biogas per year, with a methane percentage of 55 – 60%. During the site visit a HORSTMANN representative stated that once the system was successfully started up on the organic fraction of MSW they would be attempting to source other organic industrial wastes and slaughterhouse wastes in order to boost plant economics in terms of gate fees and extra biogas production. The biogas is stored on-site (Figure 246), in order to provide a steady input to the CHP unit. The biogas is then cleaned (de-sulphurised, and put through a condensing unit to remove water vapour) before being utilised in the CHP units.

ENERGY PRODUCTION

Total electricity produced would be approximately 10,568 – 14,411 MWh/a. Approximately 2/3 of the total electricity produced will be used on site, and the other 1/3 will be exported to the grid. Based on these figures 3487 – 4756 MWh/a would be available for export. These figures are based on expected biogas production figures, rather than observed figures. The heat produced more than covers all on-site requirements, including heating the waste stream to the operating temperature of 37^oC, heating the anaerobic digester to keep digestion as close as possible to 37^oC, de-watering and drying the digestate to the required dry solids percentage for landfill, and the heating requirements of all buildings on site. The mechanical part of the process is a net energy user, although it is designed to recover RDF from which energy can be recovered. The aerobic treatment (liquid maturation) is also a net energy user, although no further energy balance figures were made available.

EXHAUST GAS TREATMENT

Exhaust air (from the entire plant) is treated by regenerative thermal oxidation, at a temperature of approximately 850^oC. Treated exhaust gases are continuously analysed for content prior to being released to atmosphere by chimney (Figure 247).

Figure 247 Exhaust gas thermal oxidation plant and chimney

WATER AND WASTEWATER TREATMENT

Approximately 4500 m^3 of fresh water is used per year (Kuhlmann, Personal Communication, 2006). This corresponds to 0.05 m^3 of fresh water per tonne of waste treated. The amount of fresh water required depends on the exact water content of the incoming wastes. Approximately 2000 – 3000 m^3 of wastewater are produced annually. This corresponds to 0.036 – 0.055 m^3/tonne of residual MSW processed, or 0.022 – 0.375 m^3/tonne of MSW and commercial waste processed. Without knowing the exact content of the commercial wastes accepted it is not possible to comment on these figures. Wastewater is sent to the wastewater treatment works already on site before being discharged to sewer.

MASS BALANCE

A mass balance for the process is shown below. Incoming wastes are shown in Table 56, and outgoing materials in Table 57.

Table 56 Approximate mass balance of the input

Input Waste	**Amount (tpa)**
Residual MSW	55,000
Commercial Wastes	25,000 – 35,000
Total	**80,000 – 90,000**

Table 57 Approximate mass balance of the output (based on residual MSW only)

Output	**Amount (tpa)**
RDF	10,000
Losses by AD	7000
Metals *etc.*	5000
Stabilised residue for landfill	33,000
Total	**55,000**

The mass balance of the process will be further discussed in Section 6.2.1 and Appendix 2.

COSTS AND ECONOMICS

No figures for the capital costs of the project were made available. HORSTMANN stated at the time and again in July 2006 when asked again that the costs would not be revealed as the plant was designed and constructed to meet German Regulations, under German conditions, and therefore would not be comparable to UK application (Dippert, Personal Communication, 2005, and Kuhlmann, Personal Communication, 2006). The plant was also a pilot project, with several trials included, and so costs would not be applicable to new processes, either in Germany or elsewhere. Operating costs were not made available, but it was indicated that normal operating costs of MBT plants are around €60/tonne, with an additional €60/tonne of credit costs (Dippert, Personal Communication, 2006).

Based on calculations from HORSTMANN's expected biogas production and content figures, and based on 1/3 of the electricity produced being exportable (Dippert, Personal Communication, 2006), and a biogas to electricity conversion efficiency of 30%, then 3487 – 4756 MWh/a of electricity would be available for export. In the UK in September 2006, this would be worth £374,853 – £511,270 (based on September 2006 average price of £107.50/MWh, NFPA website, accessed September 2006). Process economics are dependant (as are the economics of all other processes) on the stability and development of renewable energy markets, RDF markets, gate fees and landfill costs.

VISUAL AND LOCAL IMPACT

The MBT plant is located around 2 miles outside a small village. It is located next to an existing landfill site. The highest point of the plant is approximately 20 m (the anaerobic digesters). Although the surrounding countryside is flat, the site is well 'landscaped in'. Trees are planted around the site, and the inert waste has been used to landscape the site and minimise its visual impact. The site is not visible from the road or the surrounding area. There were no odours detected outside the site on the day of the visit, and no rubbish escaping the site, despite high wind strength. On-site, unpleasant odours were detectable in the pulping area (although it was indoors with fresh air re-circulation and exhaust air treatment). Exhaust air from all process stages was treated prior to being released to atmosphere.

CHALLENGES AND DISCUSSION

Saschenhagen/Schaumberg was a pilot project for HORSTMANN, and as such several process stages (and their integration with other process stages) are being developed and adapted throughout the start-up and early stages of operation. Also, the CHP units and parts of the pre-treatment were already installed at the site, so these facilities were integrated in to the new MBT system. This lowered costs but presented engineering challenges.

The HORSTMANN tunnel composting system is a well established residual waste treatment option. HORSTMANN have supplied at least four MBT plants with AD processes, with the AD sub-contracted to another company. The Saschenhagen plant was the first anaerobic digestion system to be built by HORSTMANN themselves (along with their system at Jever, Germany), and it had not yet started up on the full waste stream. For this reason the HORSTMANN process (when including self-supplied AD) can not be considered proven. Several years of reliable, problem free operation of this site, the Jever site, and other HORSTMANN anaerobic systems that may be commissioned could lead to HORSTMANN becoming a major player in the anaerobic digestion of municipal based organic wastes. They can already be considered amongst the market leaders in MSW in-vessel composting systems and mechanical separation processes. A few points worthy of note that arose from the visit and conversations thereon are:

- Good pre-treatment is 'vital' for avoiding problems further down the line.
- The entire biological treatment step is carried out in 2 parallel process lines. This adds an extra safety element, as if there is a problem with one line, the other will remain operational.
- The viability of this type of system (that produces an RDF) relies heavily on the presence of an incineration facility that will accept the RDF at a reasonable gate fee.

Sand is a major problem in wet digestion systems due to the problems it can cause with pump and piping erosion. The removal of sand had been a major problem at the Saschenhagen site. A centrifuge-based sand removal system was added to the process line after pulping and before the anaerobic digestion stages.

HORSTMANN claim that a two month trial was carried out at their biowaste reference plant in Singhofen to demonstrate that the process could meet the temperature requirements of the ABPR (Juniper MBT Report 2005), but the results were not made available for verification. It was stated that if necessary a pasteurisation stage could be added to the processing line (Dippert, Personal Communication, 2006). The Saschenhagen MBT plant was not yet working at full capacity at the time of the visit. As such, its performance criteria are theoretical and as yet unproven. Any comparisons made with other processes will be based on the theoretical performance criteria given by HORSTMANN. This should be considered when comparing the processes.

Only around 1/3 of the original quantity of waste delivered (to the site as a whole) is sent to the landfill site. The other 2/3 is successfully treated, recovered for recycling, materially or energetically used. It should be noted however that although the organic fraction is fully biostabilised, it is still landfilled and therefore can not be counted as recycled. HORSTMANN anticipate a high biogas production (160 – 200 m^3/tonne digested). If production matches expectations the energy balance of the plant should be favourable, with a considerable export of electricity possible.

5.2.7 Kahlenberg (ZAK) MBT Plant

INTRODUCTION

The plant is owned and operated by ZAK (Zweckverband Abfallbehandlung Kahlenberg), which is the regional municipally owned waste handling company. The planning and the management of the building of the new site was carried out by ZAK, with the individual areas of expertise sub-contracted to companies with specific areas of expertise. The anaerobic digester was built by Wehrle Werk (www.wehrle-werk.de). The MBT Plant and landfill site accepts 100,000 tpa of residual waste from a population of approximately 600,000. This is the equivalent of 170 kg per person per year. Recyclates are separately collected and sent elsewhere for processing or recovery. Kitchen waste is not source separated and is included in the residual waste stream.

Ringsheim is a village on the edge of the Black Forest, and is a popular tourist destination in Germany, due to the attractions of the Black Forest and the proximity of Ringsheim to Germany's premier Theme Park (Europa Park). The existing landfill site, opened in 1973, was running out of space, and German and European law dictated that all biodegradable waste needed to be treated before landfilling, and that more recyclates should be removed before landfilling. Construction of the plant commenced in March 2004, and the plant started accepting waste in May 2006.

PLANT DESCRIPTION

The ZAK Ringsheim plant is currently the only one of its kind in the world. It incorporates (what the management hopes) are the best practices from other MBT plants to provide the best possible solution for local wastes management. Aside from the existing landfill, the plant incorporates five main features. These are:

- Mechanical (and manual) sorting.
- Percolation and Anaerobic Digestion.
- Biodrying.
- Mechanical material separation (heavy/light fraction separation for SRF production).
- Exhaust gas treatment.

Each of these features has been tried, tested and found to be successful at other plants, but the ZAK MBT is the first time that these processes have been designed and implemented as part of the same system. The combination of processes meant that some of the individual process needed to be adapted, in order to fit in with the rest of the system. This required innovative thinking and engineering on the part of the project managers (ZAK). Several parts of the process are original and have been patented by ZAK. As the plant has only just started up, it is too early to call the concept 'proven', but early indications look good (Gibis, Personal Communication, 2006). Due to its innovative nature the plant is promoted by the European Union in by the LIFE Program (www.ruk-online.de/life-ZAK-Kahlenberg/index.html, Accessed August 2006). An aerial photograph of the ZAK MBT plant and landfill site is shown in Figure 248. A process flow diagram is shown in Figure 249.

ZAK Ringsheim has 50 employees in total, including many administrative staff. The plant operates a five day week (Monday to Friday). The plant is operational 12 hours per day.

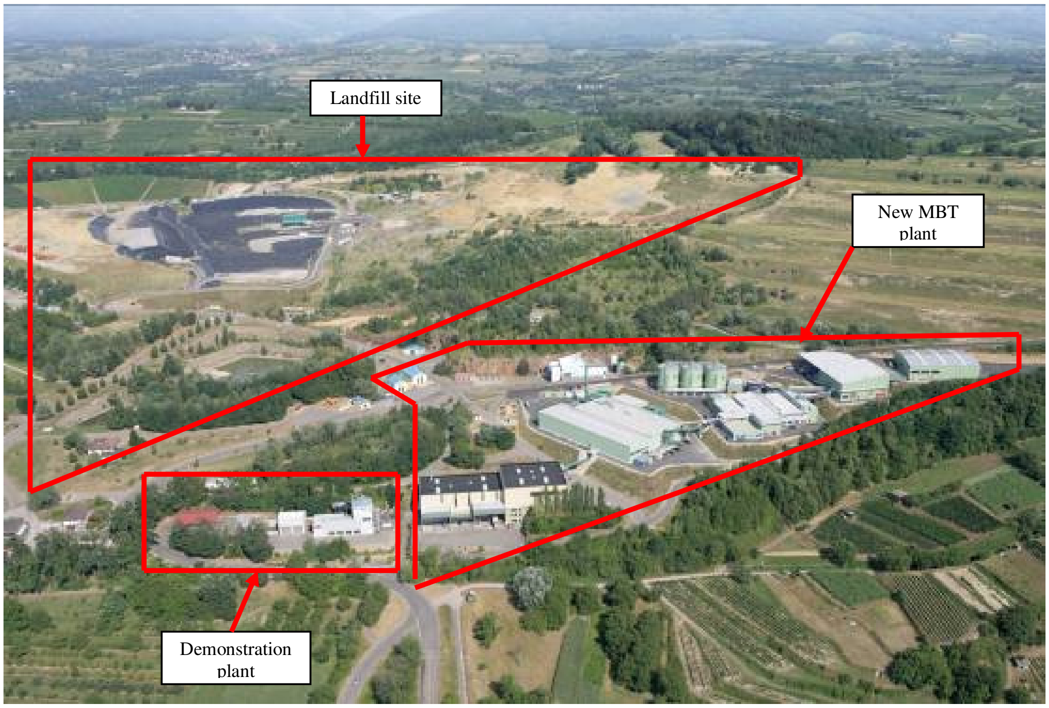

Figure 248 Kahlenberg MBT aerial photograph

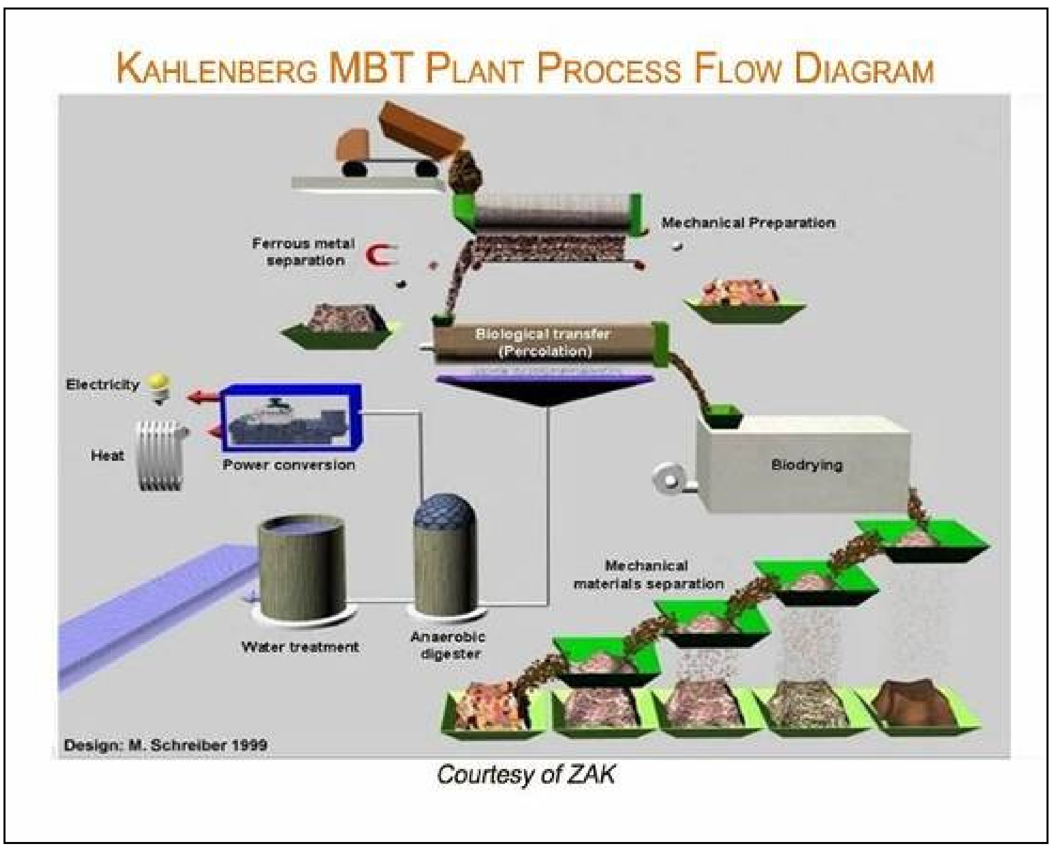

Figure 249 Process flow diagram (ZAK Promotional Information)

PRE-TREATMENT DESCRIPTION

After being weighed on the weighbridge, the waste is emptied from the collection vehicles onto the floor in an enclosed reception hall. The purpose of emptying on to the floor is so that the digger and crane operators can 'pick' out large obvious items from the waste stream (for example bicycles, wardrobes *etc*.). The wastes reception building is kept at negative pressure, so that no odours escape. In comparison to other sites, this negative pressure was very noticeable as, standing in the doorway, a breeze could be felt as soon as the door was opened. There was also no detectable odour whatsoever outside, despite the fact that a fresh load of waste had just arrived (Figure 250).

Figure 250 Waste reception hall

After being unloaded on the floor, the waste is pushed by a digger and lifted by a crane (Figure 250) to a hopper, from where it is transferred through to trommel sieves (Figure 251). There are two trommel sieves, operating in parallel. The first half of each trommel sieve separates the waste stream into a fraction less than 60mm and an oversize fraction. The undersize fraction is sent to a specially designed and patented 'battery separation unit'. The 'battery separation unit' consists of an especially powerful magnet station that removes batteries and even weakly magnetic components such as electrical scrap (Person, Personal Communication, 2006). The oversize fraction (>60 mm) is passed through to the second half of the trommel sieves, where the separating size is increased to 150 mm. Fractions between 60 and 150mm are also sent through a battery separator, metal separators and a manual sorting stage before being sent to the percolators (together with the fine fraction <60 mm). Oversize fractions passing through both size distinctions in the trommel sieves are wind-sifted to separate light fractions (which are used as RDF) and heavy fractions (which go to landfill).

Figure 251 Trommel sieves

The manual sorters, of which there are two per shift, separate large stones and leather shoes from the waste stream. The stones are removed as they can cause problems later in the plant, especially to pumps and piping. Other plants have mechanical separation techniques that can (reportedly) successfully remove stones. Leather shoes are removed as they contain a high chromium content, which would jeopardise the quality of the fuel being produced at the back-end of the plant. These shoes are presumably re-introduced to the RDF stream that is destined for a municipal wastes incinerator. Although inside the plant, odour was detected at the manual sorting stations, and considering the commendable lack of odour elsewhere more care could perhaps be taken to improve working conditions at this point of the plant. After batteries, metals, leather shoes and stones are removed, the fractions (<150 mm) are passed to the percolators (Figure 252). There are six percolators, which are horizontal cylindrical tanks, around 20 m long with a volume of 250 m^3 each. The waste is introduced at one end of these percolators, mixed with cold water and passed through, towards the other end, where it exits. The total residence time in these percolators is 2 days.

The incoming waste has a 40-50% water content, and the volume water required in these percolators was not considered to be excessive. No figures for water usage were given. After two days passing through the percolators, the waste stream is de-watered in screw-presses (one screw-press after each percolator). Two of the six screw-presses can be observed in Figure 252. The liquid fraction is sent through a specially designed and patented unit to removed small stones and grit. If not removed these fine inerts could damage pumps and piping, and lead to sedimentation in the anaerobic reactors. Some fine inerts removed by the unit can be observed in Figure 253.

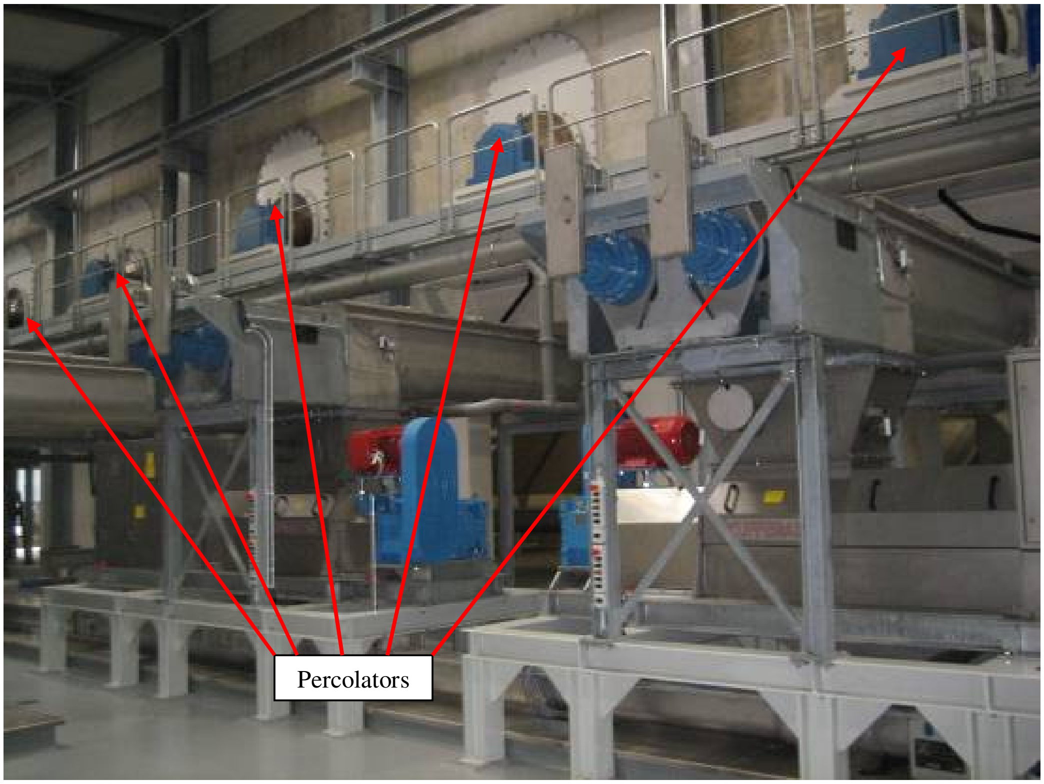

Figure 252 Percolators and screw presses

Figure 253 Fine inerts

The liquid fraction, now with fine inerts greatly minimised, is passed an underground buffer/storage tank prior to being introduced to the anaerobic digesters. The solid fraction of the waste stream after percolation and de-watering is passed by conveyor to the biodrying units.

AD PLANT DESCRIPTION

There are three identical anaerobic digesters, two of which are shown in Figure 254, with a combined volume of approximately 5000 m^3. The digesters operate in parallel, but can each be fed, monitored and controlled separately. As mentioned above, the digesters were built by Wehrle Umwelt GmbH. Digester design was not given, but a high rate reactor (such as a standard single-stage UASB, EGSB or anaerobic filter type reactor) is presumably utilised. As only the liquid fraction is digested, digestion is 'wet'. The total solids percentage in the reactors was 2.5 – 4%. Digestion occurs in the mesophilic temperature range at 37^{o}C. Retention time is 4 days. As digesters were still in the start-up phase (having operated less than 6 weeks), and given the lack of available information, no comments can be made on their status, reliability or efficiency of operation.

Figure 254 Two (of the three) anaerobic digesters

BIODRYING

The solid fraction of the de-watered percolated waste stream is sent to the biodrying hall, where a biodrying unit is filled and sealed. There are 9 fully enclosed biodrying units, in which a 'batch' of waste is left, with intermittent forced aeration with warm air, for a period of approximately 5 days. In these five days, the forced aeration facilitates partial aerobic composting, resulting in considerable heat production (over 55^{o}C in places), which serves to drive off excess moisture from the waste stream. As well as reducing the moisture content, this reduces the mass of the waste stream, and makes it more suitable for use as a fuel. As with the anaerobic digesters the biodrying units are all completely enclosed to minimise odour escape, and exhaust gases are fully treated.

Figure 255 Biodrying bays (5 of 9)

MECHANICAL MATERIALS SEPARATION

The heavy and light fractions of the waste stream are separated by air classification for SRF production. The SRF can be made to a required standard in terms of content, quality and particle size. The difference between this SRF and RDF is that the SRF (due to its strictly controlled contents) is recognised as a fuel and its combustion does not cause plants to install expensive exhaust air treatment (because it will not produce extra contaminants). RDF can usually only be utilised at an MSW incinerator, an EFW plant, a co-firing power plant or another facility with specialised exhaust air treatment facilities. Cement kilns (or other industries) can occasionally be exempted from air emissions legislation and these facilities could also provide an RDF disposal route.

WATER USE AND WASTEWATER TREATMENT

The incoming waste has a 40-50% water content, and the volume of water required in these percolators was not considered to be excessive. No figures for water usage were given. The MBT Plant has an aerobic wastewater treatment plant to treat wastewater, prior to discharge to sewer. It is assumed that the sludge from this plant is probably re-circulated to either the percolators or the anaerobic digesters, although this information was not given.

FINAL SOLID PRODUCTS

As well as biogas the plant can produce 6 grades of stones/inerts, ranging from a maximum size of 1mm up to rubble. These products are currently landfilled, but it is hoped that (construction-based) markets can be found in the future. The plant can also produce 4 different ranges of 'solid fuel', ranging from a specified quality SRF that meets the requirements of industry and therefore attracts revenue, to unspecified RDF that can be used to produce energy in a municipal incinerator, cement kiln or other thermal treatment. Despite its energy value, incinerators or industries must be paid a gate fee to accept this poorer quality 'fuel'. The finest grade SRF (which is so fine that it can be co-fired with pulverised coal) is shown in Figure 256, and the RDF is shown in Figure 257. The investments made to upgrade the SRF to different quality grades can be made according to contracts negotiated with other industries.

Figure 256 Fine grade SRF from residual waste

It is to help guarantee the standard of this SRF that items such as leather shoes and electrical scrap are removed from the waste stream. The guaranteed removal of batteries would also be necessary to ensure the heavy metal content of the SRF is minimised. These heavy metals (including chromium) would mean that the fuel could not be accepted by industries without expensive adaptations to their air emissions treatment systems.

Figure 257 RDF from residual waste stream

BIOGAS UTILISATION

At the time of our visit the plant had only been started up for 6 weeks, as such the digesters were still in their start-up phase, and were producing a combined total of 360 m^3 of biogas per hour. It was expected that this would eventually rise to 700–800 m^3/hour once the digesters were successfully started up and fully operational. This corresponds to approximately 61–70 m^3 of biogas per tonne of residual waste accepted through the plant. Biogas is mixed with landfill gas (which is produced at around 2000 m^3/day, or 730,000 m^3/year) and burnt in 5 gas engines to produce electricity and heat. The five biogas engines and the pumping unit for the district heating scheme are contained in the buildings shown in Figure 258. The landfill site can be observed in the background in Figure 258.

Figure 258 Biogas utilisation building

Excluding the input from landfill gas, approximately 90% of the electricity produced is used to cover on-site requirements. The other 10% (or whatever excess there is) is sold to the grid. Considering only biogas from the anaerobic digesters, only 10% of the heat energy produced is required to cover all on-site requirements. The rest of the heat energy is utilised in a district heating scheme serving the nearby village of Ringsheim. The thermal oxidation exhaust gas treatment is one of the most energy intensive parts of the plant.

ENERGY PRODUCTION

Heat and electricity recovery from the biogas produced at the plant are shown in Table 58 and Table 59.

Table 58 Electricity balance from biogas produced on-site

Electricity production	13,578 MWh/a
Electricity use on-site	12,812 MWh/a
Excess electricity	766 MWh/a

(Translated from ZAK Ringsheim Promotional Information).

Table 59 Heat balance from biogas produced on-site

Heat production	18,828 MWh/a
Heat used on-site	8646 MWh/a
Heat excess	10,183 MWh/a

(Translated from ZAK Ringsheim Promotional Information).

The concept also recovers all possible recyclates and recovers all possible energy from the waste. Only inerts such as stones and sand are landfilled, and it is hoped that a market or at least a beneficial use can be found for these.

EXHAUST GAS TREATMENT

Exhaust gases are pre-treated in an air-washing unit. After 'washing' exhaust gases are treated in biofilter (Figure 259) or a thermal oxidation unit (Figure 260) depending on the exhaust gas quality. Different exhaust gases are treated in different proportions in the different exhaust gas treatment facilities in order to fully meet the German Legislation in the most economical way. By having the choice of different exhaust air treatment units, the expensive thermal oxidation can be used sparingly, only when absolutely necessary.

Figure 259 Biofilter for exhaust gas treatment

Figure 260 Thermal oxidation unit for exhaust gas treatment

COSTS AND ECONOMICS

The total capital cost of the plant was €45 million (Gibis, Personal Communication, 2006). Operating cost per tonne of incoming waste is €70 (including finance). It is assumed that the incomes from the excess electricity and heat produced are included in this figure. As the plant is publicly owned, the gate fee charged is slightly above €70/tonne. The exact figure was not given. ZAK are confident that their 'concept' represents the best possible residual wastes solution given German Legislation, but accepts that it may be an elaborate and expensive option in other nations given the less strict Legislation.

VISUAL AND LOCAL IMPACT

The plant was built at the local landfill site, which was on the site of a hill and therefore visible, although well wooded, to the local town and motorway. The sections of the landfill site that had been restored were restored to a high quality, and turned into a public recreation area, with wooded areas and picnic facilities. The employees of the plant even keep animals on the restored landfill (Figure 261), horses, goats and donkeys including more exotic species to improve the area's image.

Figure 261 Restored landfill site

There are domestic houses within 10 metres of the edge of the restored landfill (also observable in Figure 261). The proximity of these residences exacerbated the importance of landscaping and odour minimisation. As for the MBT plant, despite being on the edge of a hill, it was well landscaped into the hillside with trees. No odours were detectable outside the plant, or even on the site outside the buildings, despite the warm (28^{o}C) and windless conditions. This was an original aim of the process, due to the proximity of residential housing. From this point of view the plant should meet its zero-odour objectives (if it maintains a similar standard).

CHALLENGES

It could be expected that any new plant would have teething problems that required sorting out during the first year or so of operation. At the time of the visit the plant had only been up and running for a period of 6 weeks, and if this plant was experiencing any particular teething problems, they were not revealed.

DISCUSSION AND CONCLUSIONS

The total throughput time of the plant is around 8 - 9 days. The time in the mechanical sorting is less than 1 day, time in the percolator is 2 days, AD retention time is 4 days, while simultaneously the solid fraction is biodried for approximately 5 days. Mechanical sorting of the biodried output is assumed to take a maximum of one day. This represents a very fast throughput of wastes, enabling the plant to treat 100,000 tpa of residual waste on a relatively small site (8000 – 9000 m^2 [Juniper, 2005]).

As ZAK is municipally owned, wastes contracts are not an issue. Given this scenario, decisions to make large investments in plants that will benefit the whole community environmentally and financially can be made more easily and with greater confidence.

If the company owning or running the plant was privately owned, the potential danger of losing wastes contracts would be a very important parameter, and could potentially limit investment and development.

In the percolators, the waste stream is mixed with cold water. If warm water or steam was to be used (as in the ISKA system) then a higher proportion of the organics could presumably be recovered from the solid to the liquid fraction. If more organics could be recovered, then more biogas could be produced. In any case there is usually an excess of heat energy in the form of steam, due to the difficulty of finding a use for all of the heat produced. The reason why cold water was used rather than hot water was that a certain proportion of the organics must be retained in the solid fraction to provide enough heat (as a by-product of its aerobic decomposition) in the subsequent biodrying stage of the process.

The housekeeping and odour control at the plant were impressive. The plant had only started up six weeks previously and therefore looked new and free from dust and grime, but if the same (or similar) levels of housekeeping and odour control are maintained, then no odour at all would be detected, even from a distance of only a few metres.

All in all the ZAK concept, should time to prove it to be reliable, is perhaps one of the best possible MBT plant designs with regards to landfill diversion and energy recovery. The high scoring of the plant in both of these key areas (landfill diversion and energy recovery) is primarily down to the fact that the solid fraction of the percolated waste is biodried and upgraded to SRF rather than landfilled. The percentage of the residual waste stream that is landfilled has been reduced to 15%. Only inert material is landfilled. It must be remembered that the residual waste stream consists of only those sections of the waste stream that are not recycled, re-used or disposed of as hazardous waste. In real terms therefore, the actual percentage of the waste stream being landfilled is considerably lower.

The ZAK management are confident that their 'concept' represents the best possible solution for residual wastes in Germany, and they expect that when the Legislation of other nations 'catches up' that their concept will become much more common throughout Europe. The plant compares well with other MBT options for residual waste processing in the following key areas;

- Energy.
- Landfill diversion.
- Odour minimisation.
- Total throughput time.

5.3 Case studies from other anaerobic wastes treatment systems

5.3.1 Holsworthy (Summerleaze) Biogas Plant

INTRODUCTION

The Holsworthy Biogas Plant is owned and operated by Summerleaze AnDigestion. Information used in this case study was either from personal communication (Prior, Personal Communication, 2006), from the Holsworthy biogas website (accessed September 2005) or from the Strathclyde University website (accessed April 2006).

The Holsworthy Biogas Plant remains the only full scale anaerobic digester in the UK with the primary aim of producing renewable energy. The site was bought by Summerleaze in March 2005, after initially being owned and operated by Farmatic Biotech Energy UK Ltd. The plant is designed for a maximum throughput of 150,000 tpa of animal manure. Current throughput is around 100,000 tpa. The majority of this throughput is cattle manure from surrounding farms, other wastes accepted include pig manure, poultry litter, bakers waste, Ginsters food production waste and abattoir waste (Prior, Personal Communication, 2006). Around 30,000 tpa of food waste is currently accepted, but this figure is constantly changing depending on what wastes are available and what contracts are won. A process flow diagram (Strathclyde University website, accessed April 2006) is shown in Figure 262.

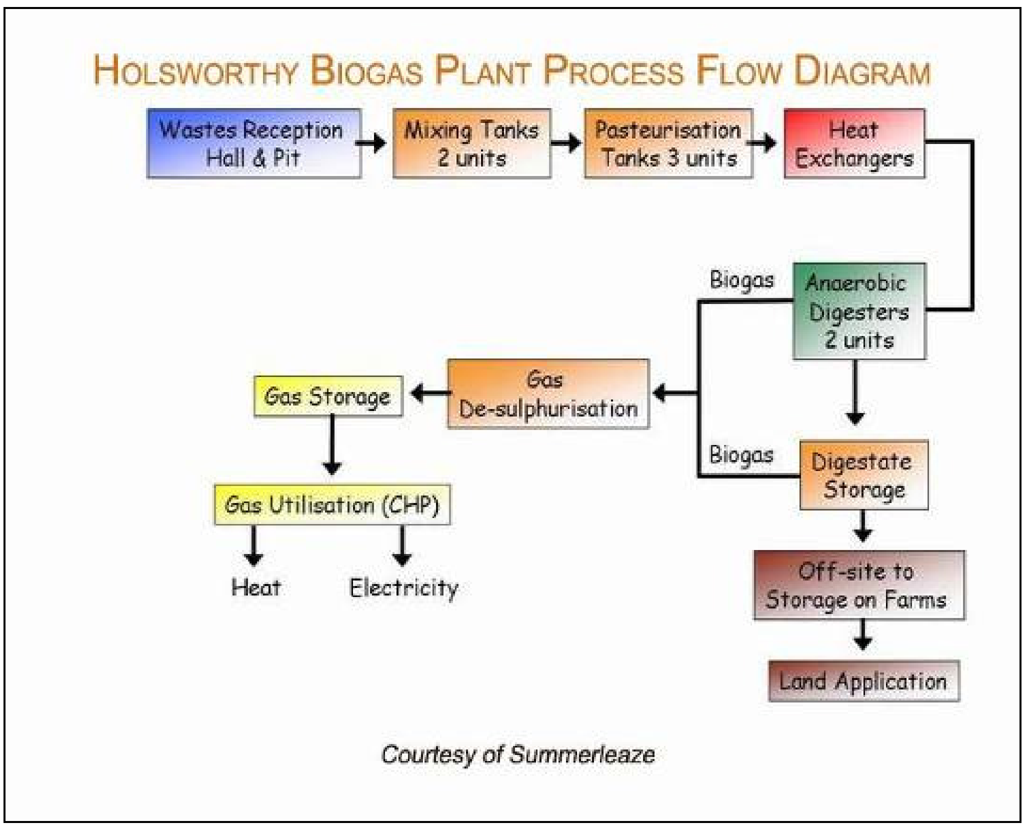

Figure 262 Process flow diagram of Holsworthy Biogas Plant

WASTES COLLECTION

All the manure is collected from farms within a 6 mile radius of the plant. Within a 10 mile radius, five times more manure is produced than is required. Summerleaze owns 3 specially designed tankers (Figure 263). These tankers collect cattle slurry from around 17 surrounding farms (five days a week).

Figure 263 Summerleaze tanker on lanes outside Holsworthy Biogas Plant

The tankers hold 20,000 litres (around 20 tonnes), and have specially designed pumps to 'suck up' and deposit the slurry, so that the filling or emptying of a tanker takes approximately two minutes. It is estimated that there around 20 tanker 'drops' per day, which equates to around 400 tonnes per day of manure. Other waste arrives through the week in different lorries and tankers. On-site, the tankers empty the slurry into a reception pit in an enclosed hall (Figure 264). The enclosed hall has a sealed entrance and exit, and a disinfectant wheel washer.

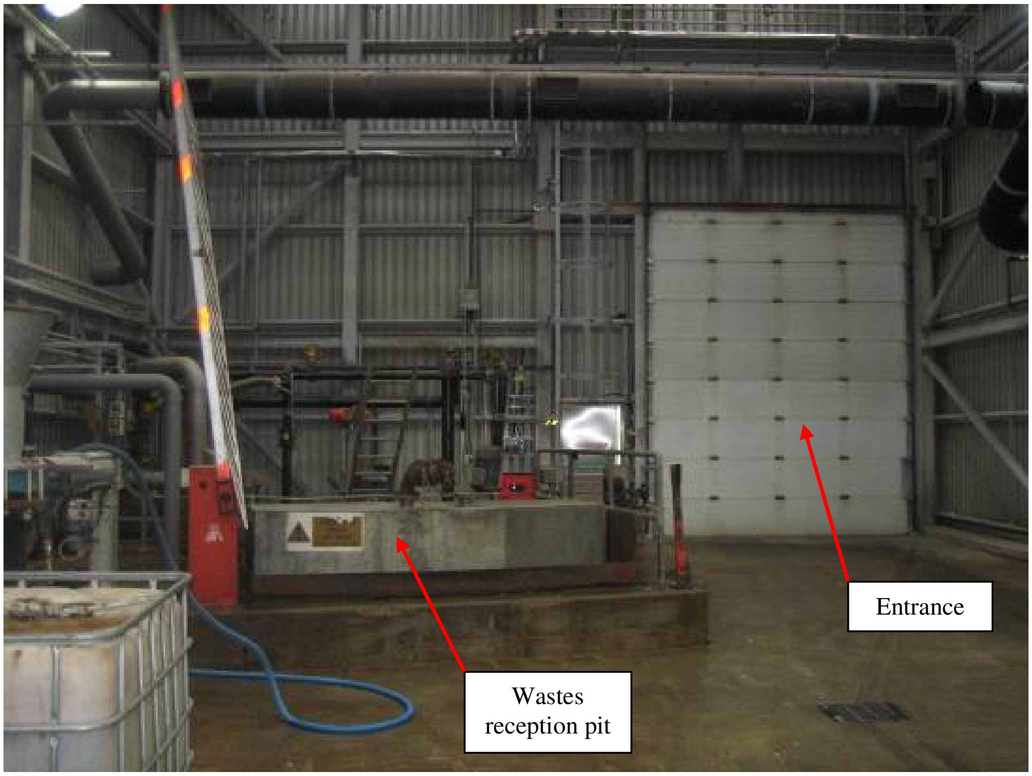

Figure 264 Wastes reception pit in enclosed wastes reception hall

PRE-TREATMENT

After the waste is pumped or tipped into the reception pit, everything in the pit is mixed together and pumped to one of two larger mixing tanks. There is no mechanical separation stage required here (as in all plants receiving BMW), as all the waste accepted is known to be free from non-organic contaminants. This is a major advantage of not accepting any municipal waste, and significantly reduces costs as reliable mechanical separation equipment can be very expensive. The reception pit is in an enclosed hall to reduce odour emissions, and waste air is oxidised prior to being re-released to the atmosphere. In the mixing tanks, it is sometimes necessary to add water to reach 12 – 15% TS, despite the high water content of manure. The mixing tank acts as a buffering tank, as if wastes were added straight to the digester as they arrived there would be great fluctuations in feeding volume, strength and content, which could lead to reactor instability and potential failure. The biological cultures in the digester thrive on stability, with the optimum culture evolving to meet the incoming waste. If feed strength and content is too unstable, no optimum culture can evolve. After the wastes are thoroughly mixed, the influent stream is passed through a macerator to reduce particle size to 12mm and then to a pasteurisation unit, which heats the waste to a minimum of 70^{o}C for one hour. This ensures compliance with the UK ABPR, by ensuring that all seeds and pathogens (including Foot and Mouth disease and TB) are killed off. This is a necessary step legally (UK ABPR), and also gives peace of mind to the farmers that they will not be introducing diseases or weeds to their land by accepting the digestate for land-spreading. There are three pasteurisation tanks to allow continuous operation. At any given hour, one tank is filling up, one tank pasteurising waste, and one tank emptying out. After pasteurisation the waste is pumped to the anaerobic digesters, via heat exchangers to recover heat energy from the 70^{o}C waste and cool it to 40^{o}C, in order to keep the reactor operating as close to 37^{o}C as possible. The heat required for pasteurisation is a by-product of electricity production from biogas and so does not represent any expenditure on energy (after the initial engineering and maintenance).

ANAEROBIC DIGESTION

The anaerobic digesters (of which there are two) have a volume of 4000 m^3 each (Figure 265). The tubes in the foreground in Figure 265 are heat exchangers, extracting the heat from the waste stream between pasteurisation and digestion.

Figure 265 Anaerobic digesters and heat exchangers

They operate as basic continuous stirred tank reactors (CSTR). Average hydraulic retention time is 28 days. This is a long compared to other digesters observed as part of this project. The reason for the longer retention time is that the aim of this operation is simply 'the production of biogas', and longer retention times will enable more biogas production. Other digesters visited have the primary aim of 'waste treatment', with energy production as a bonus, and therefore the throughput rate of the waste is of more importance than volume of biogas production. The digesters are single stage digesters, operating in the mesophilic temperature range at 37°C. Heat is provided by the heat of the influent. The reactor is heavily insulated to prevent heat loss. Mixing is provided by paddle-stirrers from the top of the reactors. Digestate is continuously removed at a similar rate to that at which the feed is added. Gas production and content, liquid levels, and gas pressure are monitored on-line, and monthly samples are taken for later lab analysis for pH, dry matter, nutrient concentrations pathogen content. These samples are not analysed on-site, but sent to a nearby private lab. Summerleaze plan to build a small lab on-site to do the necessary analysis (Prior, Personal Communication, 2006).

POST AD TREATMENTAND DIGESTATE

There is no further treatment of the digestate, only storage, before it is transported off-site and back to the farms by tanker. The digestate is stored on site (Figure 266) in a covered sealed container (although any biogas produced while in storage can be collected), until the tankers transport it back to the farms from which the manure came. Digestate is tested regularly the relevant regulatory criteria of pathogen reduction are met. Extra storage facilities to store the digestate are provided on the farms by the Holsworthy plant. EU and DEFRA grants at the start-up stage of the project made this possible. This extra storage means that the farmers can save on fertiliser costs (although they would have spread their manure anyway). They also have more flexibility as to when they apply the digestate to land, and can spread more digestate during the growing season, which reduces nitrate leaching by around 20%. The reduction in odour emissions when the farmers spread digestate (rather than manure) is estimated to be around 90%.

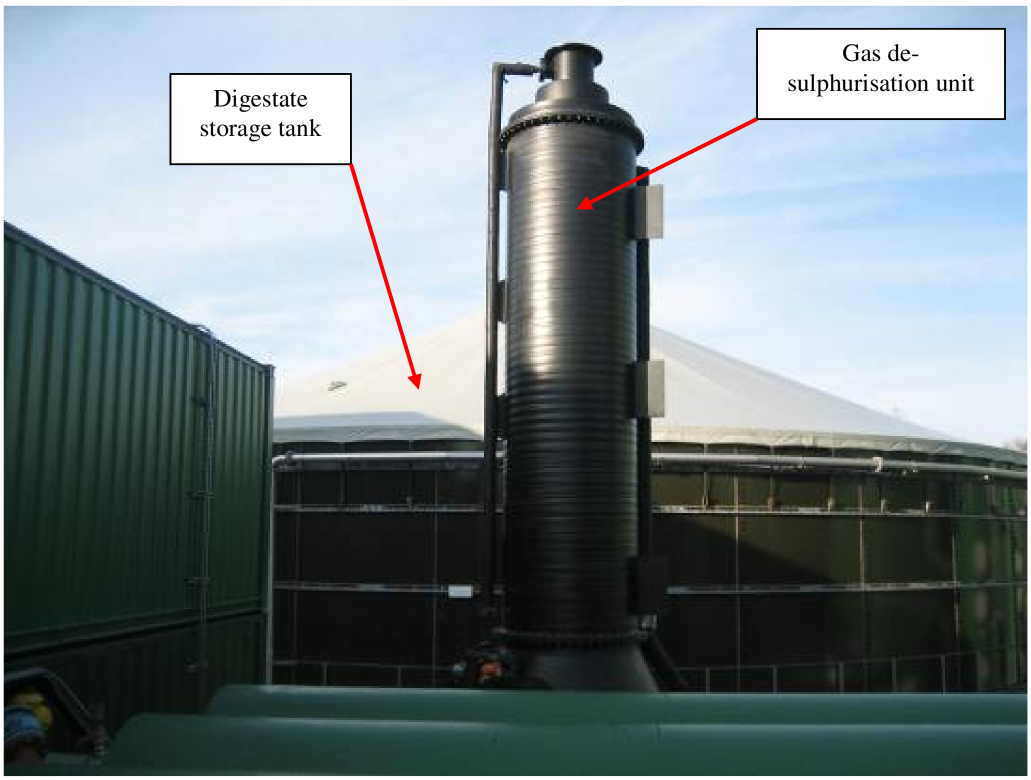

Figure 266 Digestate storage tank (with gas de-sulphurisation unit in the foreground)

The specially designed tankers described above transport the digestate back the farms for spreading on land. No money changes hands between the plant and the farmers for either the manure or the digestate, however, all slurry collection and digestate removal transport costs are paid by Summerleaze. The plant relies on the co-operation of the farmers to allow the digestate to be spread on their land, without which digestate disposal would be a major problem and the plant would not be viable. Although the digestate is a useful resource (more beneficial to soils than manure) the farmers already have an unlimited supply of manure that they can apply direct to their land at low cost, and therefore would not be willing to pay for the digestate.

BIOGAS UTILISATION AND ENERGY PRODUCTION

Total gas production is expected to be in the region of 4 million m^3/a, but this depends on the exact quantity and content of the waste received. If 100,000 tpa of wastes are received then the average biogas production would be 40 m^3/tonne. This figure is dependant on the exact quantity of high energy food waste compared to low energy manure. The biogas produced in the digesters is treated to remove hydrogen sulphide, a necessary step as hydrogen sulphide is highly corrosive. De-sulphurised biogas is stored in a sealed expandable unit within the top half of the digestate storage tank. Prior to utilisation in the gas engines a steady volume of the biogas is passed through a condensation unit to remove water vapour. The gas engines have a combined power capacity of 2.7 MW with a budgeted power production of 14,400 MWh/a. Of this approximately 90% (12,960 MWh/a) is exported as electricity. The plant covers its own electricity use and heat use. There is a considerable heat excess for which no use has yet been found. Plans are being made to make more use of the heat produced on-site (estimated to be in the region of 15,000 MWh/a). It was planned that the heat would be used for a district heating scheme, to heat public buildings, school, hospital, swimming pool *etc.* as well as domestic heating, but the infrastructure to put this scheme into place is prohibitively expensive at present. Other options being considered to utilise this heat energy include the production of wood pellets for commercial and domestic heating.

WATER AND WASTEWATER TREATMENT

No figures were available for the biogas plant's water consumption. No wastewater treatment was necessary as all of the digestate is transported back to the farms and spread on the land.

EXHAUST AIR TREATMENT

Waste air was previously treated by biofilter prior to being re-released to the atmosphere. This biofilter system has not always worked very well and the plant received several complaints from local residents about odour in previous summers. The biofilter for odour control was recently replaced with a thermal oxidation odour control system. The new set-up is judged to be more reliable and better suited to the task (Prior, Personal Communication, 2006).

VISUAL AND LOCAL IMPACT

The plant is situated in an agricultural area, approximately 2 km outside the town of Holsworthy. The site is invisible from the public road, as it is in a natural depression in the land (Figure 267).

As mentioned above, the plant has received complaints about odour in the past, but appears to have solved or at least minimised these problems with a series of odour control measures. Initially the original owners had to deal with complaints that the tanker traffic was blocking up the small rural lanes around the plant and the farms. These roads are very quiet anyway.

Figure 267 Holsworthy Biogas Plant from the road

COSTS AND ECONOMICS

Capital cost was between £7.7 and £8.2 million (in 1998), although significant work has been done on improving and updating the plant both by the previous owners and by Summerleaze. Capital grants were obtained for 50% of the plants cost. Contributors were the EU, DEFRA and the local authority. It was also necessary to have local farmers on board, without whose co-operation the biogas plant would not be possible. The project was difficult to finance, with UK banks being uninterested. A 15 year loan was eventually obtained from a German bank.

Operating expenses were not disclosed by Summerleaze, but were estimated at £450,000/a (Strathclyde University website, accessed April 2006). This corresponds to £4.50/tonne, based on 100,000 tpa, or £3.00/tonne based on 150,000 tpa. Expected income from electricity sales was stated to be £800,000/a (Strathclyde University website, accessed April 2006), but based exporting 90% of a total electricity production of 14.4 million kWh/a at today's prices (£90/MWh, Prior, Personal Communication, 2006) the income should be more in the region of £1.2 million. Each year the plant receives gate fees for any commercial or industrial organic wastes it accepts. This represents a significant revenue, and one that the plant operators would be looking to expand. More food/abattoir waste not only means more gate fees, but also more biogas production. Benefits in terms of biogas production potential may enable the plant owners to pay for the transport of 'high energy wastes' to the plant and still be economic. Any new waste being added could also potentially improve the nutrient balance entering the reactors. Thorough testing would be carried out before new feedstocks were introduced on a full scale.

De-watering the digestate prior to transporting back to the farms could significantly reduce transport costs, although it is not necessary, as both the solid and liquid fractions will go to the farmers anyway. De-watering could be either mechanical or biological (biodrying). Digestate de-watering equipment could prove expensive, and would take up more space (especially biodrying). De-watering could also cause problems to the current tanker fleet (and probable the farmer's muckspreading equipment) which are designed to cope with slurry/digestate.

Plant economics (of all AD and composting plants) would be greatly improved if a sustainable market could be established for the digestate. Any digestate sale strategy will be limited by the relatively large cost of transporting the digestate to the buyer. The main input to the plant, cow manure, is low in solids content, relatively low in energy, and requires the transport to and from the site at the expense of the owners. Therefore, from this point of view, the plant is run as a co-operative with local farmers. Securing more commercial and industrial organic waste contracts to supplement the manure must be a major goal for the owners. To increase the gate fees received but also to provide a more balanced reactor input and to increase the production of biogas. Based on 14.4 million kWh of electricity being produced, and 90% of this being available for export (10% used on-site) the annual income from electricity (in April 2006) would be:

14,400,000 kWh x 90% = 12,960,000kWh
12,960,000 kWh x 8.95p/kWh = **£1,159,920.**

CHALLENGES AND DISCUSSION

As this is the first site of its kind in the UK, there have been many 'teething problems' that have had to be overcome in order to fully optimise the process. This is to be expected, as is the fact that new owners will want to fine-tune the process and upgrade it. It seems that the main problem for the previous owners was that they did not receive the waste that the plant had been designed to receive, therefore they did not produce enough energy to be economically viable. Some specific problems and solutions are noted below:

- The enclosed loading bay around the reception pit was corroded and needed galvanising because of the corrosive atmosphere.
- Some pumping problems have been experienced pumping the waste from the bottom of the reception pit to the mixing tanks, due to the depth of the reception tank and the (potentially, not always) high solids concentration of the waste. For this reason, the current pump, which is on ground level (and pumps by sucking waste upwards), is being replaced by a submerged pump (which will 'push' waste upwards). It is anticipated that this pumping solution will be more reliable.
- It is unclear how sand/grit/fine inerts are removed from the waste stream. If these fine inerts are not removed from the digester, or as part of the pre-treatment, then it is possible that they will accumulate in the digesters. This sedimentation will decrease active digestion areas, and could eventually cause more serious problems such as blockages or downtime.
- In the past, the site has experienced significant odour problems. On summer days, with certain wind directions, complaints would be received from Holsworthy town (1.5 miles away). The new owners have taken steps to reduce the emission of odours. These steps have reportedly met with considerable success, and are described briefly below.

- When the site was taken over by Summerleaze, the mixing tanks had canvas roofs. These roofs were not airtight and as such odour was a major problem, especially in the summer months. One of these roofs has been replaced by an airtight plastic roof, which has solved the problem. The remaining canvas mixing tank roof is due to be replaced soon, after which there will be no further odour emissions from the mixing tanks.
- The biofilter for odour control was replaced with a thermal oxidation odour control system. The new set-up is judged to be more reliable and better suited to the task.

Environmentally, the combined preparation, pasteurisation, digestion and storage of the treated material is considered as 'Best Practice' and is an environmentally and socially responsible form of waste management. Not only is renewable energy produced, but the digestate the farmers receive is more stable, with a higher fertiliser and compost value than the manure they donated. Advantages of the biogas plant, aside from the organic wastes treatment and renewable energy production are;

- Employment creation. The biogas plant employs 15 people in a rural area. Importantly, the jobs created are at a variety of levels, including approximately 5 managers/engineers, 5 on-site technicians and 5 drivers.
- Digestate can reduce pollution of water courses by reducing run-off (when compared with manure). Run-off is the liquid slurry which is sprayed onto farmland, but then drains into surface water. It can carry sediments and pollutants into the receiving waters.
- AD can lessen the risks of the spread of disease and contamination by destroying bacteria, viruses and weed seeds.
- Well-managed AD can decrease methane (CH_4) release more effectively than conventional waste management, because the methane is converted into carbon dioxide (CO_2), a less potent greenhouse gas.

As oil prices rise, significant potential exists to roll out similar manure-based anaerobic digestion systems across the UK with the main aim of renewable energy production. Fundamental to the success of the project, and other similar future projects (amongst a multitude of other technical and planning factors) are;

- The co-operation of local farmers, without whom there would be no manure and no free disposal of digestate.
- The signing of long term contracts for other high energy organic wastes, without which biogas production would be beneath levels that ensure profitable operation. Gate fees from these organic industrial wastes also impact positively on plant economics.

5.3.2 Linkoping (Svensk Biogas) Biogas Plant

INTRODUCTION

The biogas plant at Aby Vastergard in Linkoping was originally owned by the Linkoping Biogas AP Company, which was a joint venture between a wastewater treatment company and two agricultural partners, Swedish Meats and LRF (Swedish Farmers Association). Two other companies have been involved, Scan-Farmek (one of the biggest food producers in Sweden) and Konvex (which runs several recycling plants for slaughterhouse wastes). The plant is presently owned by Tekniska Verken i Linkoping AB (the Public Utility owned by the municipality of Linkoping responsible for wastes treatment, water treatment and energy supply). The plant was planned and built by Svensk Biogas (www.svenskbiogas.se) which is a subsidiary of Tekniska Verken i Linkoping AB. The plant is operated by Svensk Biogas.

Linkoping is a University city (in Ostergotland county) with around 140,000 inhabitants in the extended area. It is a good example of a sustainable city. Around 90% of the apartment buildings have access to a district heating network, and work going on continuously towards the 100% figure. There are 3 CHP plants in Linkoping, one with a capacity of 150 MWh, and another with a capacity of 19 MWh electricity and 83 MWh heat. The 150 MWh capacity state of the art MSW (combustible fraction) incinerator co-fires on wood, oil and gas. Oil and gas are planned to be phased out (oil first) by increasing the percentage of wood added. Other waste-based fuels such as unrecyclable plastics and waste tyres are also burnt. Wood (mainly wood waste, bark and sawdust, but also forestry/coppicing projects dedicated to power production) is a major fuel source in the smaller CHP plants, and the use of fossil fuels has decreased dramatically in the past 10 years.

The Linkoping anaerobic digester, started up in 1998, is a primarily a biogas plant, as opposed to wastes treatment facility (although the treatment of organic wastes that would otherwise be landfilled represents an environmental gain in itself). Biogas is upgraded and used as a vehicle fuel to fuel the city's bus and municipal refuse fleets. The plant treats 50,000 tpa of the wastes indicated in Table 60. Originally the plant treated mostly manure (~51% in 1998), but over time more and more higher energy wastes were added as they became available, and by 2001 low risk (Category 3) animal wastes represented 72% of the incoming waste (Energy Cities website [b], accessed June 2006). By 2006 the manure content in the incoming waste stream was reduced to 5%, with 70% being made up from Category 3 slaughterhouse wastes and the balance (25%) higher energy wastes such as dairy wastes, restaurant wastes and other food and animal processing wastes. At the time of the site visit, a load of waste hamburgers had just arrived for digestion (Figure 268).

Table 60 Wastes treated at Linkoping Biogas Plant

Waste	Throughput in 2005 (tpa)	Percentage of Total Throughput (%)
Slaughterhouse waste (Category 3)	~36,000	~72
Dairy waste/restaurant waste	~11,500	~23
Manure	~2500	5

Figure 268 Component of wastes stream at Linkoping Biogas Plant in May 2006

The plant manager has experimented with different ratios of the available wastes and found the optimum mix to be the present mix in terms of both biogas production and process stability. It was mentioned during the site visit that the site did not operate well with no manure input, which is why a 5% proportion remains in the incoming feed despite its lower biogas potential.

PLANT DESCRIPTION

A process flow diagram is available in Figure 269. The plant will be described in more detail below.

On arrival at the site the waste is emptied into a reception pit in a covered reception hall (see the building on the left in Figure 270), before being shredded (maximum particle size not revealed) and being pumped into a mixing/homogenisation tank (Figure 270). The mixing/homogenisation tank is the tank in the foreground, of which all but the top metre is underground.

The large tank immediately to the right of the reception hall is a heating tank, where heat exchangers heat the incoming homogenised waste to around 56^{o}C, prior to hygienisation. Behind the heating tank, there is a buffer/storage tank, where heat exchangers cool the hygienised waste to the desired input temperature of around 35 – 40^{o}C. From the right the two larger tanks are the anaerobic digesters. The red brick building on the right contains the biofilter for exhaust gas treatment.

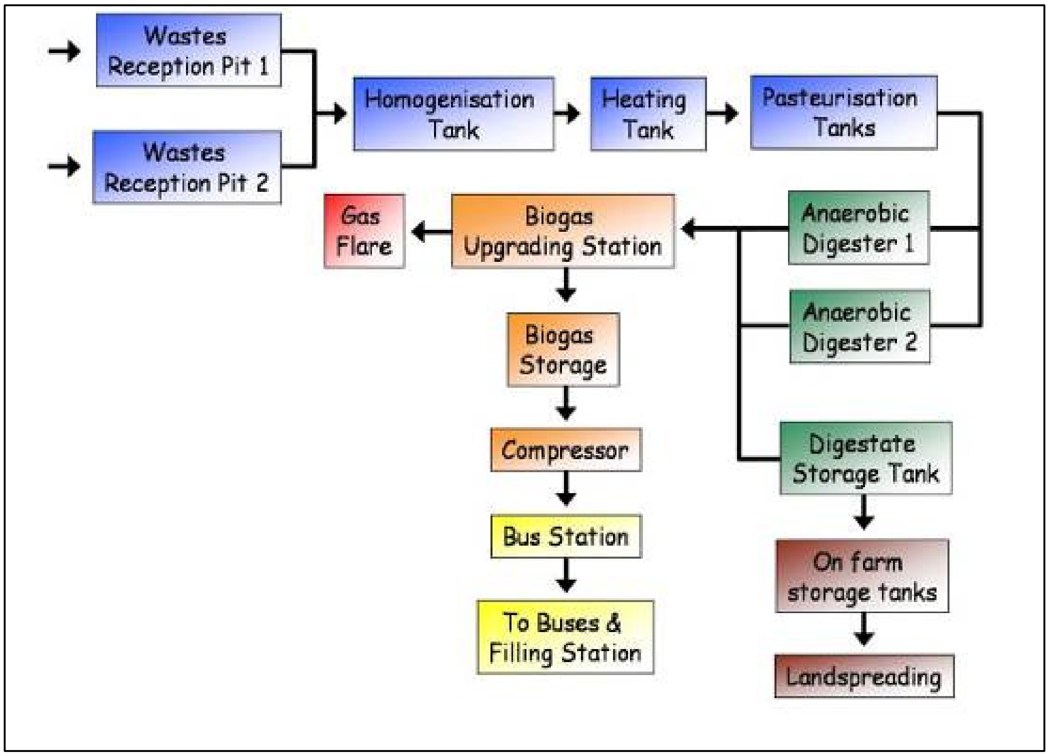

Figure 269 Linkoping Biogas Plant process flow diagram

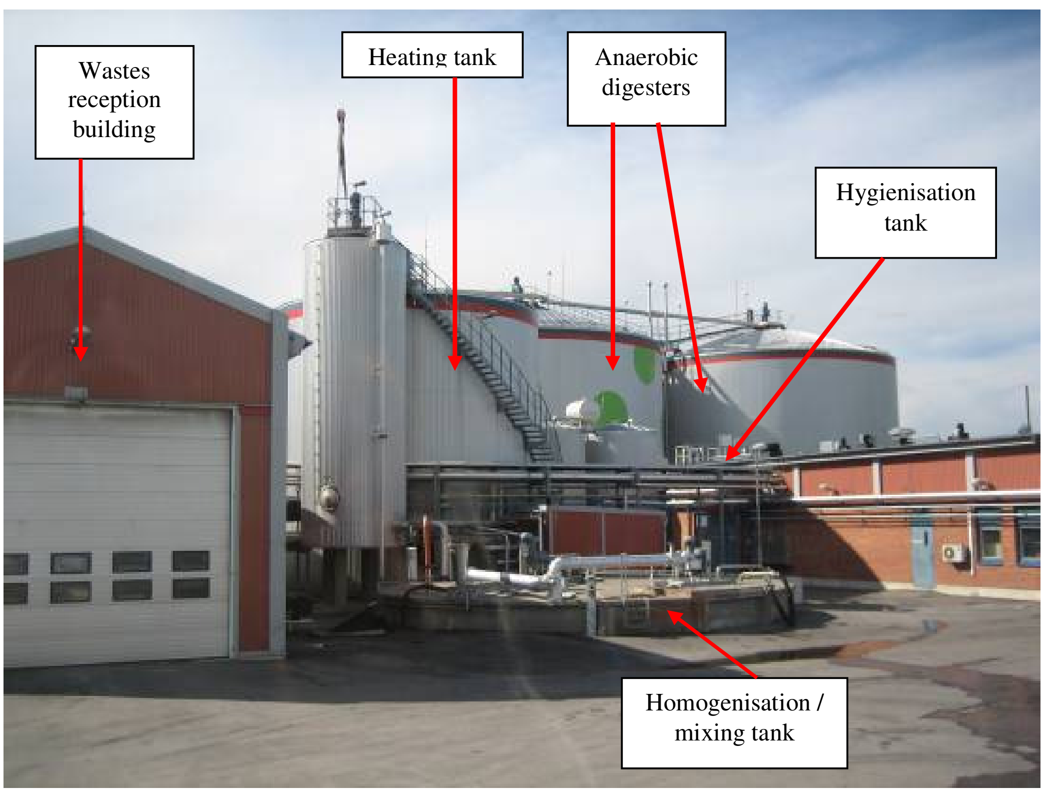

Figure 270 Linkoping Biogas Plant

After being homogenised and raised to the preferred total solids content (% TS not revealed) by water addition, the slurried wastes are pasteurised to 70°C for 1 hour. There are two pasteurisation tanks, to facilitate continuous operation. The homogenised pasteurised slurry is cooled to 35 - 40°C in the buffer tank (Figure 270) and pumped into the digesters (of which there are two). The digesters, each with a volume of 3700 m^3 operate in parallel. The digesters can be observed in Figure 270. The digesters are operated in the CSTR mode, with mixing provided by mechanical stirring. Operational temperature is kept as close as possible to 35°C by the temperature of the incoming wastes stream and heating from the local district heating grid. The reactor is fed continuously. The pH range was not revealed. The natural buffering provided by the ammonium bicarbonate (from the protein rich feed) is sufficient to keep the pH within the required range. The retention time is around 30 days. The retention time is long due to the goal of the process being to extract as much methane as possible, rather than have as high a wastes throughput as possible.

EXHAUST GAS TREATMENT

Exhaust gases are treated by biofilter to meet the local legislation before being released to atmosphere.

WATER AND WASTEWATER TREATMENT

Exact water requirements were not revealed but are estimated to be low, due to the low TS percentage in the incoming waste. No wastewater treatment plant is necessary as the digestate is applied to farmland.

DIGESTATE

Digestate is pumped straight to a storage tank (Figure 271), where it is stored until it is transferred by tanker (at the expense of the Company) to local farms. The digestate is not de-watered or further treated. Various de-watering and post-AD composting options have been considered, but have been considered an unnecessary expense until now. Also, the farmers like the slurried nature of the digestate for its ease of application and the quick NPK release and plant uptake it provides. The downside of no de-watering is of course the extra transport expense, borne by the company. The digestate meets the Swedish Cereal Association Quality Standards. The digestate quality is analysed periodically, including for pathogen reduction, in order to meet the quality standards, which it consistently does. Local farmers have had storage tanks installed on their farms so that they can spread the digestate at the most beneficial times. Digestate is also analysed regularly for NPK content. Farmers pay the company the equivalent current market value for NPK from mineral fertilisers. In this way, the farmers get the same fertiliser value for the same expenditure, get extra organic matter returned to their soil which improves the quality, and have the advantage of doing so 'naturally'. The biogas company, for an upfront investment in storage tanks, gets to dispose of the digestate reliably and cheaply, with only transport costs to be paid. The trucks transporting digestate to the farms run on upgraded biogas produced at the plant.

Because the digestate storage tank is not covered, methane emissions are theoretically possible, especially until the waste cools down. This may represent an unnecessary loss of methane that could be avoided were a cover to the storage tank to be added. This cover would also help minimise odour emission, although odour was not detected at the time of the visit despite the storage tank being half full.

Figure 271 Digestate storage tank

Figure 272 Inside digestate storage tank at Linkoping

BIOGAS PRODUCTION AND UTILISATION

When the plant started up, and mainly agricultural wastes were treated, a biogas production of approximately 3 million m^3/a was expected and observed. In 2005 this had risen to 4.7 million m^3. In 2006, if the current rate of production continues (which is expected) the approximate biogas production will be 6.2 million m^3/a (Personal Communication, Svensk Biogas, May 2006). The extra biogas yields have mainly been due to the different feedstock components and ratios thereof, rather than any 'tinkering' with the digestion or pre-treatment system. The biogas produced has a mean methane content of 65%, although this is variable depending on the exact ratio of incoming feed.

The biogas is continuously upgraded, and at times of high production when the upgrading capacity is exceeded, biogas is stored in a biogas storage bell. As with most plants, there is a biogas flare as a safety measure in case of emergencies. As in Västerås and Linkoping the biogas is upgraded by bubbling mixing flows of biogas and water under pressure (10 bar), resulting in the carbon dioxide dissolving into the water flow. Again, biogas is upgraded to the Swedish National Biogas Quality Standard of 97% ± 1%. Biogas from the nearby sewage sludge treatment works (<1 km away) is also piped to the Linkoping site for upgrading. As with other Swedish sewage sludge digesters, all biogas produced is exportable due to the fact that the sewage sludge digesters are heated using heat from district heating schemes.

After upgrading, the biogas is compressed to 4 bar, to enable it to be transferred by underground gas grid to the bus station at Grumpekulla, less than 1km away. Five public biogas filling stations are also connected to the grid, and there are at least 7 other biogas filling stations in the Linkoping region, all of which are run by Svensk Biogas. At the bus station, biogas is compressed to 250 bar and stored. Buses are filled up automatically at night, and 45 buses can be filled up simultaneously, although there are also quick filling stations available. As of 2006, the entire bus fleet (at least 64 buses), the entire municipal refuse fleet, and at least 700 other vehicles are fuelled by the biogas from the plant. All new taxis given licences in the city must run on a renewable fuel (either bio-ethanol or biogas), and other municipal (and Linkoping Biogas AP Company) vehicles are replaced with biogas vehicles when the old vehicles reach the end of their lifespan. Some biogas is compressed to 230 bars and stored in moveable containers, allowing the replenishing of public biogas filling stations in the area that are not connected to the localised biogas grid. Gas cylinders are also sent nightly to the biogas train (Figure 273) which runs between Linkoping and Vastervik daily.

The biogas train project is described in more detail in Section 2.6.1.8.2. It is estimated that biogas currently provides around 6% of the Linkoping area's total fuel requirements.

Figure 273 Biogas train, running between Linkoping and Vastervik

VISUAL AND LOCAL IMPACT

The plant was situated in a semi-industrial area beside a sewage treatment works. Other larger and more visually obtrusive industries were around, so landscaping the site was not necessary. Areas between the industrial sites had been devoted to willow plantations for the local biomass power plant (so that the plantations could be easily irrigated with sewage sludge/or digestate to enhance growth rates. Landscaping was reasonable despite the flat landscape, and a grass verge had been built so the industrial area could not be observed from the nearby roads. Very little odour was detectable at the plant, although conditions were windy. Considering the unpleasant nature of the wastes, odour was contained well. Covering the digestate storage tank and treating exhaust gases (particularly from the wastes reception hall) by thermal oxidation or another more sophisticated odour control system are both measures that would help contain odour further, should it be deemed necessary. Figure 274 shows a photograph of the plant from the front gates.

Figure 274 Linkoping Biogas Plant

COSTS AND ECONOMICS

The plant was started up around 1998. Initially €8.7 million was invested, which included a Government subsidy of 11.5% (€1.7 m) (Energy Cities website [b], accessed June 2006). Approximately 25% of the turnover comes from gate fees for the waste received.

The plant is cheaper than most anaerobic wastes treatment plants of a similar scale as the mechanical separation and pre-treatment requirements are greatly reduced. The inclusion of a biogas upgrading plant represents a considerable investment, and was estimated to represent around 1/3 of the total capital cost of the plant (Unden, Personal Communication, 2006). In the UK, if the biogas was to be used for electricity and heat, then the capital cost of this upgrading plant could be replaced with a considerably cheaper CHP gas engine. The biogas upgrading is estimated to cost in the region of €0.40/m^3 of upgraded biogas (at 97%). This represents total operational costs from biogas from the reactor to upgraded biogas in the grid. Capital and operational costs are lowered by the fact that no de-watering, wastewater treatment or post AD treatment is required. Plant economics are boosted greatly by the fact that all digestate is returned to the land, and an income is received for this (albeit minus transport costs).

No more figures were available for analysis, but it was stated that the plant was profitable, but not massively so (Unden, Personal Communication, 2006). Despite this statement, Svensk Biogas said that many more similar biogas plants were planned, as transport fuel prices are rising dramatically, and they anticipate the trend will continue.

DISCUSSION AND CONCLUSIONS

After the site visit a representative of Tekniska Verken was asked if the biogas plant had considered accepting the source separated kitchen waste. The reply was that the plant had not been designed with municipal wastes in mind, and that the investment costs for pre-treatment and the risk of contaminating the digestate were higher than the extra income that accepting the source separated kitchen wastes would bring. Tekniska Verken concluded that it was easier and less risky not to accept biodegradable municipal wastes.

The Swedish Government plans to treat all of the country's organic industrial waste by anaerobic digestion by 2020. The plant is one of seven similar plants in Sweden, co-digesting slaughterhouse waste, organic wastes from the food industry and manure (Nordberg and Edstrom, 2002). One of these plants also treats restaurant waste. The biogas from these plants is all upgraded and used for transport fuel. The digestate from all of these plants meets all local and European standards and is returned to local farmland.

A recurring point often re-iterated while visiting the Swedish anaerobic digesters was one that has been made in other countries employing similar systems (for example Holsworthy in the UK). That is that it is vitally important to have local farmers involved in the project from the start. Without the support of the local farmers, biogas plants are simply not viable as there is no economic disposal route for the digestate. Of course, the willingness of the farmers to participate depends on the quality of the digestate produced. Other potential disposal (or market) routes for digestate of varying qualities are discussed in Section 2.6.2.3.

The fact that the incoming feedstock for the plant is constantly changing (from 72% manure in 1998 to 5% manure in 2006) demonstrates the flexibility and robustness of the pre-treatment and digestion system to successfully digest different waste streams. This could also be important if one waste stream was to become unavailable, as may happen if a company goes out of business, moves to another area or sub-contracts its organic wastes to another company.

With regards to the original driver, to improve the air quality in the city centre, the conversion of the bus fleet from diesel to biogas has led to 'big air quality improvements' (Unden, Personal Communication, June 2006). Data is presumably available to back this statement up, but it has not been verified by the authors. Biogas buses are also quieter than their diesel predecessors, which is an important factor for a city centre.

The Linkoping biogas plant represents an economically viable and environmentally beneficial model for localised renewable energy generation. The plant also successfully treats slaughterhouse and manure wastes, resulting in a digestate that can be safely (and beneficially) returned to the farms from whence the manure came.

OTHER SVENSK BIOGAS PROJECTS

Svensk Biogas are currently building a new anaerobic digester at Norrkoping. The digester will treat the by-products from a bio-ethanol plant. The AD plant will cost a total of €4 million, and will produce approximately 3 million m^3 of biogas per year.

Svensk Biogas is also developing a 'green gas' concept, where different agricultural products will be used for biogas production in more rural, agricultural areas. The development and implementation of this concept will increase the raw material base significantly. Agricultural wastes such as manure will be utilised in conjunction with specially grown high-energy digestible energy crops. The implementation of this concept in more rural areas will increase the local availability of biogas by enabling more filling stations o be built in rural areas. Farmers will also benefit in terms of income diversification and soil improvements.

5.3.3 Lintrup (LinkoGas) Biogas Plant

INTRODUCTION

The LinkoGas Biogas Plant (near Lintrup, Denmark) treats approximately 200,000 tpa of organic wastes. LinkoGas A.m.b.a is an independent co-operative society set up by 60 local farmers, who supply the slurry which makes up the majority of the waste entering the plant. The main aim of LinkoGas A.m.b.a is to build and operate a manure-based centralised co-digestion plant. Its primary aim (or driver) was assisting the co-operative members (farmers) to meet their legal demands with regards to slurry storage and handling. The reduction of the odour nuisance from slurry application to land was also a main driver. The plant was built in 1989 – 1990, and rebuilt in 1999 when the plant was converted from mesophilic to thermophilic operation. The rebuilding also incorporated a post-digestion phase. The plant receives a total of approximately 200,000 tpa of biowastes, making it one of the largest biogas plants in the world. The incoming biowaste consists mainly of manure (approximately 150,000 tpa), which contains 62% cattle manure and 38% pig slurry. The manure is produced on the surrounding farms, which are all within a 7 km radius of the plant. The plant also receives approximately 50,000 tpa of 'alternative biomass', for which it receives a gate fee. The 'alternative biomass' includes sewage sludge, glycerol from biodiesel production, slaughterhouse waste and hospital food waste. The hospital food waste has been treated mechanically to remove non-organic contaminants, and pressure sterilised before it arrives on site (so no extra pre-treatment is necessary). No exact figures for the composition and quantities of the incoming waste were provided. The plant was built by Krüger and Bioscan.

LinkoGas has 8 employees in total. Four of these are tanker drivers. The manager and assistant manager operate more like foremen, with a 'hands on' approach, and there are two maintenance engineers. Staff work Monday to Friday. The plant is run automatically under normal circumstances, and should problems arise 'after hours' the manager or assistant manager are paged and respond immediately. They take it in turns, one week on, one week off, to be on-call after hours.

PLANT DESCRIPTION

A (very) simplified process flow diagram is shown in Figure 275.

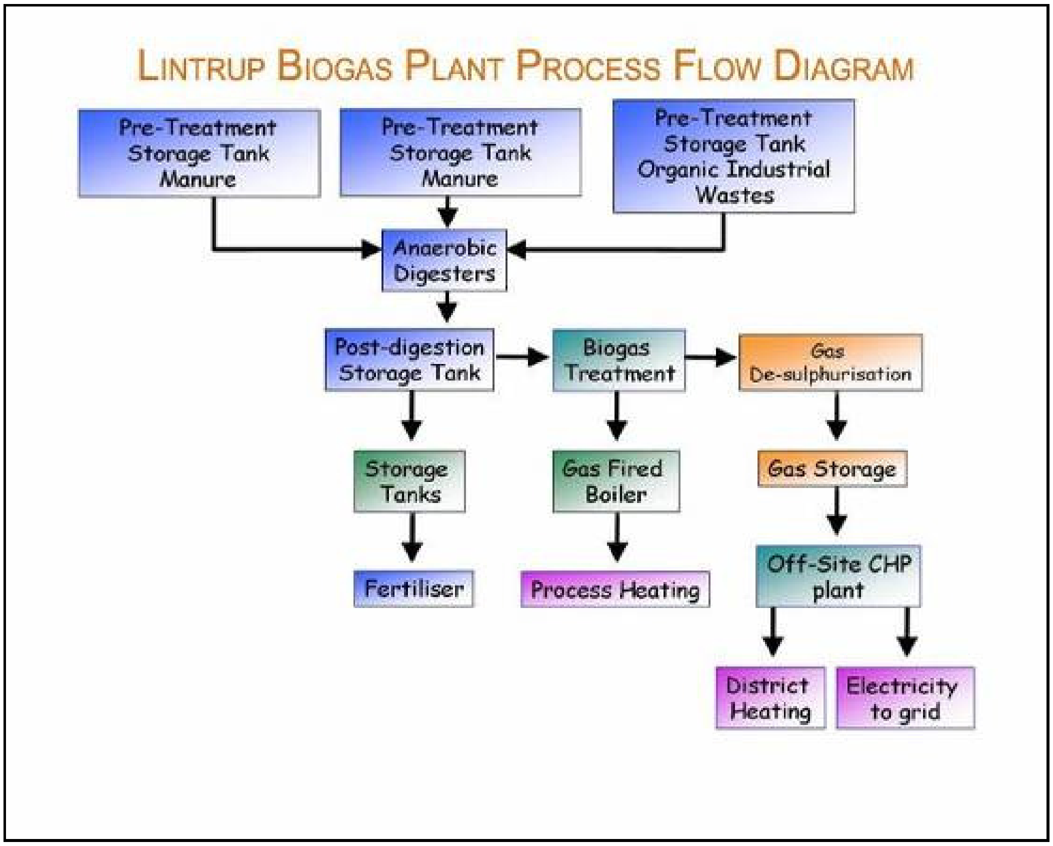

Figure 275 Lintrup Biogas Plant process flow diagram

PRE-TREATMENT DESCRIPTION

After being weighed on the weighbridge, the waste is emptied from the collection vehicles into one of three wastes reception pits. Each wastes reception pit has a volume of 800m^3. Two of these pits receive manure, and one receives industrial organic wastes. This separate storage of incoming wastes means that the exact characteristics of waste passed to the digesters can be manipulated in order to promote process stability.

The wastes reception hall is the building on the left. The offices and workshops are in the low building on the right, behind the biogas flare. Two of the three digesters can be observed between the two buildings. Figure 277 shows the inside of the wastes reception hall, with a vehicle offloading industrial organic wastes into one of the wastes reception tanks.

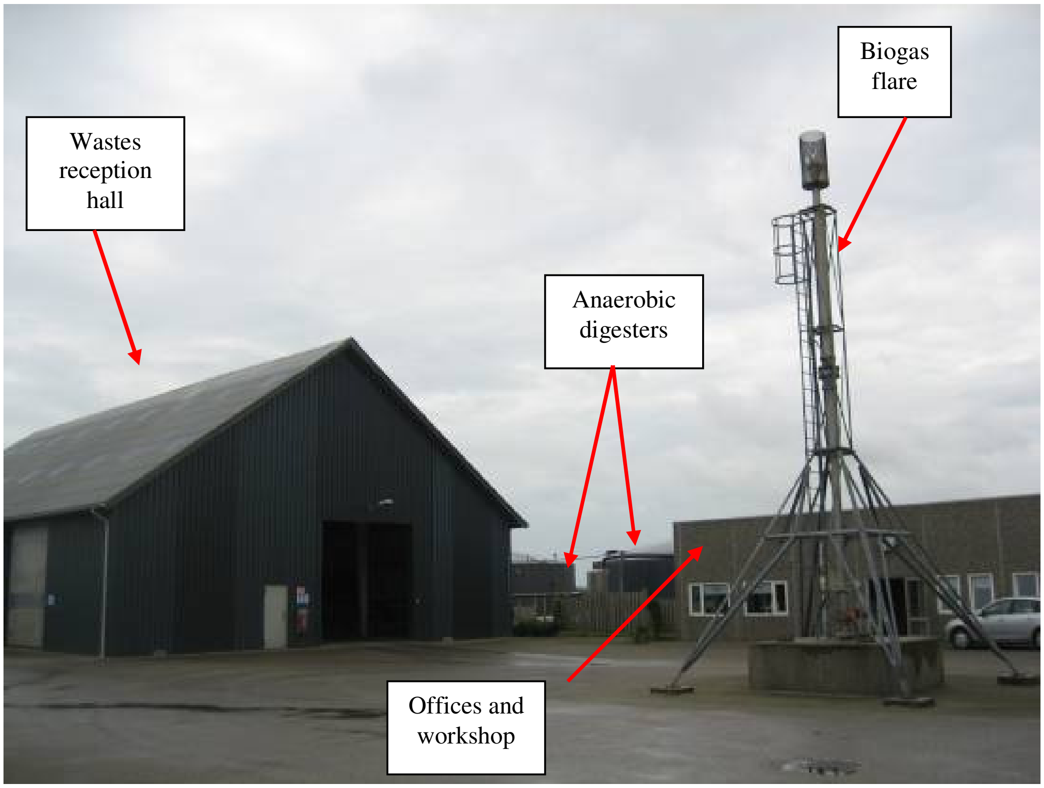

Figure 276 Wastes reception hall

Figure 277 Inside wastes reception hall

Figure 278 shows one of the wastes reception tanks from outside. As can be seen the bulk of the tank is underground, which minimises visual impact. This is the same tank into which the tanker is emptying waste (Figure 277).

Figure 278 Wastes reception tank

ANAEROBIC DIGESTION

The digesters are continuously fed, 24/7, and the storage tanks are large enough to cover bank holiday weekends with no waste deliveries. There are three digesters, each with a volume of 2400 m^3. The digesters operate in the thermophilic temperature range at 55°C. Two of the digesters are mixed by paddles attached to a vertical shaft. The third is mixed by a central vertical tube containing a pump, which sucks liquid in from the top and pumps it out the bottom, causing a circulation flow pattern from the bottom, around the edges and to the top of the digester. Experience and results have shown this mixing method to be far superior that the other type of mixing (Christiansen, Personal Communication, 2006). Also, the digesters are short and wide, which was considered 'state of the art' at the time of construction. Nowadays digesters tend to be taller and narrower, to allow for better mixing, process dynamics and efficiency. Digestion is wet, with a % TS content of 7 - 8% in the reactor and average retention time is 13 days. The minimum retention time can be guaranteed at 12 days, which at the process temperature of 53°C provides a pathogen reduction equivalent to pasteurisation (LinkoGas Promotional Information). Process heat is supplied by a biogas and oil fired boiler on site. The digestate also passes through heat exchangers after digestion, to maximise the heat transfer between outgoing and incoming waste, and keep to a minimum the volumes of biogas/oil that need to be used. Temperature, gas production, gas pressure and liquid levels are currently measured on-line. A methane content monitor will be coming on-line soon. Liquid samples are taken once per week for pH and VFA analysis. Liquid samples are taken more regularly if the on-line data is showing any irregularities. The plant manager has (and is in the process of) setting up research projects in conjunction with Danish universities. As well as supporting research that will hopefully lead to scientific advancement, and improvements in process efficiency. These projects will serve to provide the plant with continuous on- and off-line data that will provide greater insight into the digestion processes and dynamics. As described below the more data that is available, the more the process can be optimised, and LinkoGas fully realise the potential (Christiansen, Personal Communication, 2006).

Figure 279 Anaerobic digester at Lintrup

The digester operates steadily in a pH range of 8.0 – 8.3, but is almost always around 8.2. No chemical additions are required to maintain this. The incoming waste is received based on contracts with industries, so it is received regularly, and the feeding pattern to the digester is kept as constant as possible.

Sedimentation of sand or other small inerts has not yet been a problem in the digesters, although it is expected that the bottom of the reactor will contain an ever increasing layer of settled inerts. Despite taking up space in the digester, and therefore minimising the active volume and lowering throughput capacity, these inerts have not yet caused any operational problems. Once they reach levels that do cause problems however, there is no mechanism in place to remove them. As reactors have been operating since 1990 it can be said that sedimentation does not represent a major problem (although perhaps at some point in the digesters working life it will).

POST AD TREATMENT

The post-digestion phase at Lintrup is in effect another anaerobic digester, operating in series with the first three digesters, which all feed into it. It doubles as a storage tank, but as temperature is kept at 49°C, digestion is still occurring and biogas is produced and harvested. LinkoGas have plans to convert this post-digestion storage tank to another thermophilic digester. Lab-scale tests done on behalf of LinkoGas by a Danish University show that a 25% increase in biogas production will be possible by making this change.

FINAL SOLID PRODUCTS

The digestate is stored in underground storage tanks on site (Figure 280), before being transported by tanker back to one of 128 de-centralised storage tanks on the farms of the partners from which the slurry originated. The de-centralised storage tanks are located in the fields on which the digestate will be spread. The slurry suppliers receive the amount of digestate corresponding to the nutrient consumption of their crops. The surplus, around 15% of the digestate, is sold to 20 crop farms in the area (LinkoGas Promotional Information).

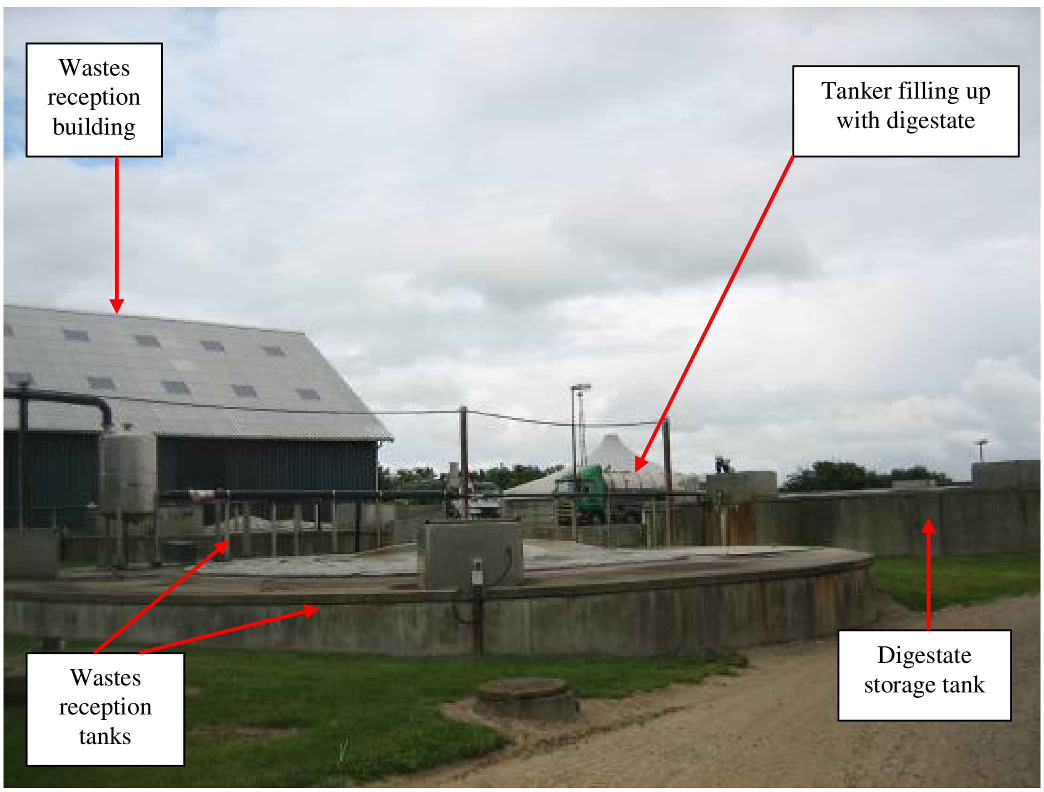

Figure 280 Digestate storage tanks

In Figure 280 a tanker can be observed collecting the digestate for delivery to the farms. The quality of the digestate is extensively tested once every three months by independent laboratories. Heavy metal levels, pathogen levels and N:P:K levels are tested and documented as part of a quality assurance scheme.

A Danish University has recently completed a study on whether or not it would be beneficial to de-water the digestate before it was transported back to the farms. The conclusions were not discussed other than the fact that de-watering was found to be unnecessary at present.

The farms would be the final destination for both the solid and liquid fractions anyway, so separating them would be of little benefit in this case.

WATER USE AND WASTEWATER TREATMENT

The plant does not use any fresh water, other than for washing down the wastes reception hall. The incoming wastes have enough moisture content to mean that no water addition is necessary. Similarly, as the digestate is stored on-site before being transported the short distance back to the de-centralised on-farm storage by tanker, no wastewater is produced and there is no need for wastewater treatment.

BIOGAS UTILISATION

The plant produces approximately 6 million m^3 of biogas per year. This represents approximately 30 m^3/tonne of organic waste incoming. This figure is low because of the high amounts of slurry treated, and its comparatively low biogas potential. Biogas is de-sulphurised on site (Figure 281). A small portion of the biogas is retained on-site to fire a combined biogas and oil boiler (0.9 MW), which provides the heat required on-site. The rest of the biogas is stored in a biogas storage tank with a volume of 5000 m^3 (which can also be seen in Figure 281), and piped via a low pressure gas transmission system to the nearby Rødding CHP plant. At the CHP plant the biogas is utilised in two biogas engines to produce electricity (maximum 2084 kW) and heat (maximum 2600 kW), which is used in a district heating scheme. There is also a pressurised gas storage tank on-site (also in Figure 281), where gas is stored if the Rødding CHP plant can not accept the gas or is running below capacity due to maintenance. This pressurised gas storage tank is a safety measure, and is rarely used. There is also a biogas flare on-site (Figure 276) as a safety measure. The biogas is sold to the CHP plant, which in turn sells the electricity to electricity providers at a green tariff, and sells the heat to the 'town'. The costs for the installation of the district heating scheme were met by the local municipality after a long term contract for the supply of the heat had been agreed in principle.

The emergency gas storage tank is in the foreground, and the dome-shaped gas buffer tank in the background. The taller grey unit is the biogas de-sulphurisation unit. This unit has just been installed and the old de-sulphurisation unit is lying beside the new one, awaiting removal.

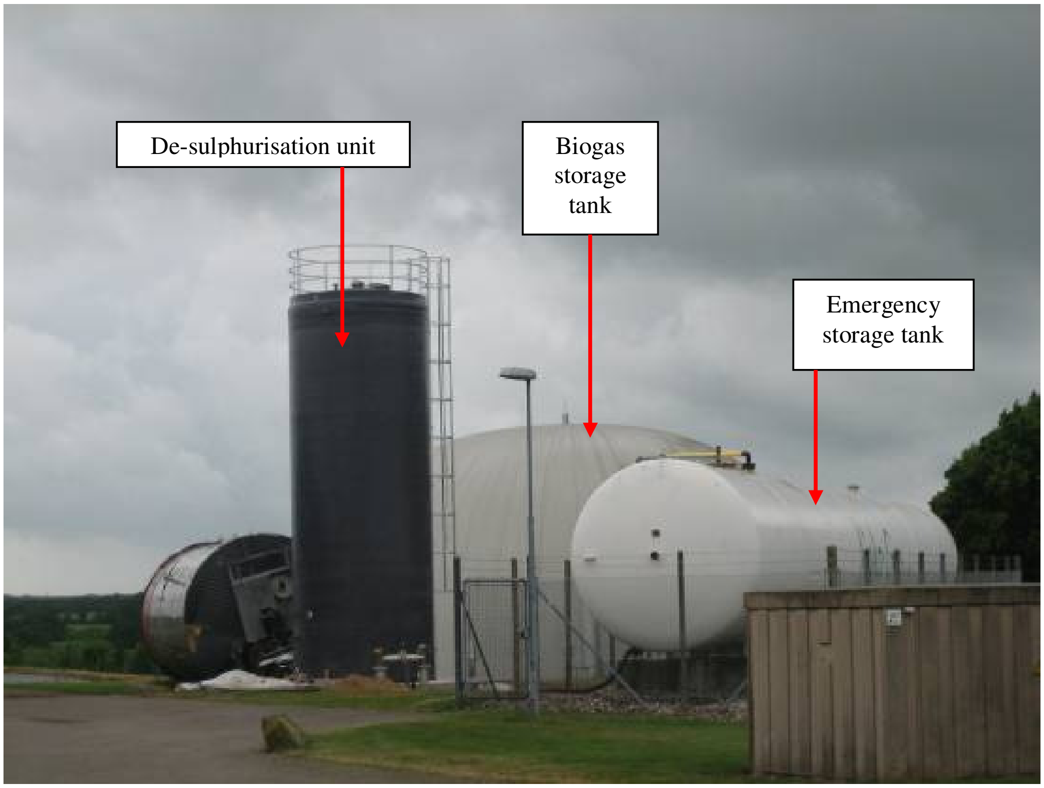

Figure 281 Biogas buffer/storage tank, emergency storage tank and de-sulphurisation unit

ENERGY PRODUCTION

From the biogas produced at Lintrup 13,000 MWh/year of electricity was produced in 2005 (LinkoGas Promotional Information). This electricity production will have produced a large amount of heat energy as a by-product.

EXHAUST GAS TREATMENT

Approximately1000 m^3/hour of exhaust gases and reception hall air is treated in a thermal oxidation unit on-site.

COSTS AND ECONOMICS

The plant was started up in 1990. The total investment cost for the plant (including the off-site storage capacity) was 43.6 million DKK (£4.1 million, or €5.5 million, using January 1990 exchange rates). A Government grant of 16.8 million DKK was awarded (£1.57 million, or €2.12 million, using January 1990 exchange rates).

From the biogas produced at Lintrup 13 million kWh/a (13,000 MWh/a) of electricity was produced in 2005 (LinkoGas Promotional Information). At current UK prices (£107.50/MWh of electricity from biomass, NFPA website, accessed September 2006) this would be worth £1,397,500. The plant also receives gate fees for the industrial organic waste received for treatment. The operating cost was quoted as around €7.5/tonne, including transportation, maintenance, and wages (Christiansen, Personal Communication, 2006). No more information on plant economics was made available.

VISUAL AND LOCAL IMPACT

Considering the scale of the plant (200,000 tpa) it is surprisingly compact and inconspicuous (Figure 282). The tallest structure on site is probably the digesters or the chimney from the thermal treatment of exhaust gases. Both of these structures have approximate height of 15 m. The wastes reception tanks, and the digestate storage tanks are all underground, as is most of the piping, which considerably reduces the visual impact of the site.

Figure 282 Lintrup Biogas Plant

The plant looks similar to the many high intensity agricultural operations in the area. Figure 283 shows a pig farm across the road from the LinkoGas site, owned by one of the participating farmers.

Figure 283 Pig farm in Lintrup

Odour control, and keeping emissions to a minimum has been given priority status in Denmark, due to the perceived importance of the image of anaerobic digestion plants. Previously, the site received many complaints about odour, especially in the summer. The Lintrup plant now uses thermal oxidation to minimise odours. Approximately 1000 m^3/hour of exhaust gases from various parts of the plant are treated by thermal oxidation. A biofilter would have been a much cheaper option, and would probably have been sufficient to meet the legislation (Christiansen, Personal Communication, 2006), but the thermal oxidation system was chosen as the plant wanted to emit no odours. More emphasis than usual was probably placed on odour reduction considering the plant was locally owned, by farmers who lived within 7km of the plant. Some odour was detectable outside the buildings on the plant. Unsurprisingly, the plant smelt of manure, although the level of the odour was no worse than any farm, and was certainly not unacceptable.

CHALLENGES AND DISCUSSION

The digesters were 'state of the art' at the time the plant was built (1989). These days experience has shown that taller, narrower digesters allow for better mixing, process dynamics and efficiency. Therefore if the plant was to be rebuilt, a different digester design would be used. The stirring/mixing efficiency was found to be vastly superior in the 3rd digester, which operated on the circular pattern pumping, as compared to the first two digesters which were stirred by a vertical shaft from the centre of the top of the reactor, with attached paddles.

Occasionally, the analysis of incoming waste streams reveals that the waste exceeds the 'consent' limits for contaminants. All waste being received is tightly specified, and if it is found to exceed the contractually agreed limits, it is refused. This is not a problem for the plant, as they are entitled to refuse waste that could compromise the process or the quality of the digestate, but is a problem for the waste producers, as they must quickly remedy the problem or face the ongoing expense of finding an alternative disposal route.

The retention time in the anaerobic digesters at the time of the visit was 13 days. The retention time is low because of the high throughput. The plant manager would like to have a retention time of at least 16 days, to ensure that the maximum possible biogas yield is obtained. It is in these situations, where the plant accepts the maximum possible amount of waste, and changes to the process would be prohibitively expensive that process optimisation (and getting the depth of data and knowledge to enable optimisation) becomes a very attractive proposition. The future conversion of the post-AD storage tank to another thermophilic digester will help to optimise the system further, adding to the digestion time and biogas yield.

Biogas plants in Denmark have traditionally been managed more ‘by experience by technical foremen’, rather than ‘scientifically by educated managers’ (Christiansen, Personal Communication, 2006). Things are changing now, and a new breed of managers are emerging who recognise the fact that the anaerobic digesters are a living culture, rather than a machine. The current trend in Denmark, with its many centralised AD plants, is to have ‘technical foremen/site managers’ on-site, but to have more educated biogas plant managers overseeing the operation of 6 – 7 plants in the same area. Since taking over the management of the plant in 2004 Aage Sig Christiansen has increased the biogas production by 30% (Christiansen, Personal Communication, 2006). Key to this increase in biogas production was the input from universities, both in terms of the benefits brought by the closer monitoring of the process, and in terms of the lab scale testing, which enabled risk-free trials of major and minor processing changes (Christiansen, Personal Communication, 2006). Aage Sig Christiansen recognises the part that university research projects can play in the monitoring of the LinkoGas (and other full scale) digesters. With anaerobic digestion systems, as with other systems ‘knowledge is power’, and the more you know about a process the more you can improve it. When asked if there were any lessons to be learnt, or if there was anything that would be done differently if the plant were to be redesigned, a few suggestions were made;

- A screen/grid should be added at the wastes reception stage. This would remove solid plastics, pieces of rope *etc*. that sometimes find their way into the waste stream. A considerable amount of time is spent every week taking pumps apart and cleaning them to remove these non-organics.

- The pumps mentioned above are often submerged, in the wastes reception/storage tanks. As these pumps are submerged, cleaning/maintaining them is not an easy task.

- The plant should ALWAYS be built bigger than required. There are always more organic wastes available, and it is easier to fill up to capacity than to expand.

- Universities should be brought on board at an early stage to monitor the full scale process as part of research projects. With anaerobic digesters ‘knowledge is power’, and the more data you have the more you know about your process and the more you can ’tweak’ things here and there to optimise performance.

- Along the same theme, having 'partner universities' to perform lab scale trials and experiments is very beneficial, as you can't experiment at full scale. There are plenty of minor amendments a manager may want to try, and lab-scale processes are necessary.

It was also mentioned that people building new plants still make the mistake of not 'learning from experience' and not taking on board advice from experienced operators. As an experienced operator, Mr Christiansen and other Danish biogas plant managers are regularly asked for advice or comments on the design of new plants. Often well intentioned advice is ignored, for the sake of short term cost-savings. Examples of this advice having been ignored were given. When asked if the plant would consider accepting BMW, the response was;

'*Why*?.... *There are plenty of other organic wastes to choose from'*.

The opinion was that it was not worth the risk, as any contamination on a plant of this scale could lead to massive digestate disposal problems and costs. Another barrier would have been the introduction of upfront mechanical separation processes, which are simply not necessary when liquid industrial and agricultural wastes are treated.

The LinkoGas anaerobic digestion system at Lintrup is a proven, successful operation that provides a solution to the slurry storage and disposal problems faced by the farmers, and also provides them with an extra income, from the gate fees received for organic industrial wastes and from energy sales. The simplicity of the plant, combined with the large volumes of organic waste available locally make it an attractive model. No definitive comment can be made on the plant economics, but considering the scale of the plant, its simplicity and the proximity of the waste producers, it is assumed that the business model is attractive. If the plant were to be rebuilt now, significant improvements could be made in a number of areas. As it stands, the plant must be considered durable, robust, and proven to be successful, although sedimentation may prove a problem at some stage in the future.

5.4 Literature based case studies

As mentioned above it was not possible to visit sites designed and constructed by several of the major suppliers, including BTA, Haase and Linde. A literature based case study on a plant supplied from each of these suppliers is included below. Table 61 sums up the key data of the sites described in the literature based case studies.

Table 61 Key data on sites in literature based case studies

Plant and Location	Wastes Treated	Capacity (tpa)	Owner	AD Supplier
Ypres (Ieper), Belgium	Source separated kitchen and garden wastes.	55,000	IVVO	BTA
Lemgo, Germany	Source separated kitchen and yard waste.	38,000	n/a	Linde BRV
Lisbon, Portugal	Source separated kitchen and garden waste.	40,000 initially 60,000 eventually	Valorsul	Linde KCA
Wels, Austria	Source separated kitchen and yard waste, sewage sludge.	15,000	n/a	Linde KCA
Luebeck, Germany	Residual MSW	150,000*	Entsorgungs betriebe Luebeck	Haase

* Capacity of MBT plant.

5.4.1 Ypres (IVVO) Biowastes Treatment Plant

INTRODUCTION

The majority of the information on the organic waste treatment system at Ypres was from Blischke (2004). The recycling of organics is well developed in the Belgian province of Flanders. In or around the city of Ypres (West Flanders) there are four organics recycling facilities. As well as the centralised anaerobic digester described below there is a green waste chipping and windrow operation, and two in-vessel composting facilities, treating mushroom waste and chicken litter respectively. The AD plant is adjacent to the mushroom IVC and the windrow facility, all of which are situated a few kilometres from Ypres Market Square. The centralised anaerobic digester treats 45,000 – 55,000 tpa of source separated organic waste from the city and surrounding area. The anaerobic system includes wet digestion in two mesophilic digesters. The plant is owned and operated by Intercommunale Vereniging voor vuilverwerking van Veurne en Ommeland (IVVO), which is comprised of 12 municipalities as well as private investors. The IVVO consortium was formed to build and operate the waste treatment plant in Ypres, as a result of tightened regulatory requirements (Blischke, 2004). Tenders were invited to provide a turnkey AD, CHP and composting system in the autumn of 1999. Applications from suppliers of wet and dry AD systems were considered, and in 2000 the wet AD process supplied by German company Muell and Abfalltechnik GmbH (MAT), a licensee of the BTA technology, were chosen. The plant was started up in July 2003 after some unexpected delays, and IVVO requested that the plant was operated by the suppliers for a ‘start-up’ period of 12 months, to verify the plant’s reliable operation and deal with any ‘teething problems’. In December 2003 the plant passed its first performance test and in June 2004 produced its first saleable compost (Blischke, 2004). Although annual throughput averages around 50,000 tpa, the original design criteria called for a plant treating 38,554 tpa of source separated organic waste. As waste generation studies showed considerable seasonal variation a flexible plant design was required. Plant capacity is 55,116 tpa, although in the winter throughput may fall as low as 40,000 tpa.

PLANT DESCRIPTION

Technically, the plant can be described in 8 stages:

- Wastes reception
- Mechanical treatment and conditioning
- AD
- Solids de-watering
- Composting, curing and storage
- Biogas and energy utilisation
- Wastewater treatment
- Exhaust air treatment/odour control.

These stages are described below, with all of the information from Blischke (2004).

PRE-TREATMENT

Waste is unloaded into a covered, sealed wastes reception area, with fast-closing doors to minimise odour escape. A front loader transfers the waste to a bunker and dosing unit. This machine is designed to feed the trommel screen, and is equipped with a set of swinging knives that open the bin bags that have been delivered. The trommel sieves are a key part of the process, as materials over 15 cm are often woody and therefore not suitable for AD. Oversize materials usually comprise around 10% of the total inflow, and are sent direct to the composting area of the plant. The waste stream under 15cm normally contains a high percentage of organics, and is forwarded via a chain-scraper directly underneath the trommel sieve to a deep bunker unit, from where it is screw-pumped into hydro-pulpers. The hydro-pulpers, designed to operate in alternating batch mode, have a volume of 32 m^3 each. Here the waste is mixed vigorously, and re-circulated process water to the desired total solids content (8 – 10% TS). The batch operation takes 60 – 75 minutes and also involves the raking out of floating materials (such as plastics, textiles and wood), and the heavy fraction (containing glass, metals, stones, batteries and bones) is also removed. With this (reportedly) effective and fully automated process no hand-sorting is required. The bottom of the hydro-pulper is equipped with a screen so that the organic waste suspension that is pumped out only contains heavy inerts less than 1cm. To protect equipment installed downstream from unnecessary wear and tear these fine inerts (<1 cm) are removed in a hydro-dynamic grit removal system that is comprised of a charge tank, two hydro-cyclones and a buffer tank. This specially designed system ensures that only minimal amounts of digestible organic matter are removed along with the fine inerts. The light fraction is incinerated, while the heavy fraction is landfilled. The organic waste suspension, now virtually free from non-organic contaminants and easily pumpable, is pumped to the anaerobic digesters.

ANAEROBIC DIGESTION

There are two anaerobic digesters, each with a volume of 2500 m^3. Each digester is 15 m tall. The digesters can be run in series (two-stage digestion) or in parallel (one-stage digestion), which increases the flexibility of the system. The flexible process design allows the operator to find optimum for retention time and biogas content and yield, and other operational parameters given that the volume and content of the incoming waste stream varies seasonally. Retention time is usually between 12 and 15 days. Both digesters are mixed continuously to prevent sedimentation and the forming of floating layers. Proper mixing also ensures even contact between bacteria and waste, and homogenous temperature, pH and nutrient balances throughout the digester. Digesters are mixed by compressed biogas being re-circulated through the bottom of the reactor. The content of both reactors is also pumped through separate tube heat exchangers installed in the adjacent wastes processing building. Both heat exchangers are charged with the cooling water from the gas engines to maintain mesophilic process conditions in the digesters.

POST AD TREATMENT AND DIGESTATE

A flocculant/polymer solution is added to the digestate, which is then pumped to three double-pack de-watering screw presses. The liquid fraction is re-circulated to the hydro-pulpers. Excess liquid is treated in the on-site wastewater treatment process. The de-watered digestate, with a dry matter content of 22 – 35% is discharged onto a conveyor belt that is placed at the tail end of the screw presses. It is here that the trommel screen underflow is rejoined with the trommel screen overflow from the receiving hall and sent to the composting stages.

De-watered digestate is in-vessel composted in one of 7 composting tunnels in a fully enclosed building. These tunnels are operated in batch mode. With concrete walls at the end and on both sides each tunnel has two aeration channels embedded on the tunnel floor. As well as aerating the digestate, these channels collect any leachate. The composting tunnels are fitted with a greenhouse-like roof consisting of a stainless steel frame and a semi-permeable membrane cover. This membrane cover is permeable to air, but impermeable to larger molecules such as odorous gases. Composting time is 2 – 3 weeks, during which time the digestate/compost does not require turning. After this IVC step, the compost is moved to a 'curing' stage, where the compost is windrow composted (in a covered system) for a further 8 weeks, before being stored in an enclosed building until being sold to the end user. The plant produces 18,740 tpa of high-grade compost when operating at full capacity. Quality is regularly tested to ensure conformity with the Flemish standards (established by VLACO). The price at which the compost is sold fluctuates seasonally, but averages out at €14/t (£9.85/t, using 2004 exchange rates). As discussed in Section 2.6.2.3 any revenue received for waste based compost in the UK should be considered a bonus.

BIOGAS UTILISATION AND ENERGY PRODUCTION

Biogas yield ranges from 73 to 109 m^3/t of incoming biowaste depending on the exact content. Average methane content is 65%. The annual biogas production was estimated at 3,964,000 m^3/a (Blischke, 2004). As with other similar AD processes, the CHP system need to be designed with the flexibility to cope with seasonal fluctuations in organic waste and therefore biogas production. The CHP plant consists of four identical 12 cylinder gas engines with an electrical performance output of 300 kW each. The CHP unit can also work in 'island' mode, so plant operation is unaffected by loss of grid power. The plant provides all of its own energy (electricity and heat), and exports more than 50% of the energy produced. The figures produced and exported were not available. It is reported that enough electricity to power 2000 homes is sold to the grid (Blischke, 2004). This 'green' electricity sold to the grid fetches a fixed price of €32.2/MWh (£22.50/MWh). The current average price in the UK for electricity from AD is £107.50/MWh (NFPA website, accessed September 2006), but this is not fixed, and so may fall as well as rise.

EXHAUST GAS TREATMENT

Exhaust gases are extracted from the wastes reception areas, waste processing areas and the composting sections of the plant and passed through a water-based conditioning and scrubbing system before being sent to a biofilter. The conditioned exhaust gases enters the biofilter through four segments of the covered biofilter through a perforated plastic floor where it is distributed through the biofilter bedding material. A combination of compost and bark mulch bedding ensures an optimal surface area for microbe colonisation with high population densities, biological oxidation of the targeted volatile organic (odorous) pollutants and good water adsorption capability (Blischke, 2004).

WATER AND WASTEWATER TREATMENT

Excess process water is stored in a process water buffer tank, from where most of it is re-circulated and re-used. Process water not re-circulated or re-used is treated in an aerobic treatment system. This consists of a self-cleaning fine screen, forced aeration and fixed film packing and a clarifier for gravity separation of suspended solids. No information was available on fresh water requirements, or on wastewater production or treatment. As anaerobic digestion is 'wet digestion' the addition of some fresh water will be necessary.

VISUAL AND LOCAL IMPACT

The AD plant is adjacent to the mushroom IVC and the windrow facility, all of which are situated a few kilometres from Ypres Market Square. The highest points on the plant are the digesters, at approximately 15 m high. No further comments can be made on the visual impact or the odours, as the site has not been visited.

COSTS AND ECONOMICS

The total capital investment was €20 million (£12.5 million using January 2000 exchange rates). This cost includes the cost of the land, infrastructure and utility buildings. The plant receives a gate fee of about €73/tonne of delivered waste (£51/tonne, using 2004 exchange rates). The price at which the compost is sold fluctuates seasonally, but averages out at €14/tonne (£9.85/tonne, using 2004 exchange rates). Electricity sold to the grid fetches a fixed price of €32.20/MWh (£22.50/MWh). No figures on the amount of electricity exported were available.

CHALLENGES AND DISCUSSION

Some mechanical difficulties were observed during start-up. These problems delayed start-up but have since been overcome, and since July 2003 the plant has demonstrated its flexibility in dealing with different feedstocks and different throughputs. This operational flexibility is very important as waste availability, volumes and contracts can always be subject to change.

5.4.2 Lemgo (Linde) Biowastes Treatment Plant

INTRODUCTION

The following case study relies heavily on information provided in Beck (2004). The Lemgo plant was supplied by Linde BRV and was started up in 2000. The plant is owned by Abfallbeseitigungs GmbH Lippe. The Lemgo plant was designed to treat a total of 38,000 tpa of organic wastes (30,000 tpa kitchen wastes, 6000 tpa garden wastes and 2000 tpa industrial organic wastes). An aerial photograph of the plant is shown in Figure 284.

Figure 284 Lemgo aerial photograph (Linde website, accessed August 2006)

PLANT DESCRIPTION

A diagram summarising the Linde BRV anaerobic digestion system, as employed at Lemgo, can be seen in Figure 285.

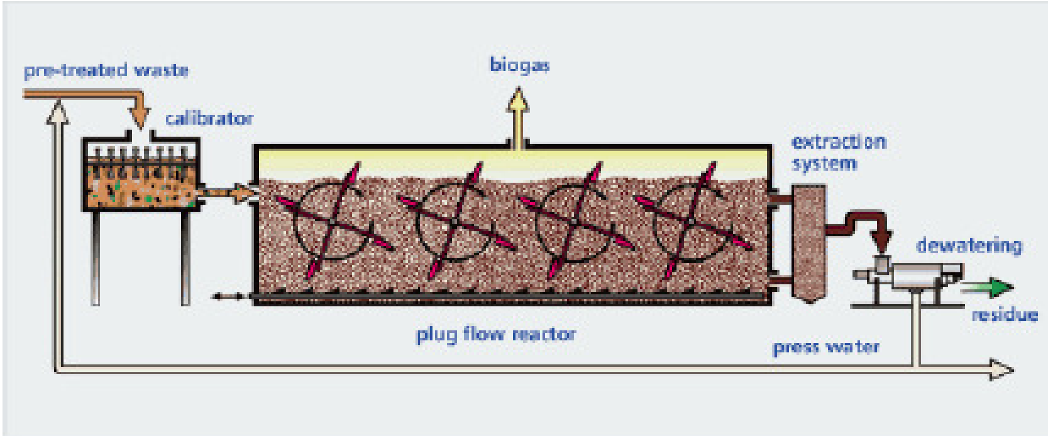

Figure 285 Linde-BRV process (Beck, 2004)

PRE-TREATMENT

In Lemgo, the incoming biowastes are reduced in size by a screw mill to a particle size of <40 mm. Before the wastes stream is fed to the digester, it undergoes a 2 to 4 day period of anaerobic hydrolysis.

ANAEROBIC DIGESTION

Anaerobic digestion is thermophilic, with a retention time of approximately 21 days. The digester is horizontal, with a volume of 2550 m^3. The Linde-BRV dry digestion system operates in a similar way to Kompogas systems, with a few important design differences. Differences from the Kompogas system include;

- Some of the reactor heating is done outside the digester with a short heat exchanger, but primarily heating occurs within the digester walls using a heat exchanger.
- After solid separation only the liquid fraction is recycled which leads to a lower inoculation rate and, hence, the retention time is longer.
- The process is not a plug-flow system because feedstock mixing is more pronounced with the transversal paddles and the walking floor (Beck, 2004).

Mixing is provided by several low-speed agitators in traverse in-line arrangement (Figure 285) which prevents the formation of floating scum and settlement/sedimentation of heavier material. A sturdy conveyor frame is fixed to the digester floor which transfers the sediments to the digester discharge point (Linde Promotional Information). An innovative part of the design is the batch-wise removal of the feedstock into a recipient reactor under negative pressure and the thermal concentration of the liquid digestate in a vacuum dryer at a temperature of 71 °C. The BRV system uses considerably more equipment than a comparable Kompogas system (Beck, 2004). No further information on the anaerobic digestion system was available.

POST AD TREATMENT AND DIGESTATE

The digestate is separated into a liquid fraction with a 20% TS content and a solid fraction having a TS content greater than 45%. The liquid fraction is recycled to dilute the incoming fresh waste, and to moisten the compost windrows. The excess liquid is concentrated and added to the compost. After the AD stage, the digestate is post-composted for a period of approximately 30 days. The quality of the compost, as usual, is dependant on the quality of the incoming wastes. No information on contamination levels or markets for the digestate/compost was available.

BIOGAS UTILISATION AND ENERGY PRODUCTION

Biogas production is reported to be around 3,800,036 m^3/a (Beck, 2004), which corresponds to approximately 100 m^3 of biogas per tonne of waste treated. A volume of 3,800,036 m^3 of biogas (assuming a methane content of 60%) would provide 6845 MWh/a of electricity (assuming a conversion efficiency of 30%). No details of on-site requirements were available, but assuming on-site requirements were 30 – 50% of total electricity production, then the site could export 3422 – 4791 MWh/a of electricity to the grid.

EXHAUST GAS TREATMENT

No information on the technologies used to treat exhaust gases was available. Given the strict German legislation it is expected that a biofilter would not have been sufficient. A thermal oxidation system was probably required, which would add to the capital and operating costs of the plant.

WATER AND WASTEWATER TREATMENT

No information on water requirements or wastewater production or treatment was available.

VISUAL AND LOCAL IMPACT

The Linde BRV anaerobic digester is horizontal and is therefore visually inconspicuous, and can be contained in a building (Figure 284). From Figure 284, it can be observed that the plant is surrounded by forest on all four sides. The housekeeping and odour control at the plant can not be commented upon, as the site was not visited.

COSTS AND ECONOMICS

Capital cost was reported to be US$15,600,000 at the time of construction (Beck, 2004). Using exchange rates from January 2000 this is around £9.7m or €15.5m. The installed cost was reported to be $460/tonne (Beck, 2004), which corresponds to around £284.50/tonne or €460/tonne (using exchange rates from January 2000). Approximately 3422 – 4791 MWh/a of electricity from AD would be worth £366,838 - £515,033 in the UK in September 2006, based on a price of £107.50/MWh (NFPA website, accessed September 2006). No other information on the costs or economics was available.

5.4.3 Lisbon Region (Valorsul) Biowastes Treatment Plant

INTRODUCTION

The Estação de Tratamento e Valorização Orgânica (ETVO) anaerobic digestion plant at São Brás (Amadora, Portugal) is currently in the start-up phase. Initially, the ETVO facility will treat 40,000 tpa of biodegradable waste per year, with provision made and plans for a future increase in capacity to 60,000 tpa. The ETVO facility is owned by Valorsul S.A. and is part of an overall wastes management strategy described below. The anaerobic digestion part of the plant was supplied by Linde KCA.

PLANT DESCRIPTION

The ETVO processes biodegradable waste selectively collected in the restaurants, hotels, supply and retail markets, gardens and parks, as well as from other big producers of this type of waste (such as institutional kitchens). An aerial photograph of the site can be seen in Figure 286. The final product is intended to be a fertiliser for domestic and agricultural use (compost), and electricity and heat from the biogas. When operating at full capacity the ETVO plant will have a capacity of 60,000 tpa, although the in first stages of operation capacity will be 40,000 tpa. With regards to planning and getting the project up and running contracts was signed in July 2001, and the first organic waste was accepted in February 2005. The plant is expected to treat wastes until at least 2020. Figure 286 is an aerial photograph of the ETVO facility.

Figure 286 Aerial photograph of ETVO facility (Valorsul, 2005)

A breakdown of the sources of the incoming waste is given in Table 62. It should be noted that kitchen waste from households is not collected, and is currently contained in the residual waste stream, of which 36% is organic (Valorsul, 2005). The residual waste stream is incinerated for energy recovery. Waste is collected from restaurants and caterers on a daily basis. Regular wastes collection is essential due to the hot climate. Restaurants/caterers/institutional kitchens are encouraged to co-operate as they must pay for residual waste to be removed, but organics are removed by Valorsul free of charge. The costs for organics bins, as well as transport/collection which is considerable, is met by Valorsul. If a similar scheme were to be introduced in the UK it is anticipated that daily collection would not be necessary, but that distances that needed to be covered to collect similar volumes of waste may be greater, given the high-rise building style in and around Lisbon.

Table 62 Breakdown of the sources of the incoming waste (Valorsul Promotional Information)

Sectors Included	Biodegradable Waste to be Processed (% of total)
Restaurants, and similar outlets, shopping centres, hotels.	30 - 50
Lisbon Regional Supply Market (and other smaller markets).	30 - 45
Canteens (of companies, universities, hospitals, prisons, military quarters *etc*.)	10 - 20
Gardens, cemeteries, parks *etc*.	0 - 10

The site occupied by the ETVO facility (Figure 286) covers 30,000 m^2 in the São Brás area of Amadora municipality. This corresponds to 0.5 m^2/tonne of waste processed per year, or 2 tpa processed per m^2. In 2005 twenty three people were employed as part of the ETVO plant, but this number is set to rise. It was mentioned that 12 more similar anaerobic digestion systems treating industrial organic and restaurant wastes are planned to be rolled out across Portugal in the coming years. The ETVO facility will be described below based on all available information. Information is mostly sourced from the Valorsul website (accessed March 2006), Valorsul Promotional Information and personal communication with Vaz (2006).

<u>PLANT DESCRIPTION</u>

A process flow diagram for a Linde KCA anaerobic biowastes treatment plant is shown in Figure 287.

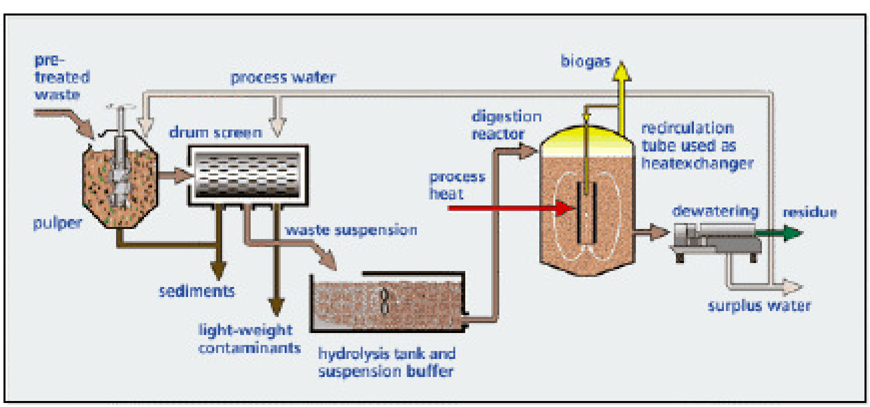

Figure 287 Linde-KCA AD process flow diagram (Beck, 2004)

PRE-TREATMENT

The biodegradable waste coming from the different sources will be delivered in the plant in two shifts, from 0000 to 0800 and from 1600 to 2400. It is stored in a bunker, confined and with isolation doors (kept closed except at times of deliveries), and then put through a wet pre-treatment process with the dual purpose of removing undesirable materials (glass, stones, plastic, *etc*.), and the solubilisation of the organic matter.

ANAEROBIC DIGESTION

The AD process is a wet two-stage thermophilic anaerobic digestion process. The AD technology used was supplied by Linde KCA. After a hydrolysis stage, the organic suspension is fed to two anaerobic reactors. Internal mixing is provided by sparging biogas and small quantities of oxygen. The oxygen is supplied at very low levels to suppress hydrogen sulphide producing bacteria, while at the same time not affecting other micro-organisms in the anaerobic consortium. Extra mixing is provided by re-circulation pumps (horizontal re-circulation rather than vertical as in the Dranco system) that make a vortex. This vortex also helps to centrifuge solids to the bottom of the reactor vessels, from where they can be removed. Retention time is approximately 20 days. A photograph of the Valorsul ETVO anaerobic digester is shown in Figure 288.

Figure 288 Anaerobic digesters at the ETVO site (Linde Promotional Information)

POST AD TREATMENT AND DIGESTATE

The digested and de-watered product goes on to a closed pre-composting stage, with forced aeration, followed by maturation in a covered area. The total time required for aerobic composting period is 12 weeks. As of March 2006, the compost did not yet reach the required standards to permit its use in agriculture. Tests were on-going at the plant in order to ensure good operation and compliance. It is fully anticipated that the compost quality standards can be met. Due to the dry and arid Portuguese soil, it is expected that there will be a lasting and reliable market for the compost produced. A revenue stream is expected. Approximately 10,000 – 16,000 tonnes of compost will be produced annually.

BIOGAS UTILISATION AND ENERGY PRODUCTION

The biogas storage tank can be seen on the bottom left of Figure 286 and has a volume of 2150 m^3. Biogas is upgraded and used on site to produce electricity and heat. All of the sites heat requirements are met but no information was available on the amount of excess heat and its use (if any). Gross electrical power produced is dependent on biogas production, and is expected to be around 12,500 MWh/a. On-site electricity requirements are around 6000 MWh/a, leaving an expected exportable surplus of around 6500 MWh/a. In the UK (at the May 2006 price of £107.50/MWh (NFPA website, accessed September 2006) this electricity would provide an income of £698,750.

Generally speaking, if municipal organic waste (even source separated) was sent to the ETVO plant, it is probable that the front-end separation and pre-treatment stages would need to be more complex and robust, but by collecting organic waste from restaurant/catering and market waste non-organics contamination was limited, compared to levels that would be observed if source separated kitchen waste was collected from each household.

EXHAUST GAS TREATMENT

All contaminated exhaust air of the facility is collected (at least a rate of 6 extractions/h in the most contaminated areas) and treated in a biofilter, thus preventing the spreading of odours onsite and in the neighbourhood.

WATER AND WASTEWATER TREATMENT

No data on fresh water requirements or the volume of wastewater produced was available.

VISUAL AND LOCAL IMPACT

The site is located in the outskirts of the city, close to both residential and industrial areas (Figure 286). Without having visited the site it is not possible to comment further on landscaping or odour.

COSTS AND ECONOMICS

As the site was not yet fully operational, the total expenditure was not yet available. The initial capital cost of the project as of €20,750,000 (£13.1 million using 2001 exchange rates). Half of this capital cost (€10,375,000) was 'co-funded'. The source of the co-funding was not mentioned (Valorsul Presentation, 2006). Due to the problems experienced, the cost was still rising. The total financial outlay (as of 31/12/04) was €22,709,000 (£16 million based on exchange rates on 31/12/04). The total financial investment made by 2020 is expected to be €36,169,000 (£25.5 million based on exchange rates on 31/12/04). As the plant was not yet up and running, no figures for operational costs were available. Incomes from the sales of 'compost' and energy were also not available.

CHALLENGES AND DISCUSSION

Little information was given on the 'testing' that was being carried out at the ETVO facility, but the following issues were mentioned:

- Tests were being carried out to optimise the digestion system with regards to the exact waste stream being received.
- Problems had been experienced due to different companies supplying different parts of the plant (in particular whether or not the pre-treatment was supplying the pre-agreed waste stream to the digester, which was experiencing problems due to contaminants that had not been removed). Unclear boundaries of responsibility were slowing down work and causing problems.
- There seemed to have been some problems with the civil engineering aspects of the construction.
- The compost did not yet reach the required standards for agricultural use, and tests on the system were on-going to ensure compliance.

Valuable lessons to be learnt from the Valorsul ETVO project include:

- Use one company to supply a turnkey project, or at least to manage the overall project, and therefore organise and manage their own sub-contractors. The use of different companies to supply and build different parts of the process should be avoided where possible, even when cost savings can apparently be made. Conflicts can arise and delay the project.

- On a more positive note, the public seem happy with the systems in place, and the public education, awareness and involvement campaigns (described below) can be considered a success.

- The pre-treatment stage should always be robust enough to deal with any contaminants that may arise. Worst case scenarios must be assumed, as insufficient pre-treatment will cause knock-on effects through the whole plant.

VALORSUL S.A. WASTES MANAGEMENT STRATEGY

Valorsul S.A. is the company responsible for the treatment of approximately 750,000 tonnes of MSW produced per year in Lisbon, and the surrounding municipalities of Amadora, Loures, Odivelas, and Vila Franca de Xira. These areas represent less than 1% of the total area of Portugal, but produce almost 1/6 of the country's MSW due to the high population density. Valorsul have developed an integrated wastes management system that (based on their studies) represents an optimisation of the environmental, social, economic, technical and institutional issues. Valorsul are also pro-active in environmental education and awareness, to promote environmentally favourable behaviour by the population. A summary of the Valorsul SA public education campaign for the ETVO facility is described below. An overview of the Valorsul municipal wastes management system is shown in Figure 289.

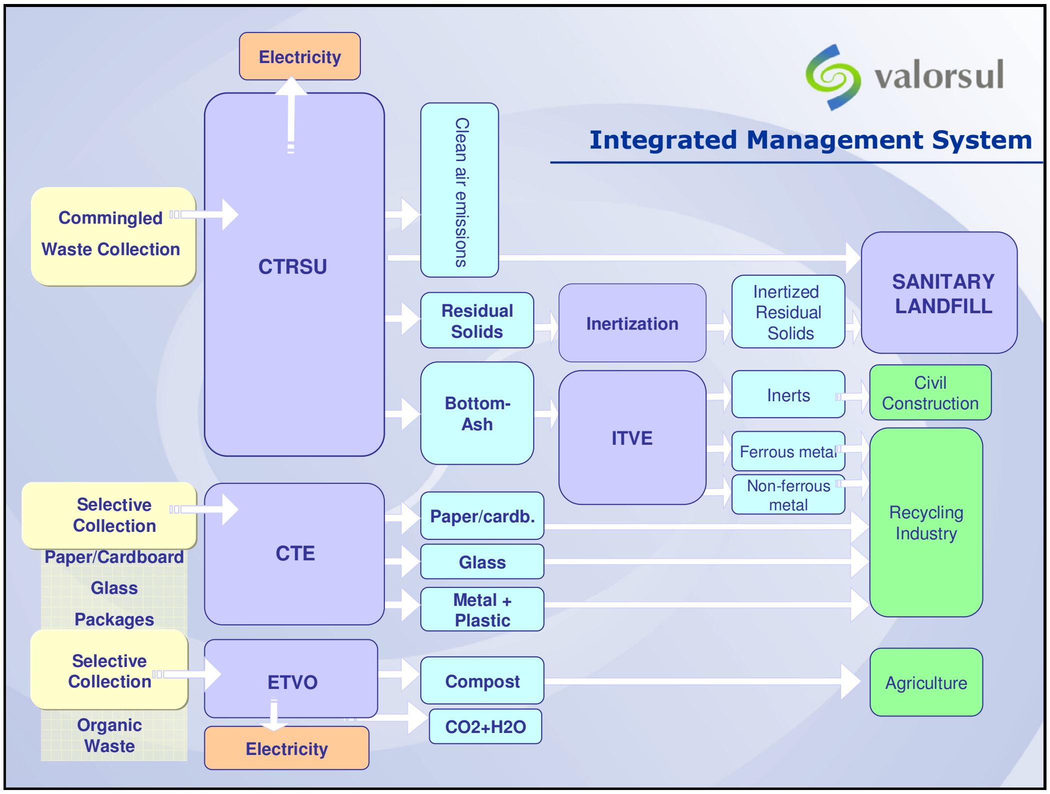

Figure 289 Overview of the Valorsul municipal wastes management system (Valorsul, 2005)

Key

ETVO	Biodegradable Waste Processing Plant.
CTE	Materials Recovery Facility and Collection Centre.
CTRSU	Municipal Solid Waste Processing Plant.
AS	Sanitary Landfill.
ITVE	Bottom Ash Processing and Recovery Plant.

The integrated wastes management system is configured around the optimum (according to Valorsul) recycling, recovery and treatment options for three waste streams collected. These are:

- Selective collection of recyclable materials.
- Selective collection of organic matter.
- Undifferentiated (residual) municipal waste.

As can be observed in Figure 289, recyclables are sent to the Materials Recovery Facility and Collection Centre (CTE), source separated organics to the Biodegradable Waste Processing Plant (ETVO), and residual waste to the Municipal Solid Waste Processing Plant (CTRSU) which is a municipal waste incinerator. In this case, rather than centralising operations and having all of the above processes on one site, Valorsul chose to spread the sites between the co-operating municipalities (Figure 290).

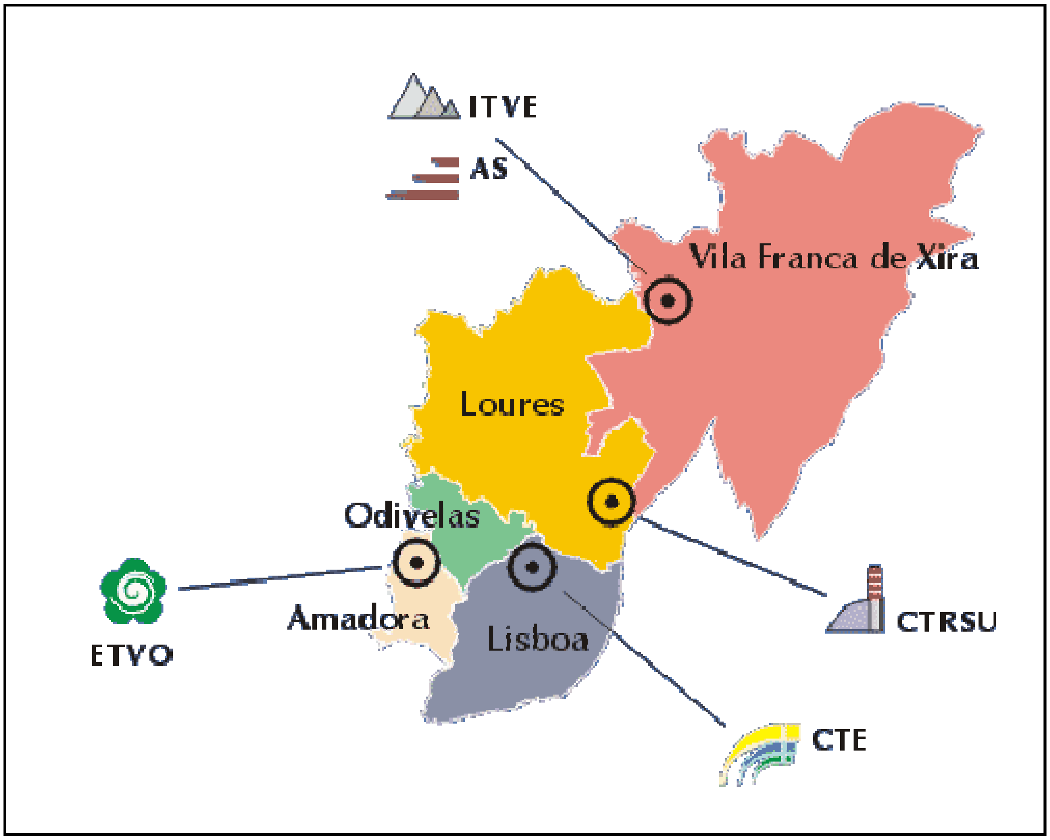

Figure 290 Location of Valorsul facilities (Valorsul, 2005)

Key

ETVO	Biodegradable Waste Processing Plant.
CTE	Materials Recovery Facility and Collection Centre.
CTRSU	Municipal Solid Waste Processing Plant.
AS	Sanitary Landfill.
ITVE	Bottom Ash Processing and Recovery Plant.

The facilities were spread between the municipalities as a concession to public and political will that no one area became associated with 'wastes treatment' (and any associated negative images). A benefit of this decision is that industry and employment is spread throughout the city and its surroundings. Disadvantages of spreading the technologies around the area include the increased transport costs and emissions between sites, and the opportunity of the symbiotic uses (and treatment/management) of water, waste heat, electricity *etc.* being lost.

VALORSUL PUBLIC EDUCATION CAMPAIGN

As mentioned above, Valorsul are pro-active in environmental education and awareness actions, to promote environmentally favourable behaviour by the population. In 2005, Valorsul launched their collection strategy collecting organic wastes from restaurants, canteens, hotels, institutional kitchens and supplier/retailer markets in the greater Lisbon area. To ensure an efficient partnership between the private and public sector, a communication strategy was implemented. This communication strategy is described in Loureiro and Xavier (2006). The main conclusions, as they appear in Loureiro and Xavier (2006) are:

'Every new selective collection implementation requires a great investment in communication. For the success of the collection operations it is mandatory to have a communication strategy that includes data collection, communication planning, target training and customer relationship management system to respond efficiently to customer needs throughout the time. It is also extremely important to monitor customer satisfaction, as it is the customer that does the selection of the waste'.

Some examples of posters displayed around Lisbon and the covered municipalities are shown in Figure 292, Figure 292, and Figure 293.

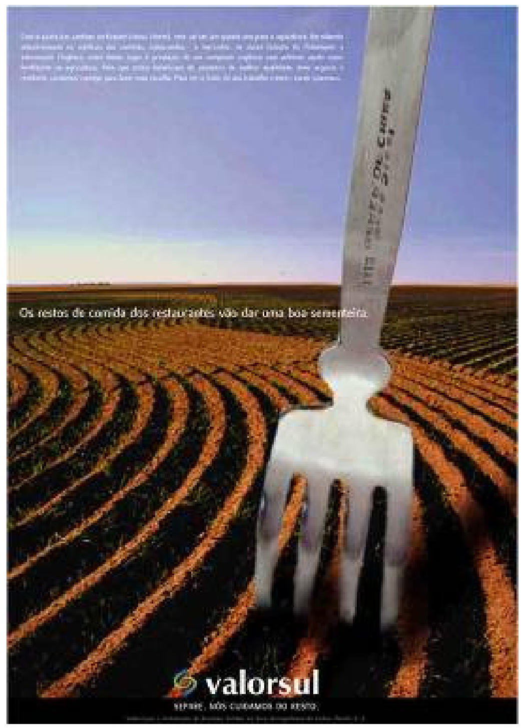

Figure 291 Public education poster by Valorsul (example 1)

Figure 292 Public education poster by Valorsul (example 2)

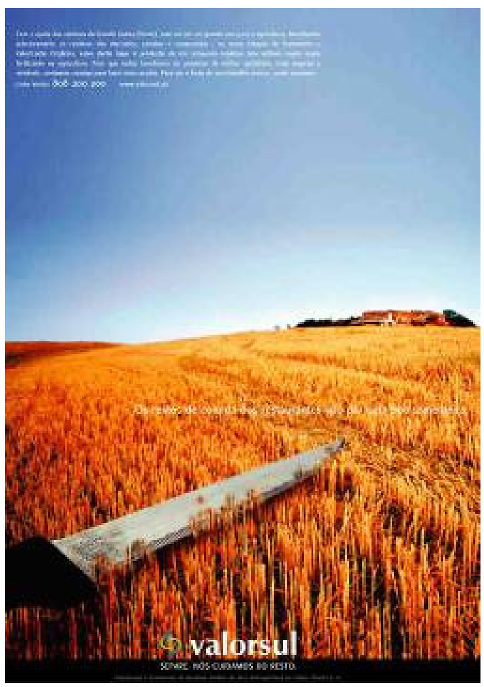

Figure 293 Public education poster by Valorsul (example 3)

There were another series of posters promoting the materials recovery facility and the incinerator.

5.4.4 Wels (Linde) Biowastes Treatment Plant

INTRODUCTION

The following case study relies heavily on information provided in Beck (2004). Wels is a medium sized city in Austria which applied an advanced integrated waste treatment concept in 1996 to treat 185,000 tpa of wastes. The capacity of the anaerobic digester is approximately 15,000 tpa. As well as the anaerobic digestion system the integrated wastes recycling and treatment park consists of facilities to:

- Recycle waste materials.
- Sort packaging materials.
- Recycle construction materials.
- Incinerate grey/residual waste for energy recovery.
- Compost yard waste.
- Landfill inert materials.
- Treat wastewater.

The facilities (including the waste incineration plant) meet the highest environmental protection standards (Raninger *et al*., 2006). Raninger *et al*. (2006) also reported that 39% of the input material is recovered as secondary raw materials (such as paper, woods, and compost) and 36 million kW electrical power is provided from waste incineration and biogas production (no breakdown was given, but an approximation of the energy produced by the anaerobic digestion system is given below). Approximately 10,000 tpa of source separated BMW and 5000 tpa of yard waste and sewage sludge is treated in the digestion system. The biogas technology was based on a two-step liquid mesophilic anaerobic fermentation in a flow-through, biogas-mixed, vertical enamelled-steel fermenter. AD technology was supplied by Linde KCA. Linde-KCA-Dresden GmbH is a wholly owned subsidiary of Linde AG. Linde's wet digestion system for OFMSW is comparable to the BTA design with the major difference being how the light fraction is separated. The light fraction is separated via a drum screen in Linde systems rather than within a pulper as in the BTA process (Beck, 2004), although in the Linde systems the waste passes through a pulper before the drum screen (Figure 295).

Depending on the type of input material, Linde's two-stage wet digestion processes can be run at either thermophilic or mesophilic temperatures. The characteristic feature of the Linde technology is how the digestion reactor is fitted with a gas re-circulation system using a centrally located re-circulation tube (Beck, 2004). As mentioned above, the AD plant at Wels is part of the city's integrated recycling park, which includes an incinerator, a combined AD plant and composting unit, a unit for recycling of demolition material, and an industrial waste sorting unit. Figure 294 is a photograph of the facility with the biogas flare, biogas storage system and anaerobic digestion vessel in the foreground. Both Figure 295 and Figure 294 are from Beck (2004).

Figure 294 Wels AD facility (Beck, 2004)

PLANT DESCRIPTION

A process flow diagram of the AD system is shown in Figure 295.

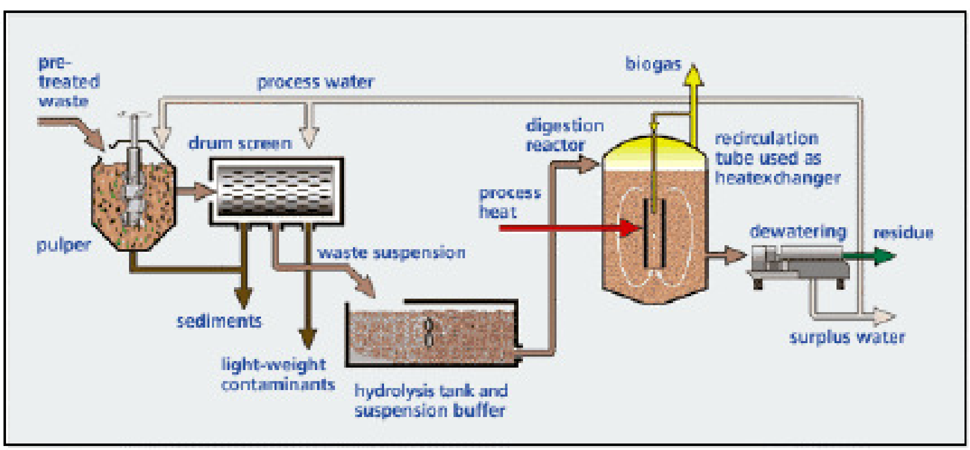

Figure 295 Linde-KCA AD process flow diagram (Beck, 2004)

PRE-TREATMENT

The facility is fed five days per week (presumably Monday to Friday), with around 66 tonnes of feedstock added per day. The organic wastes are collected from an intermediate storage area and are batch-fed into the pulper/drum screen at around 30% TS and 75 – 82% VS. The pulper has a volume of around 20 m^3. After pulping and mixing, the waste stream now has a TS concentration of around 13%. The pulped waste stream is stored in a buffer tank where it undergoes a first hydrolysis step in a tank with a 130 m^3 volume (Figure 295).

ANAEROBIC DIGESTION

From the hydrolysis tank, the waste stream is fed into the AD reactor, which operates at thermophilic temperatures. The AD reactor is sized to have a loading rate of 6 kg of volatile solids/m^3/day. With a 16 day HRT, the AD reactor has an effective volume of 1600 m^3.

BIOGAS UTILISATION AND ENERGY PRODUCTION

Biogas yields range from 88 – 137 m^3/tonne of raw waste input to the plant, with a methane content of 60% - 65% (Beck, 2004). There is a biogas storage balloon with a capacity of 800 m^3. The biogas is used in a boiler that produces approximately 335 kW of heat. The thermal energy is used to heat the plant buildings and to heat the feedstock in the sanitation tanks. Electricity production potential at the above biogas production levels would be 2378 – 4010 MWh/a (assuming 30% conversion efficiency). Assuming around 1/3 of this was required on site, 1585 – 2674 MWh/a would be available for export to the grid, or for use in other areas of the wastes treatment park. Raninger *et al*. (2006) quote the biogas production to be in the region of 1,000,000 m^3/a, which corresponds to 67 m^3/t of waste input, lower than the figures quoted in Beck (2004). These data may be for different years of operation. As there is also a residual wastes incinerator on site the infrastructure costs for using the electricity and heat produced could be minimised.

POST AD TREATMENT AND DIGESTATE USE

The digestate is de-watered and the liquid fraction is recycled for use as process water. The solid fraction undergoes a final composting process together with sewage sludge. Approximately 5000 tpa of 'clean compost' is produced from the 15,000 tpa treated by the process (Raninger *et al*., 2006). Austrian compost standards are consistently met and the compost can be sold or used agriculturally. No information is available on the exact use for the compost produced.

WATER AND WASTEWATER TREATMENT

No figures for fresh water use could be referenced. Excess water is discharged for processing in an on-site wastewater treatment plant before being discharged into the sewerage system.

EXHAUST GAS TREATMENT

No information on exhaust gas treatment was available.

COSTS AND ECONOMICS

No information on costs or economics was available.

VISUAL AND LOCAL IMPACT

It was not possible to comment on the landscaping and odour without visiting the site.

CONCLUSIONS

Having started up in 1996 the wastes treatment system can be considered proven and reliable.

5.4.5 Luebeck (Entsorgungsbetriebe Luebeck) MBT Plant

INTRODUCTION

The construction of the MBT plant at Luebeck (Germany) was commenced in July 2004. The plant was built in 2005/2006 by HAASE Anlagenbau AG on behalf of the owners Entsorgungsbetriebe Luebeck (www.entsorgung.luebeck.de), and is currently being started-up. Entsorgungsbetriebe Luebeck is responsible for the treatment and disposal of wastes in the City of Luebeck (northern Germany). The plant will treat 150,000 tpa of residual municipal waste when fully operational. A photograph of the plant is shown in Figure 296. An artist's impression of the aerial view of the site is shown in Figure 297.

Figure 296 Luebeck MBT Plant (Haase website, accessed July 2006)

Figure 297 Aerial photograph of Luebeck MBT Plant (Haase website, accessed July 2006)

PLANT DESCRIPTION

A flow diagram of a similar MBT plant built by Haase in Leon, Spain (treating 200,000 tpa of residual municipal waste) is shown in Figure 298. It is assumed (although not confirmed) that the processes are similar.

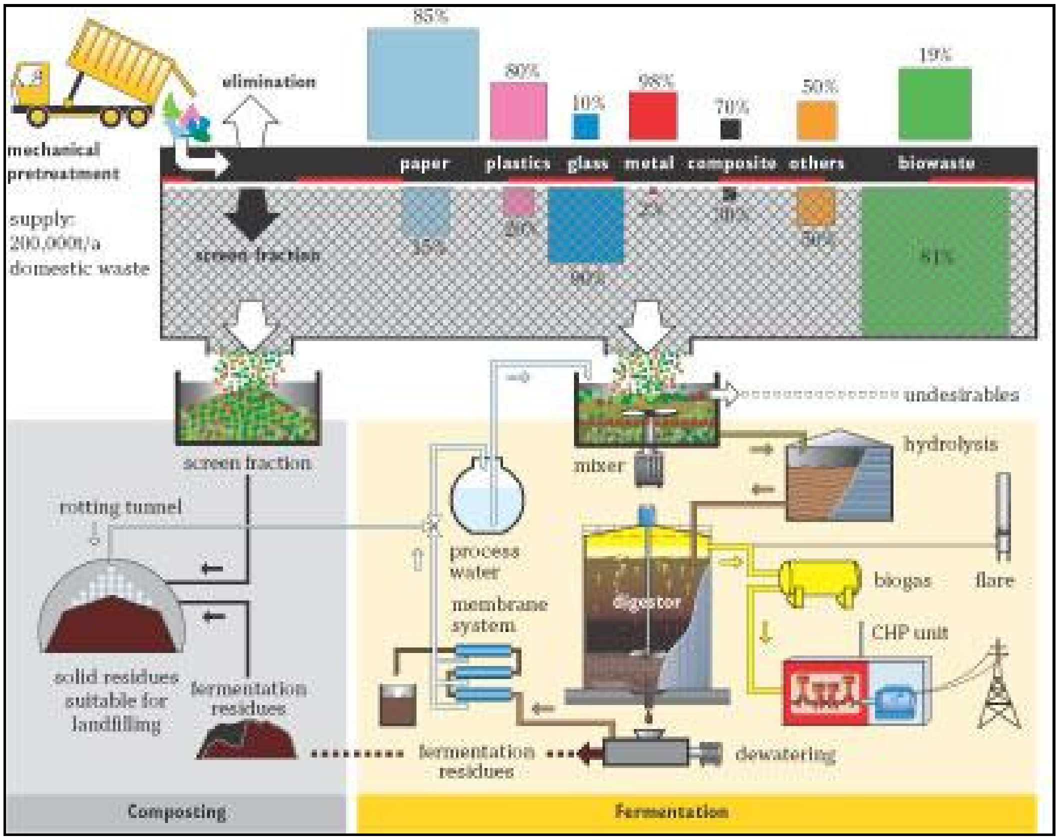

Figure 298 Process flow diagram of a similar Haase MBT Plant at Leon, Spain (Haase website, accessed July 2006)

PRE-TREATMENT

On delivery to the MBT plant the waste is mechanically sorted by trommel sieves and separating installations. Undesirables and recyclables such as sand, metals and glass are removed in two mechanical pre-treatment lines. Materials are separated using a combination of trommel sieves, shredders, iron and metal separation stages, and presumably some kind of sand/fine inerts removal system. Separated materials are recycled or used in energy recovery if possible. The putrescible fraction is forwarded to the biological treatment stages. A photograph of the mechanical treatment stages (Haase website, accessed July 2006) is shown in Figure 299.

Figure 299 Mechanical pre-treatment stages (Haase website, accessed July 2006)

ANAEROBIC DIGESTION

The pre-treated OFMSW arrives in the anaerobic digesters with a maximum particle size of 40 mm. Approximately 55,000 tpa of the OFMSW are treated anaerobically, along with 25,000 tpa of sewage sludge. The capacity of the anaerobic digestion system is 80,000 tpa. Anaerobic digestion is two-stage, incorporating a hydrolysis tank (volume 4500 m^3) and two anaerobic digesters (volume 5000 m^3 each). Digestion is 'wet' but no specifics of the total solids content were provided. Hydraulic retention time in the two-stage process is around 21 days. No other details on the anaerobic digestion system were available, but a simplified diagram of a typical Haase digestion system (Haase website, accessed July 2006) is shown in Figure 300.

The design of the anaerobic digestion system is variable and may be adapted to individual treatment requirements, *e.g.* with regard to energy balance, space requirements, and investment costs. The mass balance of a Haase anaerobic digestion process is shown in Figure 301.

After removing floating matters and suspended matters from the screened material the remaining organic fraction amounts to 82 kg. Anaerobic digestion generates 11.2 kg of biogas (103 m^3/t) and 48 kg of solids suitable for landfilling. Process water is recycled. It is possible to reduce the volume of the residual wastes being landfilled by up to 55% (Haase website, accessed July 2006).

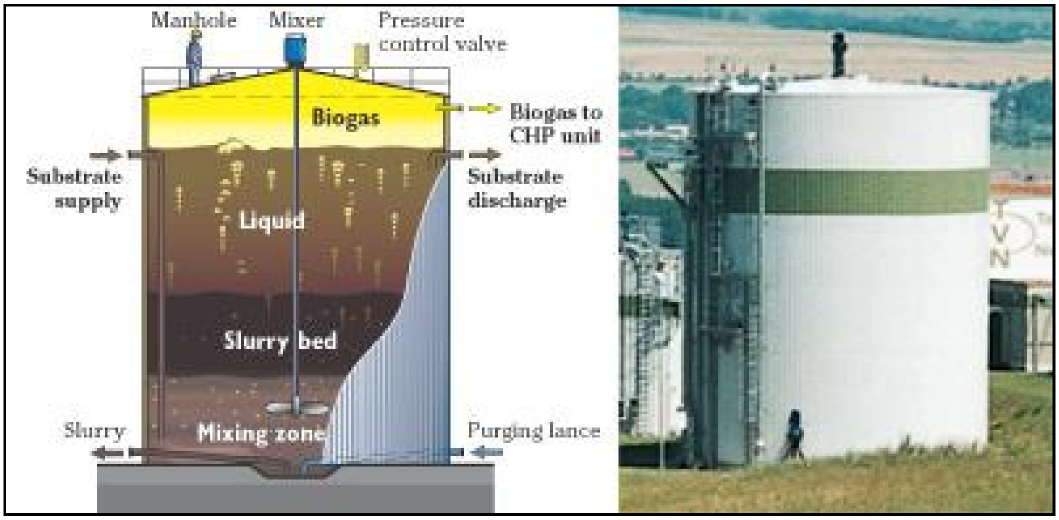

Figure 300 Diagram and photograph of a typical Haase anaerobic digester (Haase website, accessed July 2006)

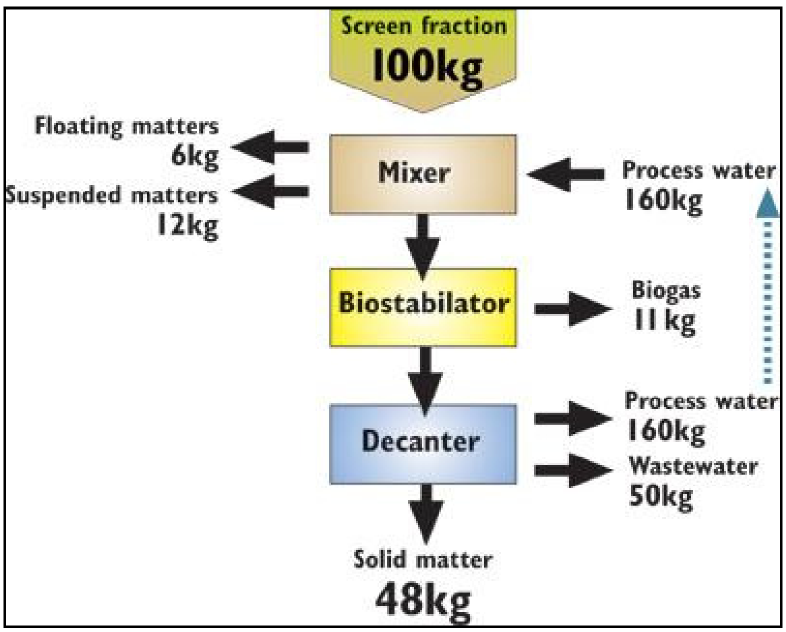

Figure 301 Example of mass balance for Haase AD system (Haase website, accessed July 2006)

POST AD TREATMENT AND DIGESTATE

Haase (and other suppliers) can design processes to suit specific national or regional legislation or requirements. After digestion in Luebeck, the digestate is de-watered. It is unclear as to whether the solid fraction is biodried or fully composted for a period of 4 – 8 weeks prior to landfilling. The final product is a biologically stable and low-emission material suitable for landfilling, fully compliant with the German waste disposal act (AbfAblV). The liquid fraction is recycled. Liquid not required for on-site use is sent for treatment on-site as described below.

BIOGAS UTILISATION

From one tonne of waste Haase expect to recover 25 to 150 m^3 of biogas with a methane content of 55 - 65%. Biogas from the digesters is stored in a biogas storage tank (volume = 800 m^3). Biogas is utilised in one of two containerised biogas CHP units, each with a capacity of 1.9 MW_e. There is also a biogas flare (HT type, 7.5 MW) as a safety feature.

ENERGY PRODUCTION

The MBT plant is equipped with a combined heat and power unit (CHP) that generates electricity and heat from the biogas produced in the plant. From the point of view of energy supply this MBT plant will be 100% self-sufficient (Haase website, accessed July 2006). Biogas recovery is expected to generate 450 kW per tonne of input material. Approximately 35% of electrical energy and 45% of thermal energy generated in this process are suitable for further utilization, after on-site requirements have been met (Haase website, accessed July 2006).

EXHAUST GAS TREATMENT

Exhaust gases are treated by regenerative thermal oxidation (RTO) in a VocsiBox® system, also supplied by Haase. A maximum of 2 x 28,500 m^3/h of process air can be treated. VocsiBox® works according to the principle of regenerative thermal oxidation (RTO) at temperatures of about 1000°C, to treat odorous substances, trace gases and methane (escaping from the composting halls). After treatment, exhaust gases fully comply with the limit values of the 30th BImSchV emission directive (Haase website, accessed July 2006). More details of the VocsiBox® system and other exhaust air treatment solutions are available on the Haase website (www.haase-energietechnik.de/en/). Biofilters can be a cheaper alternative in countries other than Germany, with less stringent exhaust gas emission requirements.

WATER AND WASTEWATER TREATMENT

No details of the plant's fresh water requirements were available. With regards to wastewater, most of the process water is recycled, however each anaerobic digester produces a maximum of 37.5 m^3/day of excess wastewater, that is not recycled and therefore needs treatment (Haase website, accessed July 2006). Excess water is treated in a containerised membrane plant (with ultra-filtration and 2-stage reverse osmosis) before it is discharged. The containerised units are ready for connection on delivery and can represent permanent or short term wastewater treatment solutions. By means of a containerised UF/RO facility the volume of the excess water for disposal is reduced to approximately a quarter of its initial volume and can be discharged from the process as a fertilizer of high quality. Roughly three quarters can be discharged as clean water (Haase website, accessed July 2006). Depending on the plant design, the treated effluent meets either the requirements of Appendix 23 of the German wastewater regulation for direct discharge or the requirements for discharge into the local wastewater system. More details of the wastewater treatment options provided by Haase as part of their MBT plants are available on the Haase website.

VISUAL AND LOCAL IMPACT

The visual impact of the site, its housekeeping and odour control can not be commented upon, as the site was not visited.

COSTS AND ECONOMICS

No information on costs and economics was available. The fact that the CLO was designed to be landfilled would lead to increasing costs as the price of landfilling increases. Thermal oxidation of the exhaust gases to meet the strict German legislation would also represent a major expense. This may not be necessary in the UK, where it is possible that a considerably cheaper biofilter system may be sufficient.

CHALLENGES AND DISCUSSION

Although the optimisation phase has not been finished, a part of the output already adheres to the limit values. The quality of the rest of the solid output is close to the target mark, and therefore it is likely that the residues can be landfilled as planned (Haase website, accessed July 2006).

As the site has not yet fully started up, it lacks a history of reliable operation. Haase have recently completed the construction of several other MBT plants treating residual municipal waste, including Leon, Spain (200,000 tpa) and Salamanca, Spain (70,000 tpa). Although these plants are new, other Haase-built plants treating biowaste have been operating successfully for longer periods. Examples of these sites include:

- Nentzelsrode, treating 17,000 tpa of biowastes since 1999.
- Groeden-Schraden, treating 110,000 tpa of manure and biowastes since 1995.
- Schwanebeck, treating 50,000 tpa of manure and biowastes since 1999.

6.0 CRITICAL COMPARISONS OF CASE STUDIES

Introduction to comparisons

These comparison sections are based solely on information supplied by the anaerobic digestion companies or the wastes treatment companies themselves, and on information already publicly available. As such, it has not been possible to verify the data. The commercial nature of the processes has meant that the acquisition of the detailed in-depth data required for critical analysis has been difficult. Data such as the exact details of the incoming wastes, economic data, energy consumption data and the distribution of energy/costs over the various process sub-systems are limited. Critical analysis of the anaerobic digestion systems themselves is hindered by the fact that limited data is available on the exact content of the wastes being treated.

Comparison of the Digestion of Source and Centrally Separated BMW

The treatment of source separated biodegradable municipal wastes and the treatment of centrally separated organic fraction of MSW incorporate the same or similar anaerobic digesters as part of significantly different systems. Anaerobic digesters treating source separated kitchen and/or garden waste are employed at a smaller scale on average (29,835 tpa) than those treating centrally separated OFMSW (56,094 tpa), based on data from Table 29. Systems treating centrally separated OFMSW tend to be part of large, centralised MBT plants, whereas systems accepting BMW can be smaller and more localised as the expense required for mechanical pre-treatment is considerably less. Most suppliers of anaerobic digestion plants capable of accepting municipal wastes provide systems suitable for both source and centrally separated waste streams, with the main difference being the additional pre-treatment and post-treatment technologies. Further comparison of anaerobic digesters treating BMW and OFMSW has no real value, as source separated BMW and residual OFMSW represent different waste streams. For this reason anaerobic digestion facilities treating source separated BMW will be compared in Section 6.1, and MBT plants treating the organic fraction of centrally separated residual waste will be compared in Section 6.2 and Appendix 2. It is not the objective of this project to compare MBT plants with other waste treatment facilities such as incineration, gasification or pyrolysis plants.

6.1 Comparing anaerobic digestion systems treating source separated BMW

In the following sections an attempt is made to compare the different approaches to anaerobically digesting source separated municipal biowastes. The comparisons will be based on comparisons of the available data from the sites visited as part of this report. The level of data required to make in-depth comparisons of the performance of individual anaerobic digesters was not made available. Therefore comparisons are based on basic values quoted by the site suppliers/operators. Data could not be verified. Due to the limited data available, the comparisons will be more of the ‘concepts’ behind each system than the actual AD processes.

6.1.1 Capital cost comparison for biowastes treatment plants

In all cases the process owners or suppliers were asked to provide basic information on capital and operating costs. If no information is shown, it is because none was made available. Some suppliers were justifiably reluctant to divulge financial information given the tendency of decision makers to '*head straight for the bottom line*' and consider processes on costs alone. The point should be made that AD systems are large scale projects, incorporating many different technologies, and that the cheapest solution is not always the best solution. All costs are case specific and would not necessarily be applicable to UK projects in the future. The capital costs for biowastes treatment plants visited can be seen in Table 63.

Table 63 Capital costs for biowastes treatment plants visited

Plant Capacity	Wastes Treated	Year Started -up	Total Capital Cost (£) (Reference)	Capital Cost/tonne waste throughput over 20 year operating life (£/t)
Brecht II 50,000 tpa	Source separated kitchen and garden wastes	1999/ 2000	£10 m (1)	10
Salzburg 20,000 tpa	Source separated kitchen waste (13,335 tpa), source separated garden waste (4200 tpa), industrial organic waste (3150 tpa)	1992	£8 m (2)	20
Niederuzwil 10,000 tpa Plus another 10,000 tpa in 2005 – not included	Source separated kitchen and garden waste (8,000 tpa), industrial food waste (2000 tpa)	1992	£2.5 m (3) Not including 2nd process line	12.5 Not including 2nd process line
Otelfingen 12,500 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (2500 tpa)	1996	n/a	n/a
Oetwil Am See 11,600 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (1600 tpa)	2000	£2.5 m (4)	11.8
Grindsted 52,600 tpa	Source separated kitchen waste (1150 tpa), sewage sludge (39,000 tpa) and industrial organic waste (12,200 tpa), supermarket food wastes (250 tpa)	1997	£5.5 m (5)	5.2
Ludlow 5000 tpa	Source separated kitchen and garden wastes	2006	n/a	n/a
Jonkoping 30,000 tpa	Source separated kitchen waste	2006	£5.9 m (6)	9.83
Västerås 23,000 tpa	Source separated kitchen waste (14,000 tpa), grease trap sludge (4000 tpa), ley crop (5000 tpa)	2005	£5.9 m (7)	12.8

(1) Dierick, Personal Communication (2006).
(2) Matousch, Personal Communication (2006).
(3) Beck (2004).
(4) Knecht, Personal Communication (2006).
(5) Bro, Personal Communication (2006).
(6) Kall, Personal Communication (2006).
(7) Persson, Personal Communication (2006).

Figure 302 shows the capital cost per tonne, over a 20 year operating life of the plant.

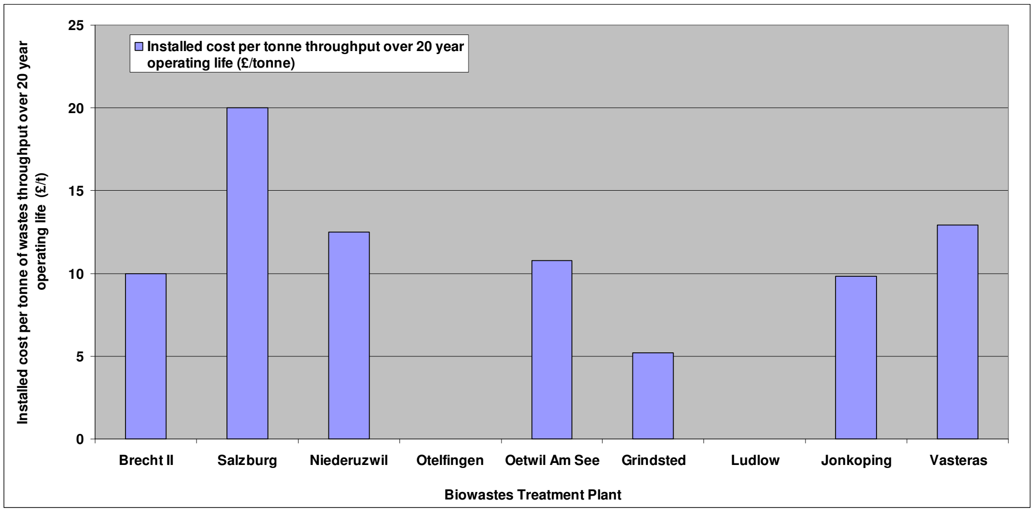

Figure 302 Capital cost per tonne throughput over 20 year operating life

These comparisons take no account of the values of currency in the year that the plant was built in relation to the value of the currency in 2006 (although wherever prices were quoted in Euros or other European currencies the exchange rate in the year that the plant started up was used when converting to British Pounds Sterling). Direct comparison of capital costs could be potentially misleading, as a plant from a reputable supplier could have a high capital cost, but incur minimal maintenance costs over the operating life, whereas a plant that was more cheaply built could experience significantly higher maintenance costs. These costs do not take the cost of finance into consideration. Some plants received considerable European and National grants to help cover capital expenditure. The availability and value of these grants can have a significant effect on the viability of a project, particularly when considering the extra finance (and cost of finance) that would be required if the grants were not available.

No information was made available on the costs of the Otelfingen site or the Ludlow site. This is not surprising, as the Ludlow site is a pilot scale process, intended to demonstrate that the concept of anaerobically digesting source separated kitchen waste is technically possible in the UK. It is likely that the process would not compare well economically due to its smaller scale. The Otelfingen site is the Kompogas ‘flagship’, designed to show visitors the possibilities that the process offers. It has a visitor centre, a greenhouse with crops growing from digestate, biogas fuelled racing karts and track and a biogas upgrading plant and vehicle filling station. Therefore, the costs for the Otelfingen site would be unfairly inflated, and would not be comparable to other sites focussed solely on wastes treatment/biogas production. The Jonkoping example includes the cost of the existing sewage sludge digesters, which were paid for in the 1980s and have been running successfully since then. This inflates the cost per tonne of waste treated but takes no account of the financial value of the 15 plus years of successful sewage sludge treatment. If these costs were not included as expenditure for the new plant, then the total cost would be €7.3 million or £5 million based on June 2006 exchange rates. This would reduce the capital cost per tonne of waste treated over 20 years to £8.33/tonne. If the sewage sludge treated was also included (as it is in the Grindsted example) then the installed cost per tonne would be greatly reduced. No information on the throughput of the sewage sludge digesters was available. The Niederuzwil plant was upgraded in 2005 to include a parallel process line, doubling the plant throughput. The cost of this upgrade is not included in the capital cost quoted here, therefore only the capital cost of the first process line (treating 10,000 tpa) is included. The capital cost of the Västerås plant per tonne of waste treated is relatively high. This is most probably due to the extra costs involved with the use of the biogas produced as a transport fuel (particularly the biogas upgrading).

It can be seen that plants with a smaller throughput generally experience higher costs per tonne, as would be expected. The costs per installed tonne are generally higher in the smaller scaled plants, such as Salzburg (20,000 tpa, cost £20/t throughput over 20 years), the Kompogas plants (scale = 10,000 – 12,500 tpa, cost = £11.80 - £12.50/t throughput over 20 years) and the Jonkoping plant (scale = 30,000 tpa, cost = £9.83/t throughput over 20 years), compared to the larger scale plants at Brecht (scale = 50,000 tpa, cost = £10/t throughput over 20 years) and Grindsted (scale = 52,600 tpa, cost = £5.20/t throughput over 20 years). The installed cost per tonne throughput of the Salzburg (£20/t) and Brecht (£10/t) plants, both built by OWS Dranco, is a good example of how costs per installed tonne come down as scale increases. The plant at Salzburg treats approximately 20,000 tpa of source separated kitchen and garden wastes, while the plant a Brecht treats in the region of 50,000 tpa of source separated kitchen and garden wastes. The increased supplier experience gained and technological development between 1991 and 2000 may also have had an effect on the costs.

The Grindsted plant had a capital cost of approximately £5.5 million in 1997, which corresponds to £5.20/t of waste throughput over a 20 year operating life, although 74% of the throughput is sewage sludge, and only 2.2% of the throughput is source separated municipal kitchen waste. The content of the wastes treated and the fact that the digester was originally a sewage sludge digester undoubtedly lowered the total capital cost. In addition, the costs of upgrading the system to accept BMW, organic industrial wastes and food wastes was not available and is therefore not included.

Other anaerobic digestion plants visited as part of this project include Lintrup, Linkoping and Holsworthy. These plants do not treat municipal biowastes, but a combination of manure and other agricultural and industrial organic wastes. In terms of capital costs these sites compare well with the sites above. The capital costs of these sites are shown in Table 64, alongside the capital cost per tonne of waste throughput over a 20 year operating life of the plant.

The capital cost for the Linkoping plant is significantly higher than the cost for Holsworthy and Lintrup because at Linkoping the biogas is upgraded and used as a vehicle fuel, which is more expensive than using the biogas in CHP systems. The capital costs for the biogas plants that do not accept municipal wastes are lower because of the fact that less mechanical pre-treatment is required (usually only very basic screens are required, to remove large non-organic contaminants from agricultural and industrial wastes).

Table 64 Biogas plants capital costs

Plant Capacity	Wastes Treated	Year Started-up	Total Capital Cost (Reference)	Capital Cost/ tonne waste throughput over 20 year operating life (£/t)
Holsworthy (150,000 tpa)	Agricultural wastes, commercial wastes	2002	£7.7 m €10.2 (1)	2.6
Linkoping (22,000 tpa)	Commercial wastes, agricultural wastes, abattoir wastes	1998	£6.5 m €8.7 m (2)	14.8
Lintrup (200,000 tpa)	Agricultural wastes, commercial wastes, abattoir wastes, hospital food wastes	1990	£4.1 m €5.5 m (3)	1.03

(1) Devon Council website, accessed September 2006.
(2) Unden, Personal Communication (2006).
(3) Christiansen, Personal Communication (2006).

6.1.2 Operating cost comparison for biowastes treatment plants

A basic comparison of the operating costs (where available) for AD systems treating source separated municipal wastes is shown in Table 65. The plants at Ludlow, Västerås and Jonkoping were not yet operating at full capacity, and therefore did not yet have sufficient operating time to ascertain accurate information on the operating costs. Of the other plants visited that had been operating for over one year, it can be seen that very few suppliers or operators were comfortable revealing their operating costs. It is understandable that companies and publicly owned bodies do not want to divulge financial information.

The operating cost at Brecht was not revealed by OWS Dranco, but was quoted as £40/tonne by Wannholt (1999) and £59 by Eunomia (2004). It is not possible to verify the accuracy of these quotes, or explain the differences. It is assumed that the fact that source separated biowastes are collected in plastic bags rather than paper bags, this will increase the amount of pre-treatment required and therefore increase the operating cost.

The low operating costs reported for the Grindsted plant (£4.1/tonne throughput) are for the whole throughput of the digester (i.e. 74% of which is sewage sludge, and 2.2% of which is source separated biowaste). It is assumed that the operating cost is lower than that at Brecht due to the lower percentage of the throughput made up by BMW (2.2% compared to 100% at Brecht). The major operating cost is maintenance (€100,000/a), followed by manpower (€27,000 – €54,000/a), chemicals (€27,000/a) and energy (€27,000/a) (Bro, 2006). A breakdown of the operating cost of the Grindsted plant is available in Table 42 in Section 5.1.2.

Table 65 Operating costs for AD plants treating source separated municipal wastes

Plant Capacity	Wastes Treated	Year Started-up	Operating Cost per tonne input (Reference)	Gate Fee Received	Notes
Brecht II 50,000 tpa	Source separated kitchen and garden wastes	1999/ 2000	**£40** (1) **£59** (2)	**£55** (3)	
Salzburg 20,000 tpa	Source separated kitchen waste (13,335 tpa), source separated garden waste (4200 tpa), industrial organic waste (3150 tpa)	1992	n/a	n/a	Other than the capital cost, no financial information was made available
Niederuzwil 20,000 tpa	Source separated kitchen and garden waste (16,000 tpa), industrial food waste (4000 tpa)	1992	n/a	n/a	No financial information was made available
Otelfingen 12,500 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (2500 tpa)	1996	n/a	n/a	No financial information was made available
Oetwil Am See 11,600 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (1600 tpa)	2000	n/a	n/a	No financial information was made available
Grindsted 52,600 tpa	Source separated kitchen waste (1150 tpa), sewage sludge (39,000 tpa) and industrial organic waste (12,200 tpa), supermarket food wastes (250 tpa)	1997	£4.1 (4)	n/a	
Ludlow 5000 tpa	Source separated kitchen and garden wastes	2006	n/a	n/a	The plant is in the process of starting up, and no operational data is available The plant is a trial scale plant
Jonkoping 30,000 tpa	Source separated kitchen waste	2006	n/a	n/a	The plant is currently being constructed, so no operating data is available
Västerås 23,000 tpa	Source separated kitchen waste (14,000 tpa), grease trap sludge (4000 tpa), ley crop (5000 tpa)	2005	n/a	n/a	The plant is in the process of starting up, and no operational data is available

(1) Wannholt (1999).
(2) Eunomia (2004).
(3) Energy Cities website [c], accessed February 2006, based on €82/t using September 2006 exchange rates.
(4) Bro (2006), based on €6.1/t using September 2006 exchange rates.

6.1.3 Comparison of biogas production in systems treating source separated biowastes

The biogas production (and subsequent energy production potential) is more dependent on the exact quantity and contents of the wastes accepted at the plant, than the type and characteristics of the digestion system used. In many of the systems, source separated municipal biowastes (either kitchen wastes or kitchen and garden wastes) are co-digested with other organic wastes. The exact characteristics of which were usually un-defined. As such, direct comparisons of the biogas production statistics without considering the broader context of the systems could lead to false impressions and conclusions. A basic comparison of the total annual biogas production and the mean biogas production per tonne of waste treated is shown in Table 66. Due to their importance, the wastes treated at the different plants are included in the table.

Table 66 Biogas production at biowastes treatment plants visited

Plant Capacity	Wastes Treated	Year Started-up	Total Annual Biogas Production (m^3)	Mean Biogas Production per tonne (m^3)
Brecht II 50,000 tpa	Source separated kitchen and garden wastes	1999	5,757,000	**115** (1)
Salzburg 20,000 tpa	Source separated kitchen waste (13,335 tpa), source separated garden waste (4200 tpa), industrial organic waste (3150 tpa)	1992	**2,700,000**	**135** (2)
Niederuzwil 20,000 tpa	Source separated kitchen and garden waste (16,000 tpa), industrial food waste (4000 tpa)	1992	2,400,000	**115 -125** (3)
Otelfingen 12,500 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (2500 tpa)	1996	1,437,500	**100 -130** (3)
Oetwil Am See 11,600 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (1600 tpa)	2000	1,252,800	**108** (3)
Grindsted 52,600 tpa	Source separated kitchen waste (1150 tpa), sewage sludge (39,000 tpa) and industrial organic waste (12,200 tpa), supermarket food wastes (250 tpa)	1997	**1,250,000**	**24** (4)
Ludlow 5000 tpa	Source separated kitchen and garden wastes	2006	*575,000	**100 - 140*** (5)
Jonkoping 30,000 tpa	Source separated kitchen waste	2006	*2,550,000	**85*** (6)
Västerås 23,000 tpa	Source separated kitchen waste (14,000 tpa), grease trap sludge (4000 tpa), ley crop (5000 tpa)	2005	*1,978,000	**86*** (7)

* Values are 'expected' and not yet observed.
Values in bold are actually quoted, values not in bold are based on calculations
(1) Dierick, Personal Communication (2006).
(2) Matousch, Personal Communication (2006).
(3) Knecht, Personal Communication (2006).
(4) Bro, Personal Communication (2006).
(5) Chesshire (2006)
(6) Kall, Personal Communication (2006).
(7) Persson, Personal Communication (2006).

In many cases figures for annual biogas production are extrapolated from the quoted figures of average biogas production per tonne. Also, the Ludlow, Jonkoping and Västerås plants are not yet operating at full capacity, therefore the biogas production figures (and subsequent electricity production and export figures) are based on estimates of the expected biogas production figures, as quoted by contacts on site. All of the sites compared above have positive energy balances due to the biogas they produce. At the Swedish sites (Jonkoping and Västerås) the biogas is upgraded and used as a transport fuel, while at

Otelfingen a proportion of the biogas is upgraded and used as a transport fuel, while the balance is used to produce electricity and heat. At Jonkoping and Västerås the on-site heat requirement is provided by district heating schemes (which are themselves powered from renewable resources, or municipal waste incinerators). At the other sites compared above the biogas is solely used to produce electricity, with heat as a by-product. In all cases the electricity and heat produced cover all on-site requirements, and in all cases (except Salzburg) the excess electricity is sold to the national grid. At Salzburg the excess electricity and heat are used in other parts of the wastes treatment site (such as the MBT plant, the wastewater treatment plant, the hazardous wastes disposal centre and the offices). Figure 303 compares the quoted values for biogas production per tonne. For sites where a range of biogas production is given, the median value is used in Figure 303.

As mentioned above, the Ludlow and Västerås plants were in the start up phase and were not yet receiving waste at full capacity, and therefore were not producing biogas at the expected rate. The expected rates, as quoted by the owner/operators were included in Table 66 and Figure 303. Similarly, the system at Jonkoping was in the construction stage, and therefore the biogas production figure shown is expected rather than observed. It can be seen that excluding the Grindsted digester the expected or observed average biogas production is always between 85 m^3/t and 135 m^3/t. The anaerobic digester at Grindsted shows the lowest average biogas production. This is not surprising given that approximately 74% of its input is low solids sewage sludge (2.5% TS), which has a low biogas potential. The digester operates at a low solids content (4.5%). Source separated kitchen wastes (with a total solids content of 10%) make up only 2.2% of the total plant throughput by mass. The biogas potential for this source separated kitchen waste was found to be 150 m^3/tonne. It is expected that the industrial organic wastes that make up 23% of the incoming waste contribute significantly to the total biogas production. Although the exact type and contents of the industrial organic wastes originated from local food processing industries was not disclosed, their total solids content was given as 50% (Bro, Personal Communication, 2006), which could indicate a high biogas potential.

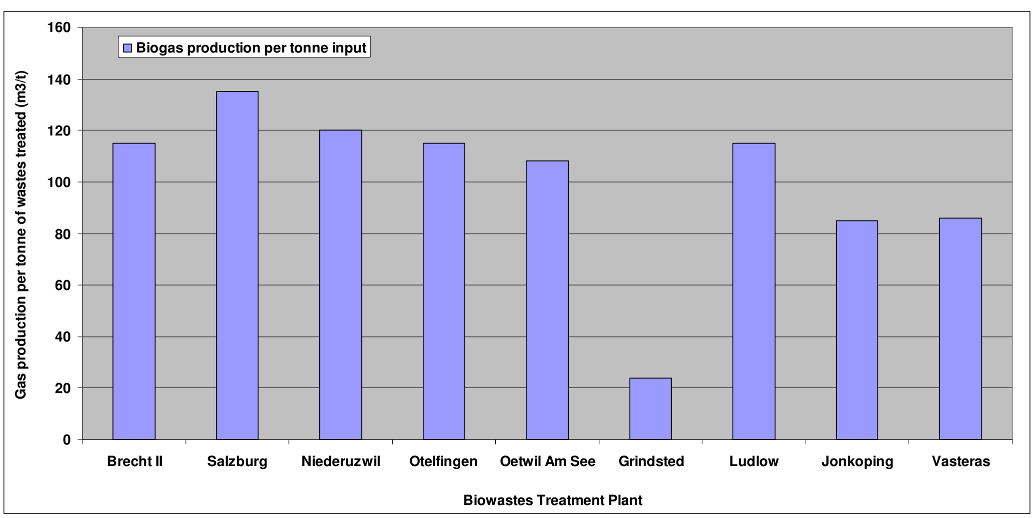

Figure 303 Biogas production per tonne of wastes treated

The differences observed in biogas production values in the two systems installed by OWS Dranco (115 m^3/tonne at Brecht and 135 m^3/tonne at Salzburg) may be due to the industrial organic waste that makes up 15% of the input of the Salzburg plant. It is also possible that the higher proportion of non-organic contaminants in the municipal wastes arriving at the Brecht site (2% compared to 1.5% at Salzburg) also has an effect on the average biogas production. The proportion of kitchen to garden wastes may also be higher at Salzburg, which would lead to a greater biogas production per tonne of waste throughput. Another possible reason for the difference is that the Brecht digester was perhaps operating at a slightly lower temperature than the Salzburg digester. The operating temperature at Brecht at the time of our visit was 49^{o}C, at the lower end of the recommended operating temperature range (48 - 55^{o}C). It is possible that operational temperature was even lower than this during the night. Temperature is known to have a great effect on biological activity, which is known to double with each rise of 10^{o}C (Stander *et al.,* 1968). It is also accepted that even minor temperature changes can have an effect on the biological efficiency. As such, biological process efficiency could perhaps be improved by tighter control of the operating temperature. If the average operating temperature was lower through the course of the year then this would have a negative effect on the biogas production, and biological process efficiency could perhaps be improved by tighter control of the operating temperature. Although OWS Dranco stated that for this digestion system no efficiency losses were detected within the temperature range 48 – 55^{o}C. The fact that the Brecht system was working over its designed capacity, and therefore operating on a retention time shorter than that at Salzburg (20 days at Brecht compared to 20 – 30 days at Salzburg) would also point to a higher biogas production in the Salzburg plant.

Considering the three Kompogas sites, as the pre-treatment and digestion systems are similar, and the recommended operating parameters are the same the minor differences observed (115 – 125 m^3/t at Niederuzwil, 100 – 130 m^3/t at Otelfingen and around 108 m^3/t at Oetwil Am See) must be due to either minor differences in the operation of the plants, or differences in the incoming industrial wastes. Niederuzwil accepts food wastes from fast food restaurants, which could potentially have a higher carbohydrate and fat content and therefore higher biogas potential than the food processing and supermarket wastes accepted at the Otelfingen and Oetwil sites.

Comparing Dranco and Kompogas systems, it can be seen that both digestion systems show very similar average biogas production figures. Mean biogas production in the two Dranco digesters is 125 m^3/t, and mean biogas production in the three Kompogas digesters is 116 m^3/t. The TS percentage in the Dranco systems is quoted as 31% compared to 30% in the Kompogas systems which may account for the slight difference. The Kompogas digesters each accept 20% organic industrial wastes, while of the Dranco digesters, Salzburg accepts 15% organic industrial wastes and Brecht treats only municipal biowastes and paper. The retention time in the Kompogas systems is quoted as 14 days, while the retention time at Brecht and Salzburg is 20 - 30 days. The longer retention time could also partially explain why the biogas production in the Dranco digesters is slightly higher than that in the Kompogas digesters, despite the Kompogas digesters accepting a higher proportion of industrial wastes. It is also possible that municipal biowaste in Belgium and Austria contain a higher proportion of kitchen waste compared to garden waste, than municipal biowaste in Switzerland. This would mean that the biogas potential of the municipal biowastes in Belgium and Austria would be higher than in Switzerland. Beyond these crude comparisons it is not possible to further analyse the biogas productions of the digesters. More detailed information on the exact content of the municipal biowastes and the industrial organic wastes would be required.

A crucial factor in the amount of biogas produced per tonne of waste treated in an anaerobic digester is the total solids content of the waste entering the digester. The higher the total solids content (and particularly the volatile solids percentage within the total solids content) of the waste entering the digester, the more organic matter it will contain and the higher the biogas potential will be. Figure 304 compares the total solids content of the anaerobic digesters visited in comparison to the average biogas production per tonne of wastes treated.

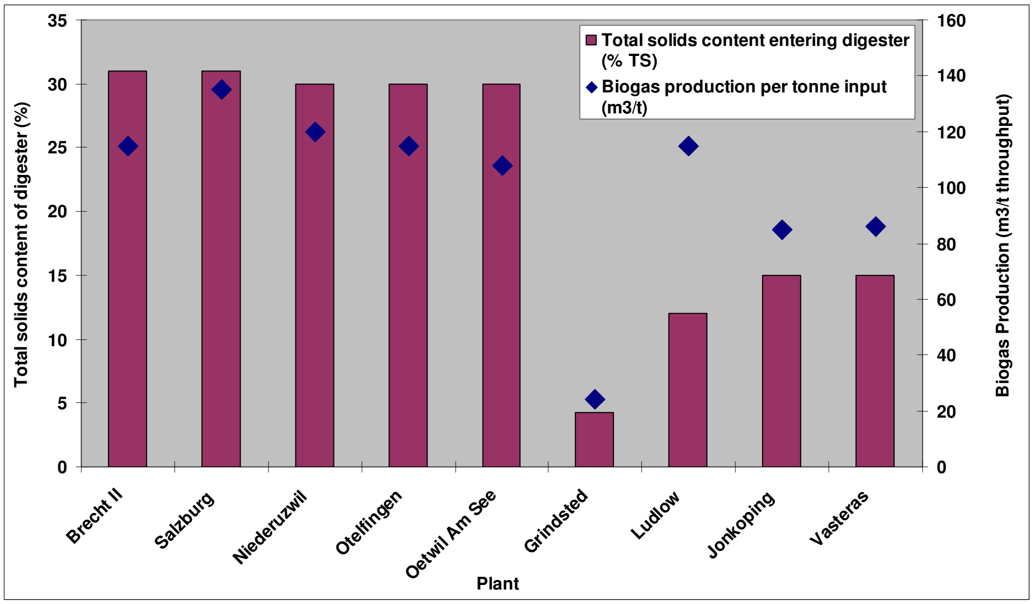

Figure 304 Total solids content of digester and average biogas production per tonne throughput

Generally, anaerobic digesters that operate at a total solids content greater than 15% are classed as 'high solids digesters' or 'dry digesters'. Digesters operating below 15% are classed as 'low solids digesters' or 'wet' digestion systems. Of the plants visited, the Dranco plants (Brecht and Salzburg) and the Kompogas plants (Niederuzwil, Otelfingen and Oetwil Am See) are dry digestion systems and the rest are wet digestion systems (although the plants at Jonkoping and Västerås operate at 15% TS which is on the borderline between the definitions). With the exception of the Ludlow plant (which as previously mentioned has an ambitious 'expected' biogas production, and has yet to be proven) it can be seen that generally speaking the dry digestion systems produce more biogas per tonne throughput. Although the data available was limited (no volatile solids data was available), when the biogas production per tonne of total solids treated in the various digestion systems was compared it can be observed (Figure 304) that the wet digestion systems produce (or are expected to produce, as only the Grindsted figure is proven) more biogas per tonne total solids treated than dry AD systems.

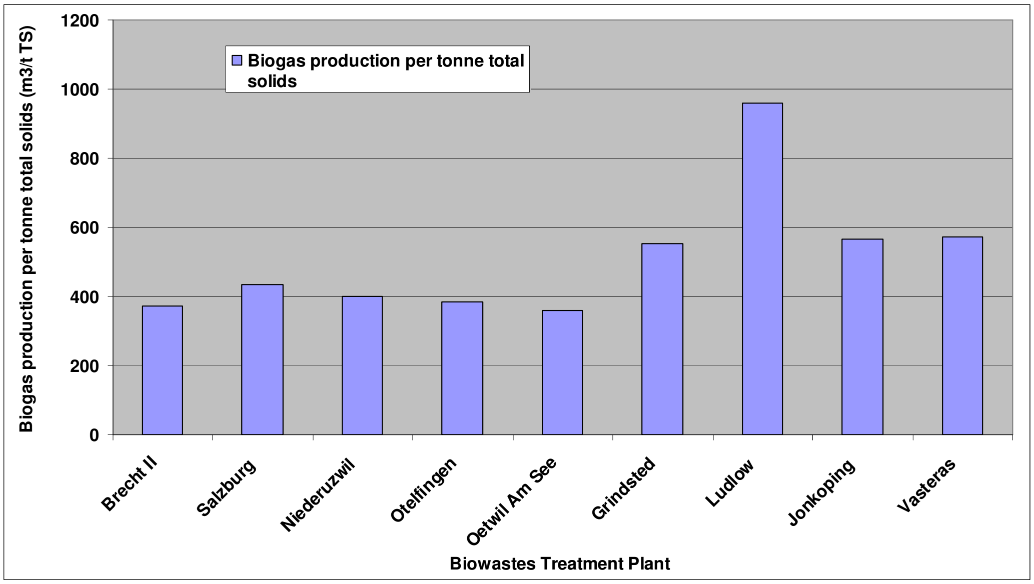

Figure 305 Biogas production per tonne of total solids treated

The average biogas production per tonne of total solids treated in the dry AD systems visited is 390 m^3/tonne TS, compared to an average biogas production per tonne of total solids treated in the wet AD systems visited of 663 m^3/tonne TS (although the figures for Västerås, Jonkoping and Ludlow are not yet proven). The only proven figure for a wet AD system (Grindsted) compares very favourably with all of the dry AD systems visited (553 m^3/tonne TS).

As no volatile solids data was available, and the exact composition of the wastes was unknown, it was not possible to further analyse the extent of the biological conversion occurring within the digestion systems, but perhaps the superior mixing and therefore enhanced waste/biomass contact in the wet digestion systems could lead to a higher volatile solids degradation efficiency, resulting in the higher biogas production per tonne of dry matter. Another possible reason for the difference is that wet systems tend to accept source separated kitchen wastes, whereas dry systems tend to accept source separated kitchen and garden wastes. The garden wastes would provide a higher total solids content, which will contain high percentages of ligno-cellulosic material. Due to the high percentages of ligno-cellulosic material, garden wastes have a lower biogas potential than kitchen wastes, due to low anaerobic biodegradability of lignin.

The Brecht, Salzburg, Niederuzwil, Otelfingen and Oetwil plants all operate in the thermophilic temperature range, and the Grindsted, Ludlow, Västerås and Jonkoping all operate (or will operate) in the mesophilic temperature range (around 37^oC). If all other factors were equal it would be expected that the systems operating in the thermophilic temperature range would have a higher rate of reaction, and possibly produce a little more biogas per tonne of TS. Given that the biogas production per tonne TS is higher on average in the systems operating in the mesophilic temperature range, it is assumed that the fact that the digestion is 'wet' rather than 'dry' may have a greater effect on the percentage TS conversion than the operating temperature. Nevertheless, the difference may be attributed more to the percentage of garden waste in the incoming waste more than any of these factors.

6.1.4 Comparison of energy production in biowastes treatment plants

Although the biogas produced is utilised in different ways at different sites, an attempt has been made to compare the theoretical annual electricity production at each site, were the biogas to be used with the primary aim of producing renewable electricity (as would be the likely case in the UK at present). At all sites where renewable electricity is produced, renewable heat is produced as a by-product. Due to the fact that renewable electricity is a higher value product, the comparisons in this section are based on theoretical electricity production. In all cases it can be assumed that exportable renewable heat will also be produced. Depending on specific cases and local factors this renewable heat may provide an additional income. Where the total electricity production was not given, a calculation of the potential annual electricity production has been made based on the total annual biogas production. A methane percentage of 60% and an electrical conversion efficiency of 30% have been assumed. In real systems, it is probable that the methane percentage of the biogas will be higher than 60%, and that the electrical conversion efficiency will be higher than 30% (probably between 30 and 38%). Many plants have gas engines with higher electrical conversion efficiencies than 30%, for example the Kompogas plants have an electrical conversion efficiency of 35 – 38% (Knecht, Personal Communication, 2006), nevertheless, for the purposes of the consistency of the calculations above an electrical conversion efficiency of 30% has been assumed for all plants. It should also be remembered that unless the digester feeding regime is specifically designed to produce a steady and consistent volume of biogas there will be fluctuations in the volume produced. Therefore some form of biogas storage is necessary on site to ensure a steady flow of biogas to the gas engines. Inaccurate design of biogas storage and utilisation facilities (in conjunction with the digester feeding regime) could result in a variable flow of biogas to the gas engines, resulting in either the gas engines operating at less than capacity or in excess biogas being flared (wasting its calorific value).

From Table 67 it can be seen that all of the plants visited produce enough biogas to produce substantial amounts of renewable electricity. The larger the plant, the more wastes it will treat and the more biogas and therefore renewable electricity (and heat) it can produce. Figure 306 compares the potential electricity production per tonne of waste treated (based on calculations).

It should be remembered that only the Brecht and Grindsted values are actual observed values, as quoted by contacts on-site. Salzburg, Niederuzwil, Otelfingen and Oetwil are based on calculations based on the quoted average biogas production, and Ludlow, Jonkoping and Västerås are based on calculations based on the quoted expected average biogas production. For the purposes of comparison, it is supposed in Figure 306 that all of the biogas produced at Otelfingen, Jonkoping and Västerås is used to produce electricity (rather than to produce transport fuel as is actually the case). It can be seen that with the exception of the Grindsted plant, which primarily treats sewage sludge, the theoretical electricity production per tonne of wastes treated is similar in all plants, ranging between 153 kWh/tonne at Jonkoping and 243 kWh/tonne at Salzburg. The three Kompogas plants theoretically produce between 194 and 216 kWh/tonne of wastes throughput. These values all lie between the upper value calculated for the Salzburg plant and the lower value (calculated for the Jonkoping plant). The average theoretical electricity production per tonne of biowaste treated (excluding the Grindsted plant) is 197 kWh/t (with a standard deviation of 30 kWh/t). It can be seen that the theoretical electricity production at all plants (excluding the Grindsted plant) lie close to this average. Again, without more specific details of the organic wastes accepted, further comment is not possible.

Table 67 Theoretical energy production for biowastes treatment plants visited

Plant, Capacity	**Wastes Treated**	**Total Annual Biogas Production (m^3)**	**Total Annual Electricity Production (MWh/a)**
Brecht II 50,000 tpa	Source separated kitchen and garden wastes	5,750,000	**10,000** (1)
Salzburg 20,000 tpa	Source separated kitchen waste (13,335 tpa), source separated garden waste (4200 tpa), industrial organic waste (3150 tpa)	**2,700,000** (2)	4863
Niederuzwil 20,000 tpa	Source separated kitchen and garden waste (16,000 tpa), industrial food waste (4000 tpa)	2,400,000	4323
Otelfingen 12,500 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (2500 tpa)	1,437,500	2590
Oetwil Am See 11,600 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (1600 tpa)	1,252,800	2256
Grindsted 52,600 tpa	Source separated kitchen waste (1150 tpa), sewage sludge (39,000 tpa) and industrial organic waste (12,200 tpa), supermarket food wastes (250 tpa)	**1,250,000** (3)	**1550-1880** (3)
Ludlow 5000 tpa	Source separated kitchen and garden wastes	*575,000	1035
Jonkoping 30,000 tpa	Source separated kitchen waste	*2,550,000	4593
Västerås 23,000 tpa	Source separated kitchen waste (14,000 tpa), grease trap sludge (4000 tpa), ley crop (5000 tpa)	*1,978,000	3563

* Expected rather than observed

Values in bold are actually quoted, values not in bold are based on calculations

Figures in blue denote calculated values of total annual electricity production if all of the biogas produced was to be used for electricity production rather than for transport fuel. These values are theoretical.

(1) Dierick, Personal Communication (2006).

(2) Matousch, Personal Communication (2006).

(3) Bro, Personal Communication (2006).

As far as plant economics are concerned, a more important factor to consider than the total biogas production and total electricity produced (or potentially produced) is the total amount of electricity that can be exported for use outside the plant. The amount of exportable energy is dependent on two factors, the total amount of biogas (and therefore energy/electricity) produced, and the amount of energy/electricity required on-site. These figures (again based on calculations unless otherwise stated) are compared in Table 68.

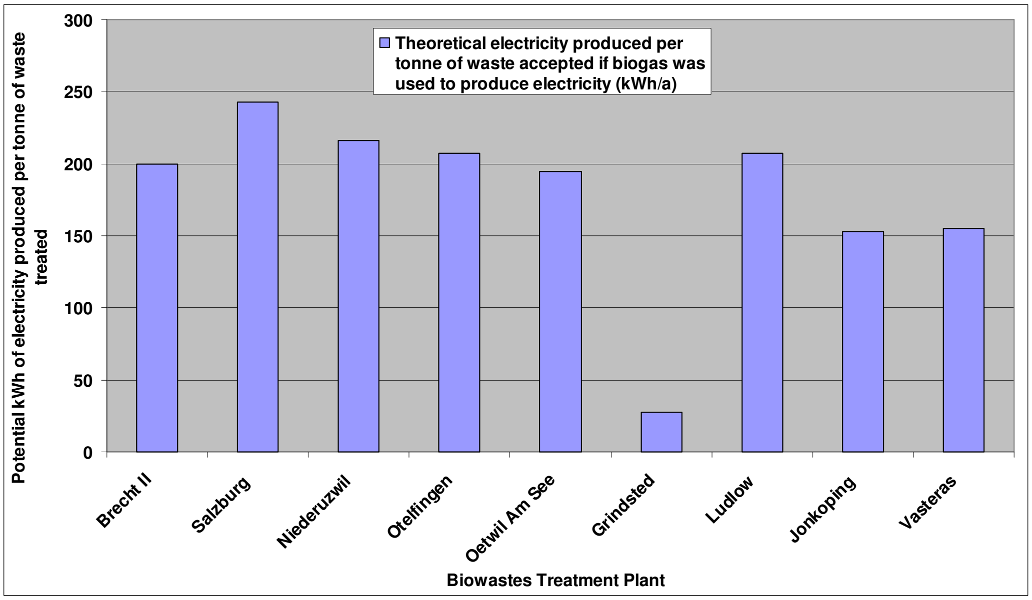

Figure 306 Potential electricity production per tonne of waste treated (based on calculations)

No on-site electricity requirement was available for the Salzburg AD plant, therefore an on-site electricity requirement of 30 – 40% was assumed, based on the requirement at the similar Dranco plant installed at Brecht. It is possible that the on-site electricity requirement is lower at Salzburg due to the lower incidence of non-organic contaminants and the fact that there is only one small communiting drum operational compared to two larger drums operational in Brecht. The figures quoted for Ludlow are based on a quoted expected biogas production of 100 – 140 m^3/tonne (Chesshire, 2006), with an average of biogas production of 120 m^3/tonne assumed). The expected on-site electricity requirement at Ludlow is quoted as 5% (Chesshire, 2006), which seems unrealistically low based on observed values in other similar systems, although the plant will have limited energy requirements compared to other plants due to the lack of upfront mechanical separation and the current lack of post-AD digestate treatment. It is likely that the on-site energy requirement will be higher than this (especially once the de-watering stages are added, and if mechanical separation stages are retro-fitted to the system). Although the plants at Jonkoping and Västerås are powered from the grid, based on values for other similar systems it is assumed that the electricity required would be approximately 25% of that produced were the biogas to be converted in a CHP system. In reality, the extra biogas upgrading, compression and pumping involved when biogas is utilised as a transport fuel would increase the amount of electricity required on the site (as compared to gas engines/CHP units). The Grindsted value of 35% is high, as this includes the electricity requirements of the attached municipal sewage treatment works. The proportion of this electricity used by the biowastes treatment plant as compared to the municipal wastewater treatment plant was not made available. The theoretical electricity produced (based on mean biogas production and throughput) and the amount of electricity theoretically exportable are shown in Figure 307.

Table 68 Energy production for biowastes treatment plants visited

Plant, Capacity	Wastes Treated	Total Annual Electricity Production (MWh/a)	Percentage Used On-site (%)	Total Exported Electricity (MWh/a)
Brecht II 50,000 tpa	Source separated kitchen and garden wastes	**10,000** (1)	**30 - 40** (1)	6000 – 7000
Salzburg 20,000 tpa	Source separated kitchen waste (13,335 tpa), source separated garden waste (4200 tpa), industrial organic waste (3150 tpa)	4863	n/a 30 – 40 assumed	All used on adjacent wastes treatment sites
Niederuzwil 20,000 tpa	Source separated kitchen and garden waste (16,000 tpa), industrial food waste (4000 tpa)	4323	**10 - 15** (2)	3674 – 3890
Otelfingen 12,500 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (2500 tpa)	2590	**10 – 15** (2)	2200 – 2331
Oetwil Am See 11,600 tpa	Source separated kitchen and garden waste (8000 tpa), industrial food waste (2000 tpa)	2256	**10 – 15** (2)	**~1500** (2) and (3) 1918 - 2034
Grindsted 52,600 tpa	Source separated kitchen waste (1150 tpa), sewage sludge (39,000 tpa) and industrial organic waste (12,200 tpa), supermarket food wastes (250 tpa)	**1550** (4)	**35** (4)	**1000-1250** (4)
Ludlow 5000 tpa	Source separated kitchen and garden wastes	1035*	**5** (5)	**1300** (5) 983
Jonkoping 30,000 tpa	Source separated kitchen waste	4593*	**33** (6)	3031
Västerås 23,000 tpa	Source separated kitchen waste (14,000 tpa), grease trap sludge (4000 tpa), ley crop (5000 tpa)	3563*	n/a 25 assumed	2672

* Expected rather than observed
Values in bold are actually quoted, values not in bold are based on calculations
Figures in blue denote calculated values of total annual electricity production if all of the biogas produced was to be used for electricity production rather than for transport fuel. These values are theoretical.
(1) Dierick, Personal Communication (2006).
(2) Knecht, Personal Communication (2006).
(3) Kompogas website [c] (accessed June 2006).
(4) Bro, Personal Communication (2006).
(5) Chesshire (2006).
(6) Kall, Personal Communication (2006).

The values in Figure 307 are based on the assumptions on total biogas production described above (Table 66), and subsequent assumptions on the amount of electricity that that biogas could produce (Table 67) combined with the quoted (or in some cases estimated) on-site requirements. The first point to be made is obvious, that the more biowastes that are treated, the more biogas (and thus energy/electricity) will be available. Secondly, based on available references between 5% and 40% of the total electricity produced from the anaerobic digestion of biowastes will be required to cover on-site requirements. The exact percentage required is case specific, and is dependent on many factors such as the extent and type of mechanical pre-treatment (which is dependent on the quality and potential contaminants in the incoming wastes), the type of digester, mixing and pumping requirements among others, and perhaps most importantly considering the amount of energy potentially required, the type of post-AD treatment. De-watering and in particular post-AD in-vessel composting can require significant electrical input. Unfortunately, exact breakdowns of the energy requirements of the different component parts of biowaste treatment plants were not made available, so no further analysis or comment could be made.

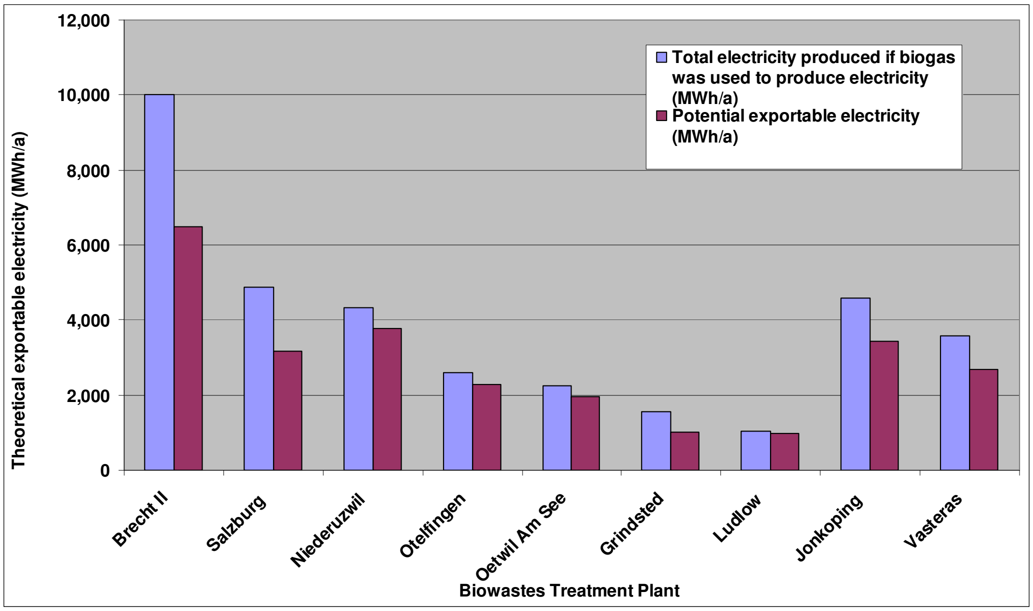

Figure 307 Total electricity theoretically produced (and exported) if all of the biogas was used for electricity production

Figure 308 shows the potential theoretical electricity exported per tonne of wastes treated, based on the total theoretical electricity production minus the on-site electricity requirement.

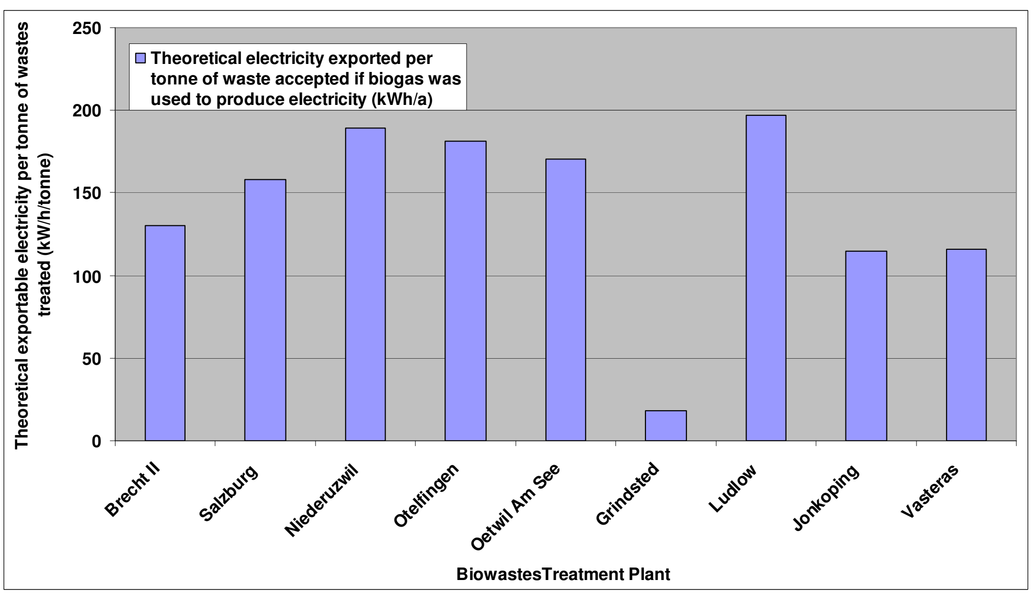

Figure 308 Potential theoretical electricity exported per tonne of wastes treated

The electricity exported per tonne of wastes treated is lowest at Grindsted (31 kWh/tonne throughput), because the Grindsted digester is a wet digestion system based on a low solids content, in which the main waste treated is sewage sludge (2.5% TS), which makes up 74% of total throughput by volume. As mentioned above, the expected on-site electricity requirement at Ludlow was quoted as 5% (Chesshire, 2006), which seems low. It is primarily this low quote for on-site electricity requirement that propels the Ludlow plant towards the higher reaches of the scale (197 kWh/a of exportable electricity per tonne of wastes treated). From Figure 307 and Figure 308, it can be observed that there is no apparent correlation between electricity requirements on-site and the operating temperature range. This is because the thermophilic systems are heated exclusively by the waste heat from the conversion of biogas to electricity. Given the different uses of the biogas produced at the AD plants visited, and that not all of the sites produce exportable electricity, the above comparisons are theoretical. Actual electricity exported from each site is shown in Figure 309.

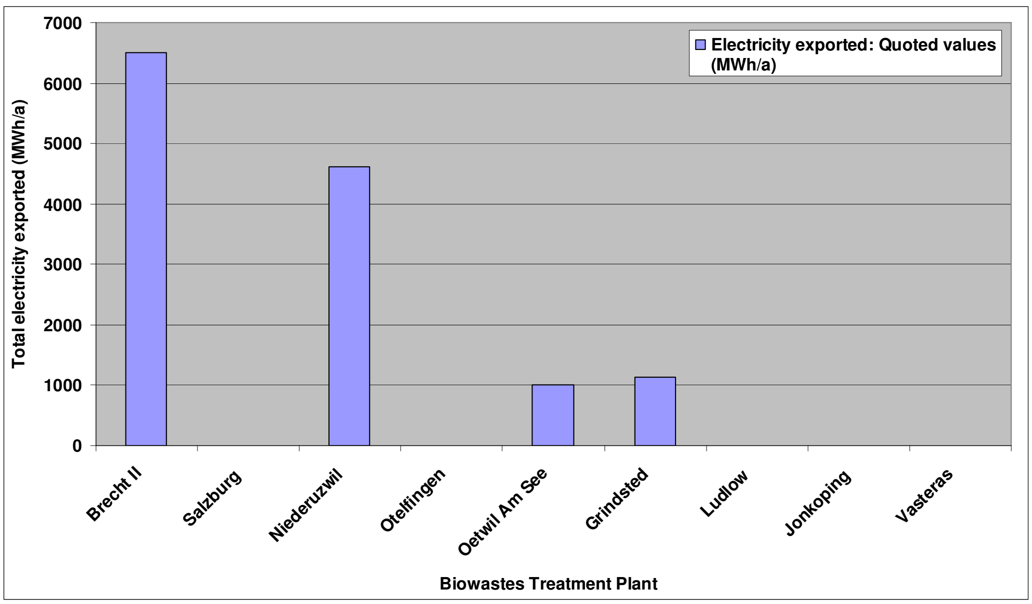

Figure 309 Total electricity actually exported

Figure 309 shows the approximate amounts of electricity actually exported form the sites visited. As described above, Salzburg does not export electricity to the grid, as all of the electricity is used to power other wastes treatment processes owned by SAB Salzburg on the same and adjacent sites. Otelfingen exports some electricity, but amounts vary depending on the amount of biogas that is required as a vehicle fuel. Despite exporting electricity, Ludlow is not included as it is not yet running at full capacity and the amount of electricity exported is not yet known. At Jonkoping and Västerås, which are also not yet running at full capacity, all of the biogas will be upgraded and used as a vehicle fuel, therefore no electricity will be exported, and on-site requirements will be met by outside sources, which will obviously constitute an extra expense.

The Brecht plant reportedly produces in the region of 10,000 MWh/a of electricity (Dierick, Personal Communication, 2006), of which it requires 30 – 40% for on-site use (Dierick, Personal Communication, 2006). Therefore, the plant produces an exportable excess in the region of 6000 – 7050 MWh/a. The Niederuzwil plant reportedly produces in the region of

4834 – 5705 MWh/a of electricity, of which it requires 10 – 15% for on-site use (Knecht, Personal Communication, 2006). Therefore the plant produces an exportable excess in the region of 4109 – 5134 MWh/a of electricity. The Oetwil Am See plant is quoted as producing an exportable excess of approximately 1500 MWh/a of electricity (Kompogas website [c], accessed June 2006), which is somewhat lower than the calculated value of 1918 – 2034 MWh/a based on the figures quoted during the site visit. Possible reasons for the differences include a change of the incoming waste, inaccuracies in the calculation based on assumptions made, inaccuracies in quoted values or the fact that the figures compared may be for different years of operation. The value referenced by Kompogas has been included in Figure 309. Given the difference in the value quoted by Kompogas and the value calculated, it is possible that the value calculated for Niederuzwil is also similarly higher than what is actually observed. Grindsted produces 1550 – 1800 MWh/a of electricity, and on-site consumption (including the wastewater treatment plant) is 550 MWh/a (Bro 2006). This would leave an exportable excess of 1000 – 1250 MWh/a of electricity, after all demands from the municipal wastewater treatment plant and the biowastes treatment plant are covered.

6.1.5 Potential incomes from biogas produced

Assuming the total annual volumes of biogas produced displayed in Table 66, and assuming the amounts of exportable electricity calculated in Table 68, the potential incomes from the biogas produced, given current UK prices, can be observed in Figure 310. Figure 310 is based on the theoretical principle that the systems were operating in the UK at present, and that the chosen biogas utilisation method would remain the same. For the Otelfingen plant, it is assumed that 50% of the biogas is used to produce transport fuel, and 50% to produce electricity and heat. These figures (and those displayed in Figure 310, Figure 311, Figure 312, Table 69 and Table 70) are based only on the biogas available for export, rather than the total volume of biogas produced. Therefore, if biogas upgrading and utilisation as a transport fuel is the desired end use, there would be extra biogas available (and therefore extra income available), however on-site electricity and heat would need to be sourced from elsewhere which would incur extra expense.

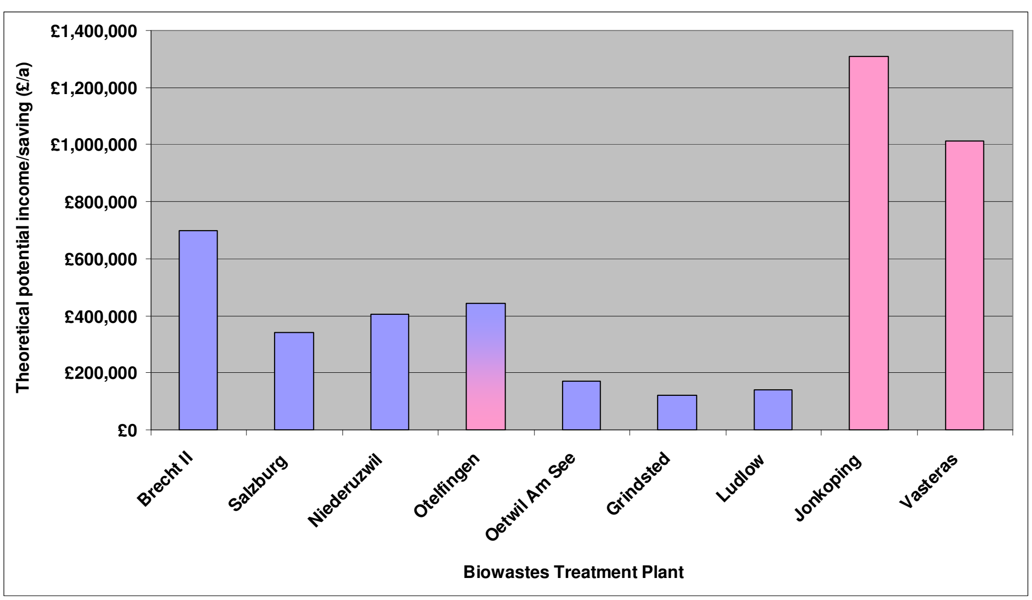

Figure 310 Potential income/savings from biogas

Estimated incomes (or savings) from exported energy, based on calculations from all available data are shown in Figure 310. The price for electricity is based on the current average price for renewable electricity from AD according to the NFPA website (£107.50/MWh). The estimated income from the use of biogas as a transport fuel is based solely on petrol savings (based on a petrol price of £0.90/litre). The estimated income from biogas as a transport fuel does not take into consideration the costs associated with upgrading or infrastructure, of the cost of finance. No account is taken of the fact that biogas may be sold cheaper than petrol to encourage the use of biomethane, or of the potential cost (or effect on cost saving) of any tax imposed on biogas sold as a transport fuel. These factors would all increase costs and lower the potential income or saving as is calculated here. No income from heat energy is assumed. Any income derived from the sale of excess heat can be considered a bonus. Due to the different capacities of the plants, the potential incomes/savings can be better compared by observing the figures per tonne of wastes treated (Figure 311). Again, the values used represent the biogas available for export, rather than the entirety of the biogas produced.

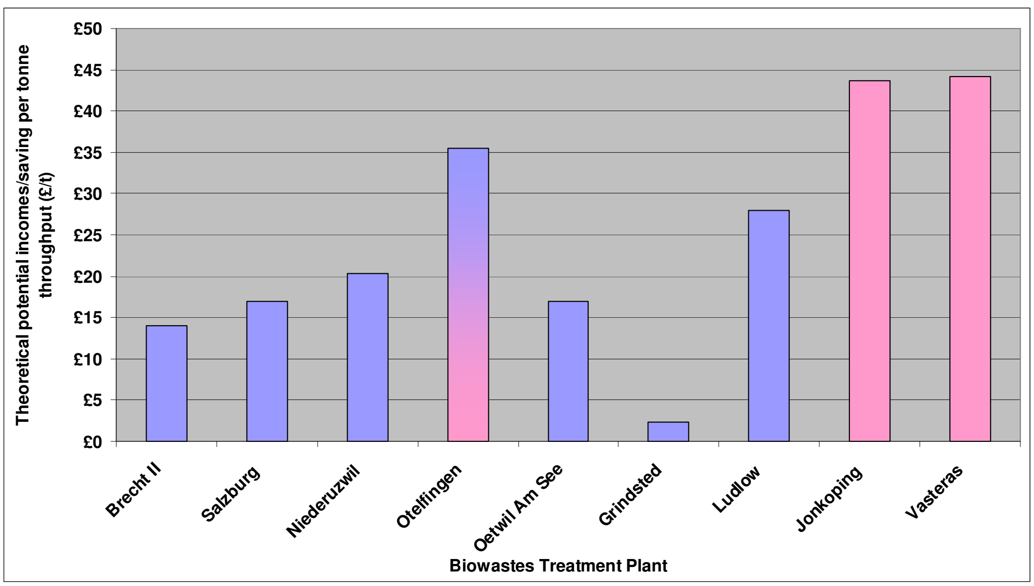

Figure 311 Theoretical potential income/saving from biogas per tonne of waste treated

Although these comparisons are simplistic and do not take into account many important factors (such as infrastructure costs, finance and tax), the main point of note is that a higher income (or cost saving) is likely to be available if the biogas is upgraded and used as a transport fuel. The two plants at which the biogas is upgraded and used as a vehicle fuel show a considerably higher income/saving per tonne of waste treated than all of the other sites (approximately £44/t compared to an average of £16/t for the sites converting the biogas to electricity). The Otelfingen plant uses the biogas for both transport fuel and electricity and heat production, and shows the third highest biogas production based on these basic comparisons. A 50:50 split between transport fuel and electricity and heat production is assumed, which is not necessarily the case. Also, the Otelfingen site is a demonstration plant and it would not normally be economic (especially on such a small scale plant) to use the two biogas utilisation options. Table 69 and Figure 312 compare the approximate volume of biogas available for export from the sites, the litres of petrol that could be replaced, and the cost of that petrol in the UK at current prices. If the on-site electricity and heat requirements were met from sources other than biogas produced on site, then the figures in Table 69 and Figure 312 would be significantly higher.

Table 69 Litres of petrol potentially replaced and potential saving if the exportable biogas from the plants were to be upgraded and used as a transport fuel

Plant	Capacity	Approximate volume of biogas available for export (m^3/a)	Litres of petrol replaced (l/a) (1)	Theoretical Potential Saving (£/a) (2)
Brecht II	50,000	3,737,500	2,130,375	£1,917,338
Salzburg	20,000	1,755,000	1,000,350	£900,315
Niederuzwil	20,000	2,100,000	1,197,000	£1,077,300
Otelfingen	12,500	1,257,813	716,953	£645,258
Oetwil Am See	11,600	1,096,200	463,125	£562,351
Grindsted	56,200	812,500	311,363	£416,813
Ludlow	5,000	546,250	311,363	£280,226
Jonkoping	30,000	1,708,500	973,845	£876,461
Västerås	23,000	1,408,500	802,845	£722,561

(1) based on 1 m^3 of biogas replacing 0.57 litres of petrol (Murphy, 2005).
(2) based on an average petrol price of £0.90/litre.

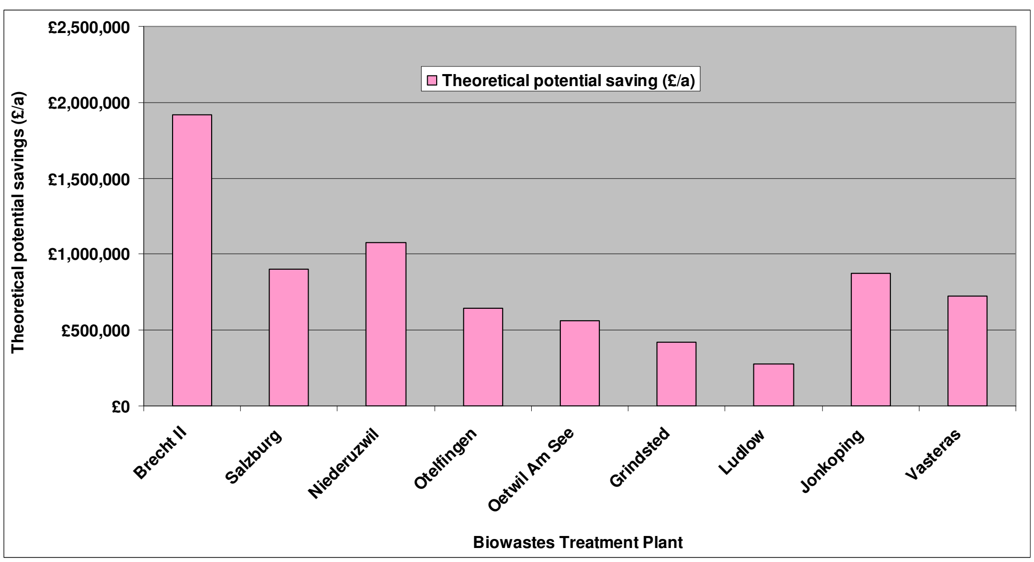

Figure 312 Theoretical potential saving from biogas if all exportable biogas was upgraded and used as a petrol substitute

It can be seen that considerable volumes of petrol could be replaced by the anaerobic digestion of biowastes, and the upgrading and use of the biogas produced as a transport fuel. This would result in considerable cost savings, and considerable carbon emission reductions (Table 70).

Table 70 Litres of petrol potentially replaced and potential carbon dioxide emission reduction if the exportable biogas from the plants were to be upgraded and used as a transport fuel

Plant	Capacity	Approximate volume of biogas available for export (m^3/a)	Litres of petrol replaced (l/a) (1)	Carbon Dioxide Emission Reduction (tpa) (2)
Brecht II	50,000	3,737,500	2,130,375	5028
Salzburg	20,000	1,755,000	1,000,350	2361
Niederuzwil	20,000	2,100,000	1,197,000	2825
Otelfingen	12,500	1,257,813	716,953	1692
Oetwil Am See	11,600	1,096,200	463,125	1475
Grindsted	56,200	812,500	311,363	1093
Ludlow	5,000	546,250	311,363	735
Jonkoping	30,000	1,708,500	973,845	2298
Västerås	23,000	1,408,500	802,845	1895

(1) based on 1m^3 of biogas replacing 0.57 l of petrol (Murphy, 2005)
(2) based on 1 litre of petrol producing 2.36kg of CO_2 (Skanetrafiken, 2006)

Although based on calculations supported by limited data (or unproven data) and several important assumptions, the comparisons reveal four main points of note:

- All of the AD plants visited produce exportable renewable energy.
- Dry digestion systems produce more biogas per tonne of wastes treated, based on their higher total solids content.
- Wet digestion systems on average produce more biogas per tonne of total solids throughput than dry AD systems, although this could be attributed to differences in the wastes treated.
- The income is likely to be greater if the biogas is used as a transport fuel.

The biogas production (and subsequent energy production potential) is highly dependent on the exact quantity and contents of the wastes accepted at the plant, as well as the type and characteristics of the digestion system used.

6.1.6 Landfill diversion potential in AD systems treating source separated biowastes

In all of the AD systems digesting (or co-digesting) source separated kitchen and/or garden waste, the digestate was used on-land. In three of the nine cases (Brecht II, Salzburg and Grindsted) digestate was de-watered and composted after AD, and then the solid ‘compost’ used on land. In the other 6 cases, digestate was (or will be, in the cases of Ludlow and Jonkoping) de-watered, and then the solid phase and the portion of the liquid phase that is not recycled for use on-site will be separately transported, stored and spread on land. In all of the systems treating source separated BMW visited as part of this report, only the non-organic 'contaminants' introduced by the public and separated before (or after) digestion are landfilled. Therefore the percentage landfill diversion under normal operating circumstances depends entirely on the percentage contaminants in the incoming waste, which is shown in Figure 313.

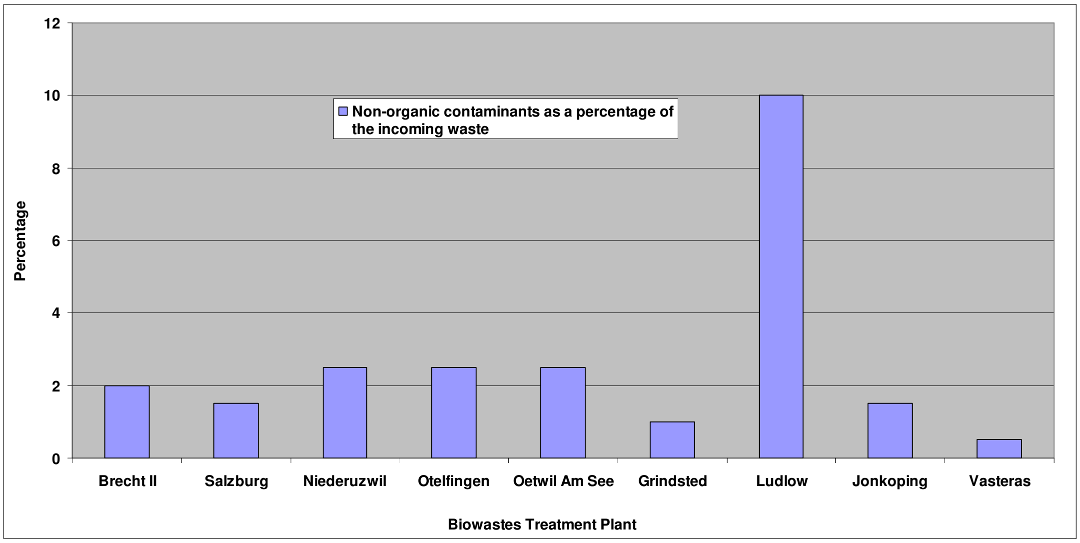

Figure 313 Percentages of non-organic contaminants in incoming wastes stream

The percentage contaminants in the incoming waste ranged from less than 0.5% at Västerås where source separation was well developed to 10% at Ludlow, where the source separation of BMW had just started. It is expected that the high incidence of non-organic contamination arriving at the Ludlow plant will decrease with time. It can be seen that the plants in Sweden (Västerås and Jonkoping), Denmark (Grindsted), Austria (Salzburg) and Switzerland (Otelfingen, Oetwil Am See, and Niederuzwil) all have low levels of non-organic contamination arriving on-site in the source separated biowastes (<3%). At Brecht, the non-organic contamination was quoted as 2%. This quoted value was surprisingly low considering the fact that citizens deposit their green waste in plastic bags, as can be seen in Figure 42 and Figure 44. The success of source separation is crucial to the realisation of a quality compost/CLO that can be used on land, and good continuous public education is key to achieving this. With regards to achieving good public co-operation experiences in other European countries have shown that:

- The quality of source separation always increases over time
- The collection of biowastes in paper bags decreases contamination rates by eliminating plastics, and by serving as a constant reminder to the householder that only biodegradable wastes should go into it
- An educated public who realise ***why*** they are source separating are less likely to introduce contaminants
- A tariff system that involves a choice of whether to source separate or not (as in Sweden) can keep contamination rates down
- All money spent on public education is well spent, and is money that will be saved many times over later

The public education schemes and waste collection schemes used in these countries are described in the case studies.

In certain circumstances, isolated incidents of contamination may occur which could contaminate the digestate beyond the legal limits for land application, ruling out the possibility of using it on land. In these rare cases, which can be avoided by careful monitoring of the incoming waste, then an alternative digestate disposal route will need to be found. Within the non-organic contaminants, metals and other contaminants can be recycled, and plastics/woody material and some other contaminants can be sent for thermal treatment to recover energy. Some systems (particularly wet digestion systems) need to remove sand, stones and other inerts, and these can also be re-used or landfilled. All in all, as long as the standards of the incoming waste are consistent, and the process operates normally, then landfill diversion can be considered to be 95 – 99%, or 100% minus contaminants.

6.1.7 Comparison of water requirements

For most plants treating source separated biowastes little or no fresh water addition is required. Generally, the required total solids content for digestion can be achieved by:

- Co-digestion of various wastes to reach the required total solids content
- Rainwater harvesting
- Process water recycling
- The use of raw or treated wastewater from a water treatment plant (as AD plants are often sited adjacent or close to wastewater treatment plants

Table 71 contains notes on the freshwater requirement (if given) and how it is met in the plants visited.

Table 71 Water requirements at biowastes treatment plants visited

Plant Capacity	Wastes Treated	Fresh Water Requirement
Brecht II 50,000 tpa	Source separated kitchen and garden wastes	Covered with incoming wastes and rainwater collection 4800 m^3/a fresh water required for production of steam and polymer solution
Salzburg 20,000 tpa	Source separated kitchen waste (13,335 tpa), source separated garden waste (4200 tpa), industrial organic waste (3150 tpa)	On the same site as a municipal sewage treatment plant. Can recycle water and wastewater
Niederuzwil 20,000 tpa	Source separated kitchen and garden waste (16,000 tpa), industrial food waste (4000 tpa)	Covered by rainwater collection
Otelfingen 12,500 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (2500 tpa)	Covered by rainwater collection
Oetwil Am See 10,000 tpa	Source separated kitchen and garden waste (8000 tpa), industrial food waste (2000 tpa)	Covered by rainwater collection
Grindsted 52,600 tpa	Source separated kitchen waste (1150 tpa), sewage sludge (39,000 tpa) and industrial organic waste (12,200 tpa), supermarket food wastes (250 tpa)	On the same site as a municipal sewage treatment plant. Can recycle water and wastewater. 81,746 m^3/a of treated municipal wastewater recycled, 90% used to clean de-watering machine. 300 m^3/a fresh water for consumption and sanitation
Ludlow 5,000 tpa	Source separated kitchen and garden wastes	Zero/very little
Jonkoping 10,000 tpa	Source separated kitchen waste	On the same site as a municipal sewage treatment plant. Can recycle water and wastewater
Västerås 23,000 tpa	Source separated kitchen waste (14,000 tpa), grease trap sludge (4000 tpa), ley crop (5000 tpa)	Covered with incoming wastes and rainwater collection

6.1.8 Comparison of wastewater production and treatment

A basic comparison of the wastewater treatment arrangements at the sites visited is shown in Table 72.

On most sites treating source separated biowastes no wastewater is produced, as excess process water is of the required standard to be spread on land. In those sites where the quality is not of the required standard for land application, excess process water (that is not re-used on-site) is treated in wastewater treatment plants. In Grindsted and Salzburg wastewater is re-circulated back to the adjacent sewage treatment works (sewage treatment works and biowastes treatment owned by same company and part of same complex). In Brecht, excess process water is sent for treatment at the wastewater treatment plant at the adjacent landfill site (landfill site and biowastes treatment plant owned by same company and part of same complex). The Jonkoping plant is also on the same site as a municipal sewage treatment works, but it is expected that the excess process water will be spread on land as a fertiliser. At the Kompogas (Niederuzwil, Otelfingen and Oetwil Am See), Västerås and Ludlow sites digestate is (or will be in the case of Ludlow) de-watered, with the solid and liquid fractions being spread on agricultural land by farmers.

Table 72 Wastewater treatment at biowastes treatment plants visited

Plant Capacity	Wastes Treated	Wastewater Treatment
Brecht II 50,000 tpa	Source separated kitchen and garden wastes	Wastewater treated at the wastewater treatment facility at the adjacent landfill site
Salzburg 20,000 tpa	Source separated kitchen waste (13,335 tpa), source separated garden waste (4200 tpa), industrial organic waste (3150 tpa)	On the same site as a municipal sewage treatment plant. Can recycle water and wastewater between sites
Niederuzwil 20,000 tpa	Source separated kitchen and garden waste (16,000 tpa), industrial food waste (4000 tpa)	None – liquid fertiliser spread to land
Otelfingen 12,500 tpa	Source separated kitchen and garden waste (10,000 tpa), industrial food waste (2500 tpa)	None – liquid fertiliser spread to land
Oetwil Am See 10,000 tpa	Source separated kitchen and garden waste (8000 tpa), industrial food waste (2000 tpa)	None – liquid fertiliser spread to land
Grindsted 52,600 tpa	Source separated kitchen waste (1150 tpa), sewage sludge (39,000 tpa) and industrial organic waste (12,200 tpa), supermarket food wastes (250 tpa)	On the same site as a municipal sewage treatment plant. Can recycle water and wastewater between sites
Ludlow 5000 tpa	Source separated kitchen and garden wastes	None expected – liquid fertiliser will be spread to land
Jonkoping 10,000 tpa	Source separated kitchen waste	None expected – liquid fertiliser will be spread to land Although also on the same site as a municipal sewage treatment plant. Can recycle water and wastewater between sites
Västerås 23,000 tpa	Source separated kitchen waste (14,000 tpa), grease trap sludge (4000 tpa), ley crop (5000 tpa)	None – liquid fertiliser spread to land

6.1.9 Space requirements

The land-take, footprint or space requirement is more important in some cases than in others, depending on the intended site of the plant. Most AD system suppliers can flexibly engineer their processes to minimise footprint, and can usually work within any specific guidelines set by the client.

The Brecht plant footprint is approximately 10,000 m^2 in total. The plant treats 50,000 tpa of municipal, biowastes. Therefore a total area of 10,000 m^2 corresponds to 0.2 m^2 per tonne of biowaste processed, or 5 tonnes of waste treated per m^2 of land. It is estimated that a Kompogas facility treating approximately 20,000 tpa of municipal biowastes (such as the Niederuzwil plant) would require an area of approximately 5000 m^2 (Kompogas website [c], accessed June 2006). This corresponds to 0.25 m^2/tonne of waste treated, or 4 tonnes of waste treated per m^2 of land. These values are very similar. The slightly smaller space required (per tonne of waste treated) by the Dranco system in Brecht is probably primarily due to the fact that the throughput is higher. The fact that Dranco digesters are vertical and Kompogas digesters are horizontal will undoubtedly have an effect, although the space taken up by the anaerobic digesters themselves is small in comparison to the total area of the plant.

The land required by wastes reception areas, mechanical separation areas and composting areas will all be significant compared to the actual footprint of the anaerobic digesters.

The land requirement for the Västerås plant (including the biogas plant, the gas upgrading plant, the silage storage area and internal roads) is 22,411 m^2 (Persson, Personal Communication, 2006). From visual observations the area required on-site for ley crop storage represents a significant proportion of this total. This area would not be required in any system treating only wastes. Also, the biogas upgrading, compression and pumping plants take up more space than would be required by a CHP gas engine, which would be the most likely biogas utilisation method in the UK at present. The land requirement for the biogas plant is 12,000 m^2, which breaks down to include 2320 m^2 for the main building, and 5915 m^2 for internal roads and driving areas (Persson, Personal Communication, 2006). Therefore assuming 23,000 tpa of wastes were to be treated, and that biogas upgrading, compression and pumping plants would not be required, the total area of 12,000 m^2 corresponds to 0.52 m^2 per tonne of biowaste processed, or 1.92 tonnes of waste treated per m^2 of land.

Although based on only three examples, it can be seen that dry AD systems (Brecht and Kompogas) require a significantly smaller area of land to treat similar tonnages of waste than wet AD systems such as Västerås (0.2 and 0.25 m^2/tonne of waste treated in dry AD systems, compared to 0.52 m^2 per tonne of waste treated in the wet AD system). This lower land requirement is to be expected due to the higher total solids content in dry digestion systems. For all AD plants treating municipal biowaste the following points can be concluded:

- All AD plants treating source separated BMW will require a considerably smaller area than in-vessel composting plants treating the same waste at the same throughput.

- The footprint of the anaerobic digesters themselves will not be important in comparison with the land required for unloading areas, mechanical separation areas and particularly composting areas. If space is an issue, then perhaps a system without the post AD composting or maturation should be considered, with or without de-watering prior to land application. Forced aeration composting systems such as the Thoni in-vessel composting system employed at Otelfingen (see Section 5.1.5.3) can considerably reduce the time and space required for post AD treatment.

- The footprint per tonne of waste treated decreases as the capacity of the plant increases.

- Generally (and from visual observation rather than actual data) the plant footprints are all reasonably similar, and despite high land prices, footprint would not usually be one of the most important factors in choosing between plant designs.

6.1.10 Summary of comparison of AD systems treating source separated BMW

In all of the AD systems digesting (or co-digesting) source separated kitchen and/or garden waste the digestate was used on land, and only the non-organic ‘contaminants’ are landfilled, assuming normal process operation. Therefore the percentage landfill diversion under normal operating circumstances depends on the percentage contaminants in the incoming waste (0.5% to 10% at the sites visited). The success of source separation is crucial to the realisation of a quality compost/CLO that can be used on land, and good continuous public education is key to achieving this. With regards to achieving good public co-operation experiences in other European countries have shown that:

- The quality of source separation always increases over time.
- The collection of biowastes in paper bags decreases contamination rates by eliminating plastics, and by serving as a constant reminder to the householder that only biodegradable wastes should go into it.
- An educated public who realise why they are source separating are less likely to introduce contaminants.
- A tariff system that involves a choice of whether to source separate or not (as in Sweden) can keep contamination rates down.
- All funds spent on public education is well spent, and these will be saved many times over later in the project.

As long as the standards of the incoming waste are consistent, and the process operates normally, then landfill diversion can be considered to be 95 – 99%, or 100% minus contaminants.

With regards to economics, AD systems are large scale projects, incorporating many different technologies, and the cheapest solution is not always the best solution. Recurrent attitudes amongst suppliers were '*costs are case specific*', '*costs in Europe would not necessarily be applicable in the UK*' and '*you get what you pay for*'. These points must be considered when comparing the capital costs of different AD systems. The capital costs for anaerobic digestion plants treating industrial organic and agricultural wastes compare well with sites accepting municipal biowastes, mainly because of the fact that less mechanical pre-treatment is required (usually only very basic screens are required, to remove large non-organic contaminants from agricultural and industrial wastes). Costs are always case specific, and different systems address specific localised requirements to specific local legislation. Plants with a smaller throughput generally experience higher costs per tonne. More detail on the treatment of BMW and OFMSW in Europe is available in Eunomia (2002a), and Eunomia (2002b). Few suppliers or operators revealed operating costs. Due to the lack of UK reference plants, areas of uncertainty on the economics of the AD of BMW in the UK remain.

For most plants treating source separated biowastes little or no fresh water addition is required. The required total solids content for digestion can be achieved by the co-digestion of various wastes to reach the required total solids content, by rainwater harvesting and process water recycling. It can also be possible to utilise the wastewater from other nearby processes. Although most plants require little or no fresh water addition for digestion, some fresh water will always be required for wash-downs, steam production among other activities. On most sites treating source separated biowastes no wastewater is produced, as excess process water (not required for the dilution of incoming wastes) is of the required standard to be spread on land.

The land-take, footprint or space requirement is more important in some cases than in others, depending on the intended site of the plant. Most AD system suppliers can flexibly engineer their processes to minimise footprint, and can usually work within any specific guidelines set by the client. The land required by wastes reception areas, mechanical separation areas and composting areas will all be significant compared to the actual footprint of the anaerobic digesters. For all types of AD systems, it can be said that the footprint per tonne of waste treated decreases as the capacity of the plant increases. Although based on only three examples, it can be seen that dry AD systems require a significantly smaller area of land to treat similar tonnages of waste than wet AD systems. This lower land requirement is to be expected due to the higher total solids content in dry digestion systems. For all AD plants treating municipal biowaste the following points were concluded.

With regard to biogas production and energy balances the first point to be made is that the more biowastes that are treated, the more biogas (and thus energy/electricity) will be available. Secondly, the biogas production (and subsequent energy production potential) is more dependent on the exact quantity and contents of the wastes accepted at the plant than the type and characteristics of the digestion system used. Biogas production per tonne of BMW treated ranges between 85 – 135 m^3/t, usually depending on the proportion of kitchen wastes and their exact contents. The co-digestion of industrial organic wastes is observed to have a positive effect on the overall biogas production figures.

Dry digestion systems produce more biogas per tonne throughput because of the higher total solids content of their incoming waste. Although the data available was limited (no volatile solids data was available), when the biogas production per tonne of total solids treated in the various digestion systems was compared it was observed that the wet digestion systems produce more biogas per tonne total solids treated than dry AD systems. The average biogas production per tonne of total solids treated in the dry AD systems visited is 390 m^3/tonne TS, compared to an average biogas production per tonne of total solids treated in the wet AD systems visited of 663 m^3/tonne TS (although the figures for Västerås, Jonkoping and Ludlow are not yet proven). The only proven figure for a wet AD system (Grindsted) compares favourably with all of the dry AD systems visited (553 m^3/tonne TS). Possible reasons for this are that wet digestion systems should have better mixing, or simply that dry systems tend to accept more garden wastes, which would lower the average biogas potential per tonne treated. Given that the biogas production per tonne TS is higher on average in the systems operating in the mesophilic temperature range, it is assumed that the fact that the digestion is 'wet' rather than 'dry' has a greater effect on the percentage TS conversion than the operating temperature (although the difference may be attributed more to the percentage of garden waste in the incoming waste more than any of these factors). It can be seen that with the exception of the Grindsted plant, which primarily treats sewage sludge, the theoretical electricity production per tonne of wastes treated is similar in all plants, ranging between 153 kWh/tonne and 243 kWh/tonne. The lower values were from sites that did not co-digest industrial organic wastes. The average theoretical electricity production per tonne of biowaste treated (excluding the Grindsted plant) is 197 kWh/t (with a standard deviation of 30 kWh/t).

All of the sites visited have positive energy balances due to the biogas they produce. Based on available references between 5% and 40% of the total electricity produced from the anaerobic digestion of biowastes will be required to cover on-site requirements. The exact percentage required is case specific, and is dependent on many factors such as the extent and type of mechanical pre-treatment (which is dependent on the quality and potential contaminants in the incoming wastes), the type of digester, mixing and pumping requirements, and perhaps most importantly considering the amount of energy potentially required, the type of post-AD treatment. De-watering and in particular post-AD in-vessel composting can require significant electrical input. There is no apparent correlation between electricity requirements on-site and the operating temperature range. This is because the thermophilic systems are heated exclusively by the waste heat from the conversion of biogas to electricity. The majority of the AD systems visited would be ABPR compliant in the UK. Those that would not be, could easily achieve compliance at a reasonably low cost by the addition of a pasteurisation stage. This pasteurisation stage would use the excess heat produced from the conversion of biogas to electricity. It can be assumed that any new AD of BMW project in the UK would comply with ABPR.

A higher income (or cost saving) is likely to be available if the biogas is upgraded and used as a transport fuel (although important factors such as infrastructure costs, finance and tax were not considered). The two plants at which the biogas is upgraded and used as a vehicle fuel show a considerably higher income/saving per tonne of waste treated than all of the other sites (approximately £44/t compared to an average of £15/t for the sites converting the biogas to electricity). Depending on specific cases and local factors this renewable heat may provide an additional income. Any income derived from the sale of excess heat can be considered a bonus. The use of this renewable heat should become more economic in the future as fuel prices increase and market distorters increase revenue from renewable heat schemes.

Although based on limited data, the comparisons reveal four main points of note:

- All of the AD plants visited produce exportable renewable energy.
- Dry digestion systems produce more biogas per tonne of wastes treated, based on their higher total solids content.
- Wet digestion systems on average produce more biogas per tonne of total solids throughput than dry AD systems, although this could be attributed to differences in the wastes treated.
- The income is likely to be greater if the biogas is used as a transport fuel.

6.2 Comparison of MBT plants treating centrally separated OFMSW

In the following section an attempt will be made to compare the different MBT approaches incorporating the anaerobic digestion of centrally separated OFMSW. The comparisons will be based on comparisons of the available data from the sites visited as part of this report. The level of data required to make in-depth comparisons of the performance of individual anaerobic digesters was rarely made available. Therefore comparisons made are based on basic values quoted by site suppliers or operators. For this reason data could not be verified. Due to the limited data available, the comparisons will be more of the ‘concepts’ behind each system than the actual AD processes.

6.2.1 Comparison of mass balances for MBT plants

The mass balances from each MBT plant visited are displayed and discussed individually in Appendix 2. The key points are summarised in Table 73 and the different approaches compared and discussed in terms of key process parameters such as landfill diversion, biogas production and energy recovery. A key point to remember is that the mass balance of material coming out of the MBT plant is very dependent on the content of the incoming waste, as well as the design and operation of the plant. The residual waste streams in the different areas served by the MBT plants compared here will be similar, but composed of slightly different materials. For example the metals removed from the waste stream as a percentage of the total incoming mass varies from 1% (at Vaasa and ZAK Ringsheim) to 9% (at Saschenhagen), yet all of the plants will separate all of the metals for recycling. The content of the residual waste stream is dependent on the local wastes strategy, with different materials recycled or disposed of in different ways.

The data in Table 73 are displayed in bar chart form in Figure 314.

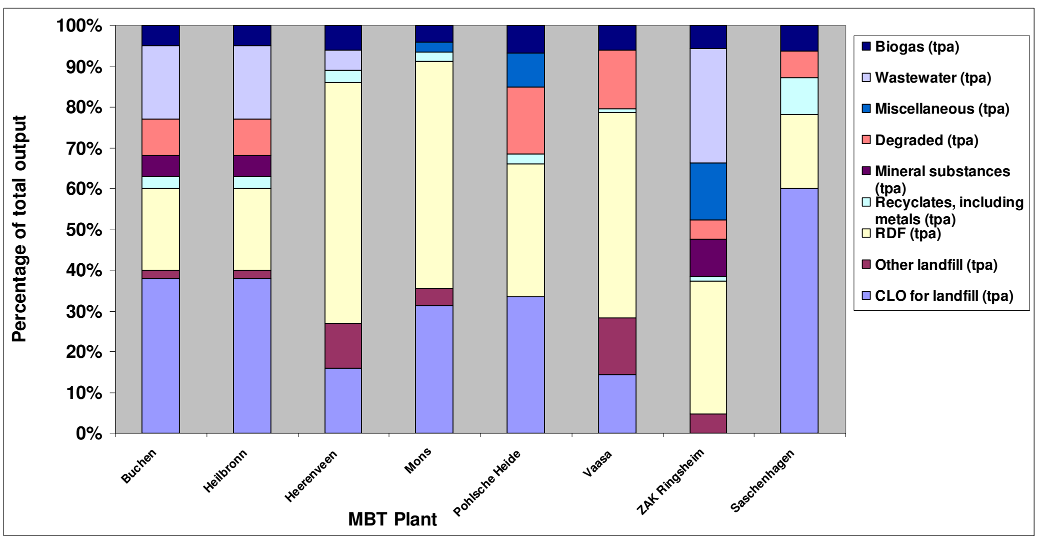

Figure 314 MBT plant outputs

Although the MBT plants visited were all primarily designed to process residual municipal waste (except Vaasa), each residual waste stream was different (depending on the waste strategy in the region, and what was included in the residual waste). The legislation that the plants were set to comply were different and the local conditions (*e.g.*, remaining landfill capacity, incinerator capacity, proximity of industries that would accept RDF/SRF, climate, availability of existing wastewater treatment facilities or biogas utilisation facilities, space available, proximity to natural and agricultural or residential areas). In addition, several of the plants were designed to co-process commercial wastes, sewage sludge or other waste streams, and therefore should not be considered solely as municipal residual wastes processing and treatment facilities. All of the above plants represent a viable and economic option to divert biodegradable and otherwise recoverable municipal wastes from landfill in their respective countries and regions.

Table 73 Mass balance summary

Plant Capacity	CLO for Landfill (tpa) (%)	Other Landfill (tpa) (%)	RDF (tpa) (%)	Recyclates, Including Metals (tpa) (%)	Mineral Substances (tpa) (%)	Degraded (tpa) (%)	Waste-water (tpa) (%)	Biogas (tpa) (%)	Miscellaneous (tpa) (%)	Total (tpa) (%)
Buchen 151,000 tpa	57,380 **38**	3020 **2**	30,200 **20**	4530 **3**	7550 **5**	n/i	27,180 **18**	7550 **5**	13,590 **9**	151,000 **100**
Heilbronn 88,000 tpa	33,440 **38**	1760 **2**	17,600 **20**	2640 **3**	4400 **5**	n/i	15,840 **18**	4400 **5**	7920 **9**	88,000 **100**
Heerenveen 230,000 tpa	36,800 **16**	25,300 **11**	135,700 **59**	6900 **3**	n/i	n/i	11,500 **5**	13,800 **6**	n/i	230,000 **100**
Mons 80,000 tpa	25,014 **31**	3337 **4.2**	44,704 **56**	1845 **2.3**	n/i	n/i	n/i	3269 **4**	1858 **2.7**	80,027 **100**
Pohlsche Heide 92,500 tpa	33,500 **33.5**	0 **0**	32,500 **32.5**	2500 **2.5**	n/i	16,500 **16.5**	n/i	6700 **6.7**	8300 **8.3**	100,000 **100**
Vaasa 42,000 tpa	6000 **14.5**	5880 **14**	21,000 **50**	420 **1**	n/i	6000 **14.5**	n/i	2520 **6**	n/i	41,820 **100**
ZAK Ringsheim 100,000 tpa	0 **0**	5000 **5**	35,000 **35**	1000 **1**	10,000 **10**	5000 **5**	30,000 **30**	6000 **6**	15000 **15**	100,000 **107**
Saschenhagen 55,000 tpa	33,000 **60**	0 **0**	10,000 **18.2**	5000 **9.1**	n/i	3500 **6.3**	n/i	3500 **6.3**	n/i	55,000 **100**

Despite the fact that the outputs are completely dependent on the content of the incoming wastes streams, and the fact that different MBT plants have presented their mass balances in different formats showing some differing data, some interesting comparisons can be made regarding the main outputs of the MBT concepts, particularly with regards to the main outputs, CLO, other waste to be landfilled and RDF. In all cases, the percentages of recyclates recovered are not a reflection of the MBT process, but a reflection of the percentage of recyclates remaining in the incoming residual waste. All plants are equipped to recover ferrous and non-ferrous metals, and some are equipped to separate recyclable plastics (although this is not the norm).

6.2.2 Comparison of landfill diversion of MBT plants

The actual landfill diversion of each of the plants visited is displayed in n Figure 315. The data is based on mass balances supplied by the owner/operators, and the information they supplied about the destination of the end products at the time of the visits.

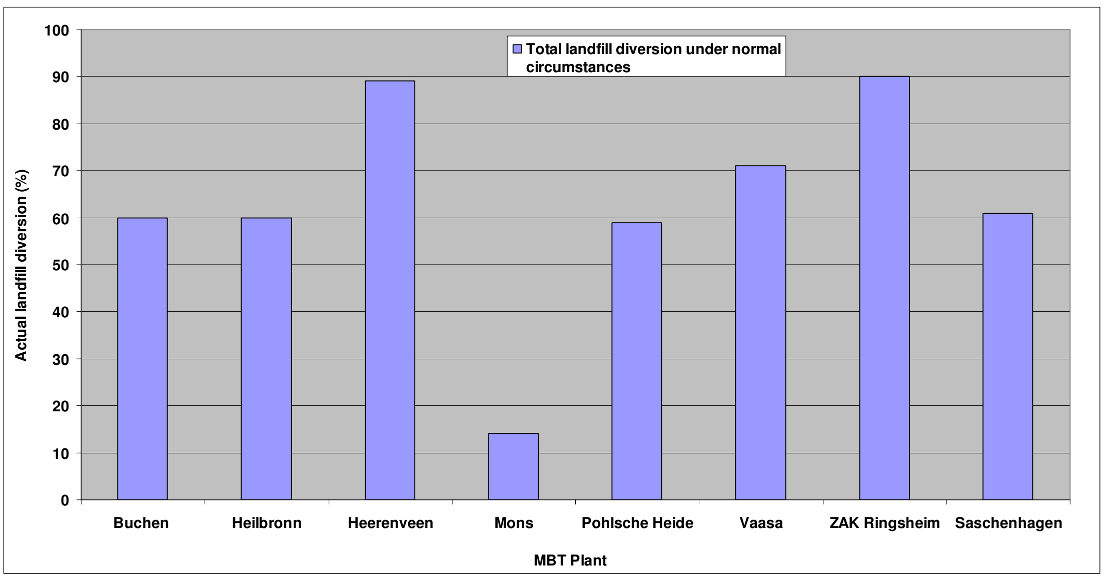

Figure 315 Actual landfill diversion

It can be seen from Figure 315 that the ZAK Ringsheim and Heerenveen sites divert around 90% of the incoming wastes from landfill. The reasons that these figures are so high are discussed in the individual mass balance discussions in Appendix 2. The Mons plant currently diverts the lowest percentage of the incoming waste from landfill (14%), but this is due to lack of incinerator capacity to accept the RDF rather than any deficiency in the MBT plant design. It is a priority of ITRADEC (the owners of the Mons plant) to find an industry/incinerator that will accept their RDF. Buchen, Heilbronn, Pohlsche Heide and Saschenhagen all divert around 60% of their total incoming wastes (by mass) from landfill. Vaasa accepts ‘kitchen waste’ (including plastics, packaging and card) rather than residual waste, and so has a high landfill diversion capacity compared to most of the other plants. In Vaasa however, residual waste (collected as ‘landfill waste’) is collected separately from householders and directly landfilled. These figures are perhaps more representative of the success of MBT plant to fit into the overall wastes strategy in the regions concerned than of the merits of the different MBT processes themselves. A more real comparison of the MBT plants themselves can be obtained by comparing the percentages by mass of CLO produced, and the 'other' wastes landfilled. Figure 316 shows the percentage by mass of the MBT plant output that is landfilled, and the percentage by mass that is CLO. In all cases, the CLO is biostabilised, and either landfilled or used for daily or permanent landfill cover depending on its qualities, local legislation and local requirements. Whether or not a CLO can be used as a daily or permanent landfill cover, and whether or not these uses count as 'beneficial' and therefore towards recycling and composting targets will have a large effect on the landfill diversion potential (and plant economics). The issue is more legislative than technical, as most process suppliers can engineer processes to meet specific local requirements.

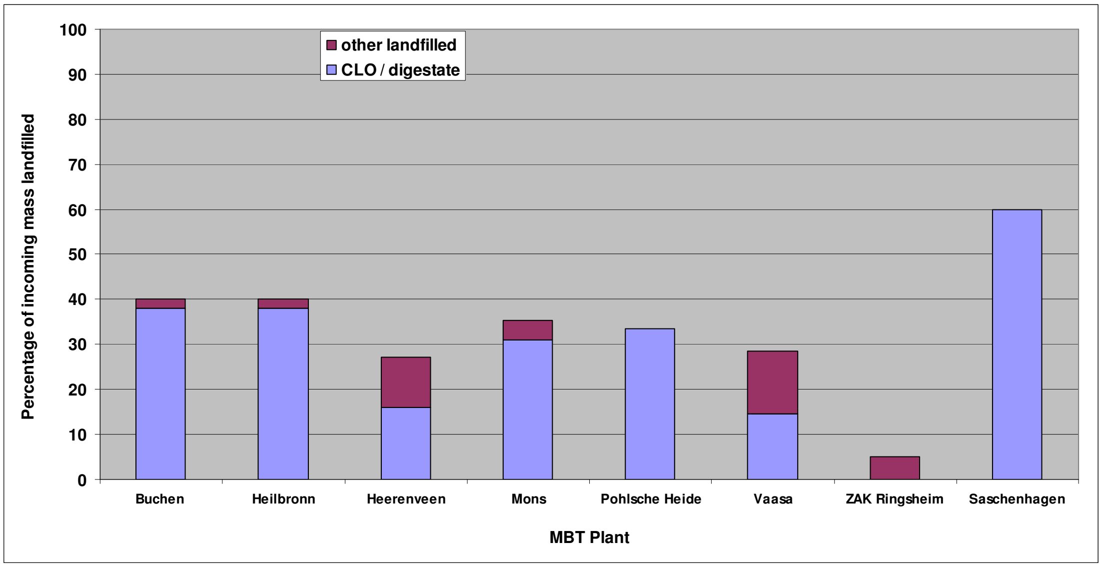

Figure 316 CLO produced and other landfilled wastes (both as a percentage of mass input)

The use or disposal for the CLO at the different plants is described in the case studies. CLO is not always landfilled. For the purposes of this comparison, the use of the CLO as a landfill cover (either daily or permanent) has not been considered as 'recycled'. In the UK, the use of the CLO as a daily landfill cover does not count as 'recycling', but use as permanent landfill cover does, provided the ABPR is met. Therefore if the possibility existed to use some of the CLO as a permanent landfill cover, the overall landfill diversion provided by the MBT concepts could be further increased. The 'actual' approach varies at different sites. For example, the digestate at Heerenveen is either incinerated or 'immobilised' for permanent landfill cover, meaning that actual landfill diversion at the site (including permanent landfill cover, which is 'recycled') is around 89%. In contrast, at Mons 98% of the RDF (38,520 tonnes) was landfilled due to lack of incinerator capacity, alongside all of the CLO and some of the mineral content meaning that the actual landfill diversion provided by the plant was only around 14% in 2005 (Figure 315), compared to a possible 63% as can be observed in Figure 317. These examples serve to illustrate that a MBT plant is only one stage in the overall wastes treatment and disposal policy, and the most beneficial approach must be considered alongside local conditions, existing infrastructure and future plans. The requirement for permanent landfill cover (present or future), and the local incinerator/thermal treatment capacity (present or future) are important factors that affect the effectiveness of different MBT approaches, and should always be considered.

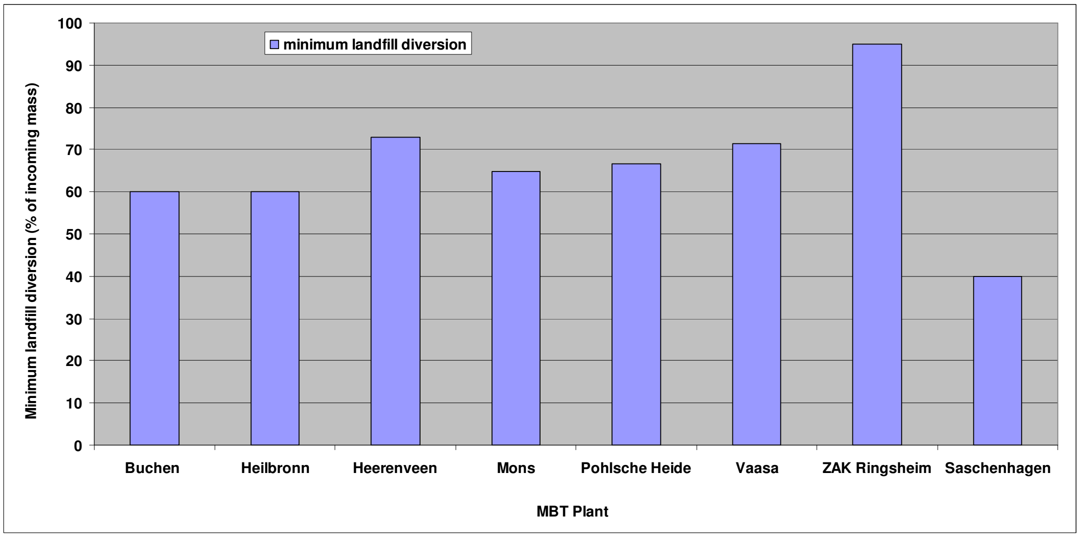

Figure 317 Theoretical minimum landfill diversion potential of each MBT plant (assuming all CLO is landfilled)

All of the values for minimum landfill diversion used in Figure 317 assume that sufficient incinerator capacity exists to thermally treat all of the RDF produced. As it has been explained, this is not always the case at present. Also, as described, many sites use the biostabilised CLO produced as a daily or permanent landfill cover. It can be seen from Figure 314 and Figure 317 that the greatest landfill diversion can be achieved by the MBT concept at ZAK Ringsheim. This is due to the fact that unlike any of the other approaches the solid fraction of the waste stream, after percolation, is biodried and mechanically sorted into different grades of SRF to be used as fuel substitute. The anaerobic digestion system used is a low solids wet system, and any excess sludge produced can also be biodried and included in the SRF or RDF streams. This approach is possible due to the large number of local industries, which are possible customers for the ‘fuel substitute’ (SRF), and also because there is available incinerator capacity to accept the RDF produced.

The lowest landfill diversion is provided by the Saschenhagen MBT approach. The exact set-up of the mechanical treatment stages of this plant were not explained, so it is possible that the mechanical pre-treatment stages at Saschenhagen were less geared towards the recovery of RDF than at the other sites. It is also possible that the ‘combustible’ fractions of the municipal waste were source separated and sent direct to an incinerator. Furthermore, alongside the 55,000 tpa of residual municipal wastes processed, the Saschenhagen site also treats 25,000 – 35,000 tpa of commercial wastes. If the entire waste stream entering the plant is considered (total input of 80,000 – 90,000 tpa) then 59 - 63% of the incoming wastes can be considered to be diverted from landfill, which brings the plant into the range of the other sites visited. Without further details of the contents of the 25,000 – 35,000 tpa of incoming commercial wastes it is not possible to comment on this figure. Buchen, Heilbronn, Heerenveen, Mons, Pohlsche Heide and Vaasa all divert between 60% and 72% of the wastes from landfill (minimum values), assuming all RDF is incinerated and all CLO is landfilled. In all cases, if the digestate/CLO was to be incinerated rather than landfilled, the energy recovery would increase and the volume of waste being landfilled would be decreased.

6.2.3 Comparison of biogas production for MBT plants

A basic comparison of the biogas production is shown in Table 74.

Table 74 Biogas production per year for MBT sites visited

Plant Capacity	Waste Treated	Total Biogas Production (approx. in million m^3)	Biogas/tonne waste processed through MBT plant (m^3)	Biogas/tonne waste processed through digestion system (m^3)
Buchen 151,000 tpa	Residual MSW	8.25	55	103
Heilbronn 88,000 tpa	Residual MSW	4	50	100
Heerenveen 230,000 tpa	Residual MSW and commercial wastes	11	55	100 - 145
Mons 80,000 tpa	Residual MSW	4.16 (7 expected if at capacity)	52	231
Saschenhagen 55,000 tpa 30,000 tpa	Residual MSW Commercial wastes	6.4 – 8 (expected, not observed)	n/a	160 – 200 (expected, not observed)
Pohlsche Heide 40,000 tpa 40,000 tpa 12,500 tpa 7500 tpa	Residual MSW Commercial wastes Sewage sludge Other sludges	5.5 – 5.8	57 - 72	115 - 120
Vaasa 42,000 tpa	Kitchen waste	1 – 1.5	70 - 100	100 - 150
ZAK Ringsheim 100,000 tpa	Residual MSW	6.1 – 7 (expected, not observed)	61 - 71 (expected, not observed)	n/a

Before looking into the figures in greater depth, it must be mentioned that although the residual municipal wastes in different regions of different countries can be similar in content, they will always be different to some degree. The content of the residual waste depends on the whole wastes and recycling policy in the particular region, the climate in the region, as well as many other factors. For example, in some regions being served by the MBT plants compared in this section kitchen waste is collected as part of the residual waste stream (for example Mons, ZAK Ringsheim, Buchen and Heilbronn). In other regions, kitchen waste is source separated and treated in a different plant (Heerenveen, Pohlsche Heide). In some plants (such as Pohlsche Heide, Saschenhagen and Heerenveen) commercial wastes and even sewage sludge are also accepted. As these commercial wastes can have a large impact on biogas production and therefore energy balance statistics, further comments are not possible without more detailed information on the nature and content of these commercial wastes. In Vaasa ‘kitchen waste’ includes unrecyclable plastics and paper, which are separated in the Vaasa plant and pelletised for RDF for energy recovery. In Vaasa, the waste destined for landfill is collected in a different bin.

The biogas production per tonne of waste accepted at the MBT plants for Pohlsche Heide, Buchen, Heilbronn, Heerenveen and Mons are all very similar (57 – 72 m^3/t, 55 m^3/t, 50 m^3/t and 55 m^3/t, and 52 m^3/t respectively). It is interesting that the Pohlsche Heide plant shows a slightly higher biogas production per tonne of waste throughput, when only 70 – 80% of the organic waste is anaerobically digested. It could be due to the commercial wastes that the plant co-digests alongside OFMSW, or the fact that anaerobic digestion is 'dry'. The Vaasa system recovers 70 – 100 m^3 of biogas per tonne of waste processed by the MBT plant (Pentinnen-Kalroos, Personal Communication, 2006). This is considerably higher than all of the other values observed. This may be simply a reflection of the organic content in the incoming waste stream, or may be because digestion is wet and thermophilic. Figure 318 shows the plant capacities compared to the total annual biogas production observed (or expected in the cases of Saschenhagen and ZAK Ringsheim).

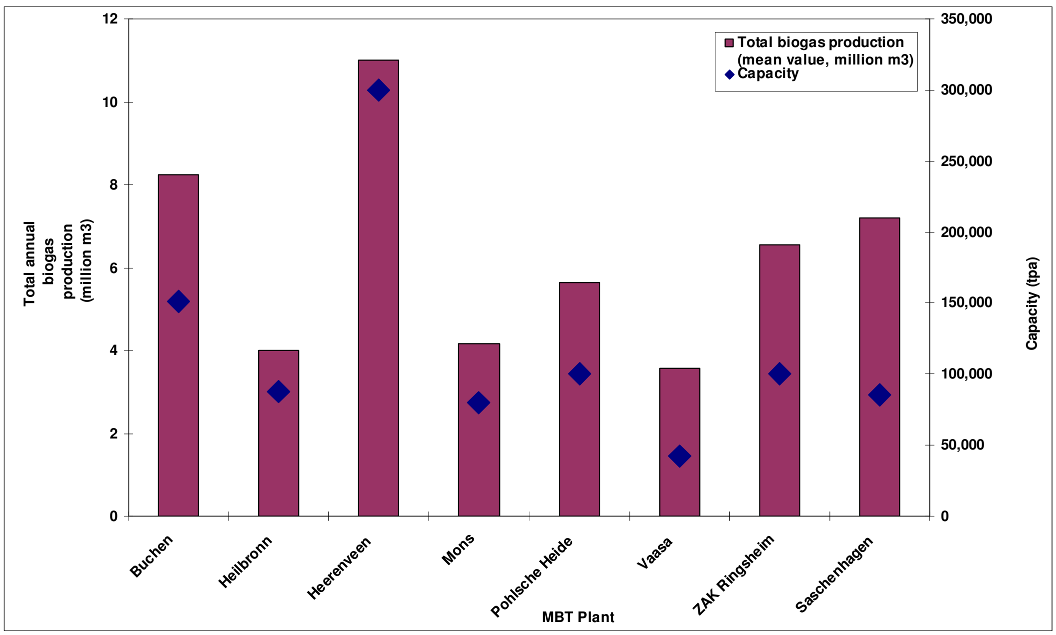

Figure 318 Total biogas production at MBT plants

Obviously, larger sites accepting more wastes will treat more organic wastes and therefore produce more biogas. Figure 319 shows the biogas produced per tonne of OFMSW (or other organic waste) anaerobically digested at the individual sites.

Data from Saschenhagen and ZAK Ringsheim have been omitted from Figure 319 because the biogas production figures are estimates, rather than observed figures. As these plants are in the start-up phase, no biogas production data at full operational capacity is available. Many sites provided a range of biogas production. In these cases the median point in the range has been used in Figure 319. The average biogas production per tonne of OFMSW anaerobically digested in the six fully operational MBT plants visited is 133 m^3/t (based on the figures quoted by contacts on site and displayed in Table 74).

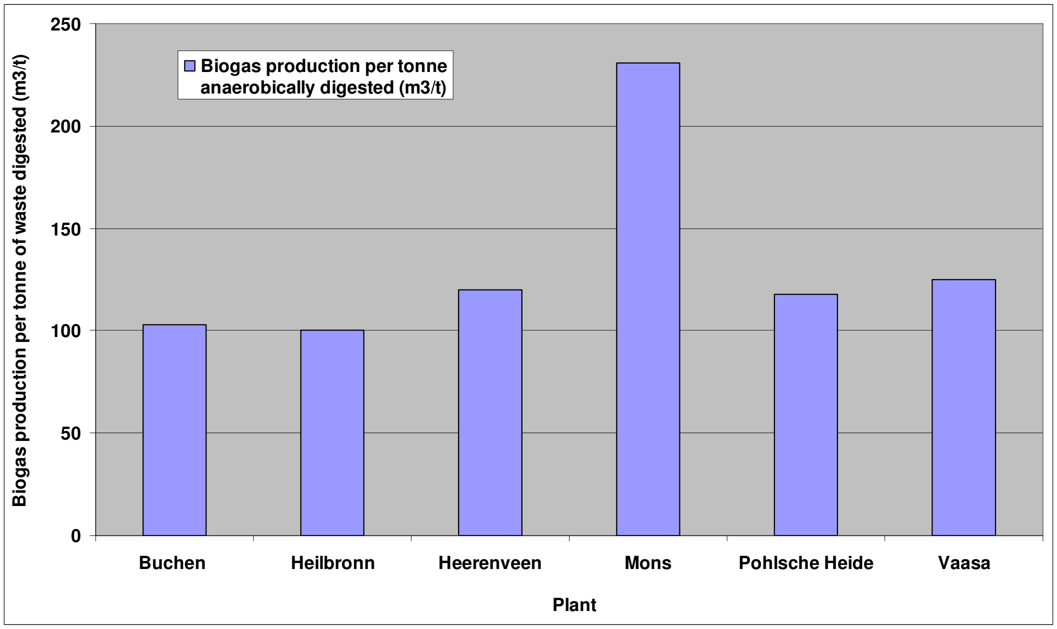

Figure 319 Biogas production per tonne of waste anaerobically digested at MBT plants

The biogas produced per tonne of organic waste processed through the anaerobic digestion system at Mons is high compared to the other values recorded (231 m^3 per tonne of waste throughput, based on a total biogas production of 4,160,000 m^3 from 18,002 tonnes of OFMSW). The average volume of biogas produced per tonne of OFMSW anaerobically digested in the other plants was 113 m^3/t (although some of the other plants also co-digested other organic wastes). The fact that kitchen waste (and not garden waste) is included in the residual waste stream in the region covered by ITRADEC (the owner/operators) of the Mons plant would have an effect on the biogas potential per tonne of OFMSW. The higher average volume of biogas produced at Mons could also be due to the digestion system used (supplied by Valorga). The fact that digestion is dry allows a higher total solids content per tonne of waste treated, and therefore presumably a higher volatile solids content. Also dry digestion would mean that not many organics are lost in the pre-treatment stages, as compared to wet pre-treatment stages in other systems. Valorga systems are also mixed by gas injection, which should allow for efficient mixing, added to which the retention time in the anaerobic digester was high compared to other digesters (30 days) which would allow more anaerobic degradation and therefore more biogas production. This high residence time is possible because the anaerobic digesters are operating well below capacity, and therefore the waste can be digested for a longer period than at plants where the throughput time needs to be faster. For the case of Saschenhagen, the figures are expected and not yet achieved or proven. Their estimates seem high, which may be because of the high energy potential in the commercial wastes that the plant accepts. Details of these commercial wastes were not made available. The ZAK Ringsheim figures are also estimated, and not yet observed or proven, as the plant was in the start-up phase at the time of the visit.

Buchen, Heilbronn and ZAK Ringsheim only treat the liquid fraction extracted from their 'percolation process'. In Buchen and Heilbronn this is estimated at 70% of the organics in the OFMSW (Kutterer, Personal Communication, 2006). In ZAK Ringsheim the percentage of the organics extracted in the percolation system is likely to be less, as the percolation is at a colder temperature. In Buchen and Heilbronn the remainder of the organics remain in the solid fraction, which is in-vessel composted to achieve full biostabilisation before landfilling. In ZAK Ringsheim the solid fraction is biodried, and then upgraded to produce a SRF that is sold to industry.

In the case of Pohlsche Heide, only around 70 - 80% of the organic waste stream is sent for anaerobic digestion, with the balance being sent directly to the in-vessel composting stage, to be mixed with digestate. This set-up forfeits the renewable energy available in the other 20 - 30% of the waste stream, but means that de-watering of the digestate prior to in-vessel composting is not required. It also means that the concentration of organics in the waste entering the post AD in-vessel composting stage is sufficiently high to ensure efficient composting, with an immediate temperature rise. Wastewater treatment costs and the costs associated with connecting the site to the grid to export the renewable electricity are also saved, as the site uses all of the energy it produces, and produces very little wastewater.

A more accurate measure of the digestion efficiency would be the biogas produced per tonne of total solids treated, or per tonne of volatile solids treated, however this information was rarely available and no comparison could be made.

6.2.4 Comparison of energy balances for MBT plants

A basic comparison of the exportable electricity produced from the anaerobic digestion of the OFMSW is shown in Table 75. These figures are based on the information made available by the contacts on site, and in the literature.

In Table 75, only electricity production and export figures are included, as all of the MBT plants produce enough heat to cover all their own uses and produce an exportable excess. In some (but not all) cases it has been possible to find a beneficial use or even an income for this excess heat (for example, ZAK Ringsheim where the heat is used in a district heating scheme, and in Vaasa where biogas is exported to a sports complex to provide under-soil heating, and to another neighbouring industry). Table 76 summarises the overall electricity balances at each MBT plant visited.

Table 75 Energy balances for MBT sites visited

Plant Capacity	Waste Treated	Total biogas production (approximation, in million m^3)	Total Electricity production (MWh/a)	On-site Use (%)	Total Electricity Export (MWh/a)
Buchen 151,000 tpa	Residual MSW	8.3	n/a	100	**None.** Plant covers vast majority of its own requirements
Heilbronn 88,000 tpa	Residual MSW	4	n/a	100	**None.** Plant covers vast majority of its own requirements
Heerenveen 230,000 tpa	Residual MSW and commercial wastes	11	13,514 20,476 (when landfill gas is also considered)	33	8920
Mons 80,000 tpa	Residual MSW	4.2 (7 expected if at capacity)	4500	n/a	Small excess
Saschenhagen 55,000 tpa 30,000 tpa	Residual MSW Commercial wastes	6.4 – 8 (expected, not observed)	10,568 – 14,411 **(1)**	66	3487 – 4756 **(1)**
Pohlsche Heide 40,000 tpa 40,000 tpa 12,500 tpa 7500 tpa	Residual MSW Commercial wastes Sewage sludge Other sludges	5.5 – 5.8	8287–10,376	100	**None.** Plant covers vast majority of its own requirements
Vaasa 42,000 tpa	Residual MSW	1 – 1.5	1801 – 2702 **(2)** 9000 – 15,750 **(3)**	n/a	**None.** Plant covers vast majority of its own requirements. Exports some biogas.
ZAK Ringsheim 100,000 tpa	Residual MSW	6.1 – 7 **(1)**	13,578 **(1)**	95 **(1)**	766 **(1)**

Note

(1) (**unproven** - calculated on **expected** biogas production).
(2) (calculated on the biogas production figures).
(3) (assumed that these figures include landfill gas and biogas from sewage sludge digester).

Table 76 Electricity exported from MBT plants

Plant Capacity	**Total Electricity Export (MWh/a)**	**Total Electricity Export from biogas per tonne of residual waste processed (kWh/t/a)**	**Other energy 'positives'** (RDF, SRF, income from heat, combined facilities with other processes *etc.*)
Buchen 151,000 tpa	0	Small excess	• Biogas and landfill gas utilised together • RDF produced
Heilbronn 88,000 tpa	0	Small energy input	• RDF produced
Heerenveen 230,000 tpa	8920	29.7	• Biogas and landfill gas utilised together • RDF produced • Some digestate thermally treated
Mons 80,000 tpa	Small excess	Small excess	• RDF produced
Saschenhagen 85,000 tpa	3487 – 4756 **(2)**	41 - 56 **(2)**	• RDF produced
Pohlsche Heide 100,000 tpa	0	Small energy input	• RDF produced
Vaasa 42,000 tpa	0	Small energy input required, to cover entire complex, although some biogas also exported	• Biogas from sewage sludge digester, and landfill gas • All biogas utilised together • RDF produced, sent for pelletisation and sold to paper mill • Excess heat exported
ZAK Ringsheim 100,000 tpa	766 **(1)**	7.7 **(1)**	• RDF produced • SRF produced • Biogas and landfill gas utilised together • Excess heat exported

Note
(1) (assumed that these figures include landfill gas and biogas from sewage sludge digester).
(2) (**unproven** - calculated based on their **expected** biogas production).

Figure 320 attempts to estimate the energy recovered through biogas and exported from each site, as a function of each tonne of residual waste input.

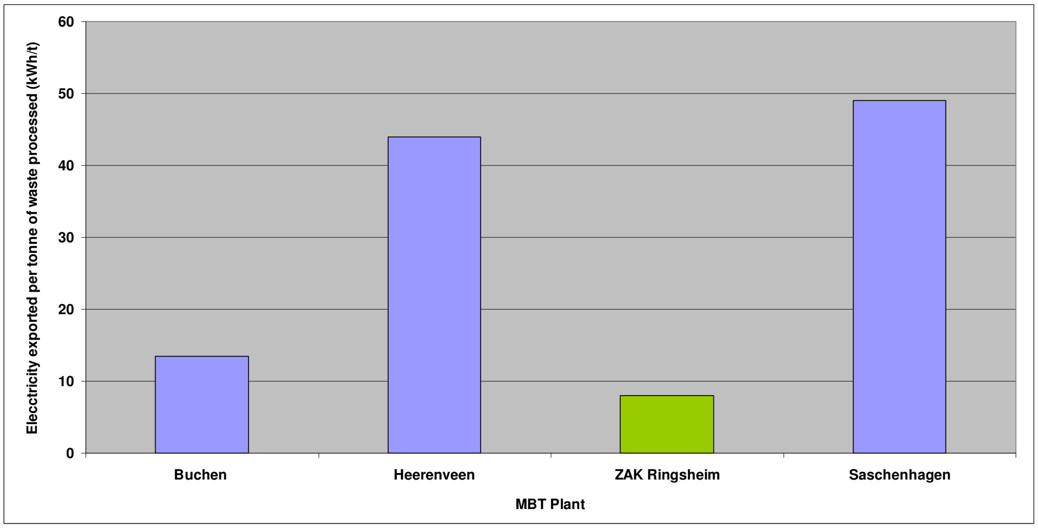

Figure 320 Energy balance (from biogas) per tonne of waste processed

The green data (ZAK Ringsheim) in Figure 320 is based on actual data provided by ZAK, while the blue data are estimations based on calculations based on data supplied by the site owners/operators. Data in Figure 320 is heavily based on estimations and assumptions based on the energy export data, or in some cases the mean biogas production observed (or in some cases the mean biogas production expected). No account of the energy available from RDF or SRF is made in Figure 320. Figure 320 is intended as a guideline only, based on limited energy data made available, and basic calculations based on these figures. For the purposes of the comparison, it is assumed that the percentage methane in the biogas in all cases is 60% and that the conversion efficiency to electricity is 30%.

Heilbronn almost totally covers on site electricity requirements, but requires a small energy input (Kutterer, Personal Communication, 2006). Similarly, Pohlsche Heide almost covers its own electricity requirements, but no exact reference was available. Mons produces a small excess (Urbain, Personal Communication, 2006), again, this was not quantified. Saschenhagen figures are related to calculations based on quoted expected biogas production figures. The ZAK Ringsheim figure is based on the energy export data, provided by the company (see case study, Section 5.2.7). Buchen is usually a net energy exporter, exporting 10 – 15% of the electricity it produces (Kutterer, Personal Communication, 2006). The Heerenveen figure of 44 kWh/t of residual waste is based on calculations based on the facts that the quoted average total annual biogas production was 11 million m^3 of biogas (Smink, Personal Communication, 2006), and the fact that 2/3 of the electricity produced is exported. Based on a biogas production rate of 70 – 100 m^3 of biogas per tonne of waste through the plant, the Vaasa plant produces 2.94 – 4.2 million m^3/a of biogas, plus biogas from the landfill site and the sewage sludge digester. All of the biogas is upgraded together, and a small proportion exported to neighbouring industries. The remainder is converted to electricity and heat to cover on site requirements (not just the MBT site, but the other wastes treatment and disposal facilities). It can be seen that (theoretically in some cases) as well as covering their own electricity requirements the MBT plants at Saschenhagen, Buchen, Heerenveen, Mons and ZAK Ringsheim are net exporters of electricity. According to the values quoted, the Heerenveen plant exports the most electricity per tonne of waste throughput. The Saschenhagen plant is also expected to export 41– 56 kWh/t of waste throughput, but this is not yet proven.

6.2.5 Total energy recovery potential

Figure 321 shows a comparison of the percentages by mass of the incoming waste streams from which energy can be recovered.

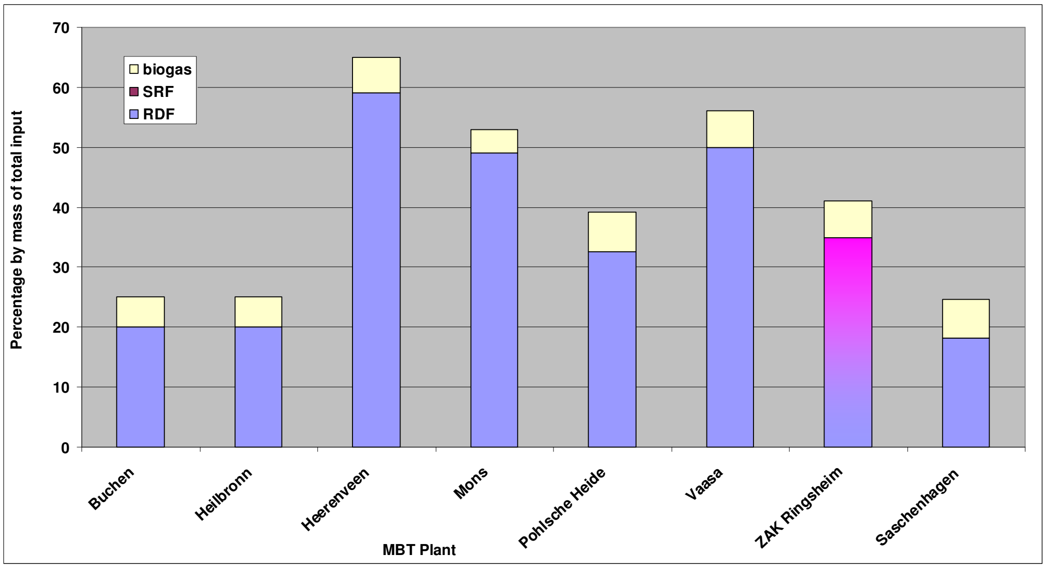

Figure 321 Energy recovery potential (by mass of wastes input)

Energy can be recovered on-site through utilisation of the biogas produced in the anaerobic digestion of the organic fraction of the wastes, and also by exporting the RDF (and SRF in the case of ZAK Ringsheim) to an industrial user or incinerator (or other thermal process). In some cases (such as Heerenveen) energy is also being recovered from the digestate, and this would represent a further energy gain in any systems/regions that could find an incinerator or industrial user to recover energy from their CLO. In Figure 321 however, energy from the thermal treatment of CLO is not included. Despite this, it can be seen that Heerenveen recovers 59% of the incoming mass as RDF (including the paper and light plastics section of the waste that is sent to a different user, and the ‘rake fraction’ removed from the top of the anaerobic digester). The next highest RDF recoveries are at Vaasa, where combustibles represent a large proportion of the incoming wastes, and 100% of the RDF is pelletised and used as a fossil fuel substitute in local industry, and Mons, where 98% of the RDF is presently landfilled due to lack of potential users. The proportion of the RDF/SRF at ZAK Ringsheim depends on the contracts for SRF. But there will always be a proportion of RDF, and any SRF that remains can always be added to the RDF stream and incinerated if no buyer can be found. It can be seen that the percentage of the incoming wastes by mass that is converted to biogas is similar in all cases. Minor differences are more likely to be due to differences in the organic content of the incoming wastes than in the efficiency of conversion provided within the anaerobic digesters. More data would be required to comment further.

6.2.6 Comparison of water requirements and wastewater production for MBT plants

A basic comparison of the water requirements is shown in Table 77. The exact water requirement of any process is dependent not only on the type of MBT process utilised, and is conceptual design, but on the water content of the incoming waste streams. The water content of residual MSW varies from region to region, and can also vary seasonally. The water usage within the MBT plant will clearly be of greater importance in drier regions than in areas such as South Wales, although fresh water and wastewater treatment will represent an operational expense in any region. Manipulation of the incoming wastes streams, for example by adding a wet or dry commercial waste can bring the water content of the combined wastes stream into the desired range, without the addition of fresh water. In any case, MBT plants can be engineered to minimise water use, and to re-circulate and recycle as much as possible of the wastewater produced on site. Also, provided the fresh water requirement is not excessive, rainwater can be harvested and stored on site until required. Another point worth considering is that if the MBT plant is located beside or close to a wastewater treatment plant, then there will be an abundant supply of potentially useful water rich wastes (raw sewage, wastewater in various stages of treatment, fully treated effluent or even sewage sludge) that the MBT plant can utilise rather than use (and pay for) fresh water. Similarly, the location of a sewage treatment works at the same site will enable the wastewater to be treated on-site, and the sewage sludge to be co-digested along with the OFMSW. Location of the MBT plant at a landfill site can save on wastewater treatment costs, as the wastewater from the MBT plant and landfill site can be treated in the same plant. The fresh water requirements of the MBT plants visited, where they were made available, are shown in Table 77.

Table 77 Fresh water requirements

Plant Capacity	Waste Treated	Fresh Water Requirement (m^3/a)	Fresh Water Requirement (m^3/tonne processed)
Buchen 151,000 tpa	 Residual MSW	n/a Small	n/a Small
Heilbronn 88,000 tpa	 Residual MSW	n/a Small	n/a Small
Heerenveen 230,000 tpa	Residual MSW and commercial wastes	12,000	0.05
Mons 80,000 tpa	 Residual MSW	5500	0.07
Saschenhagen 55,000 tpa 30,000 tpa	 Residual MSW Commercial wastes	4500	0.05
Pohlsche Heide 40,000 tpa 40,000 tpa 12,500 tpa 7500 tpa	 Residual MSW Commercial wastes Sewage sludge Other sludges	6000	0.06
Vaasa 42,000 tpa	 Residual MSW	40,794	0.97 (although this includes sewage sludge digester requirement)
ZAK Ringsheim 100,000 tpa	 Residual MSW	n/a Small	n/a Small

For the plants that provided an exact value for the volume of freshwater required, these are compared in Figure 322.

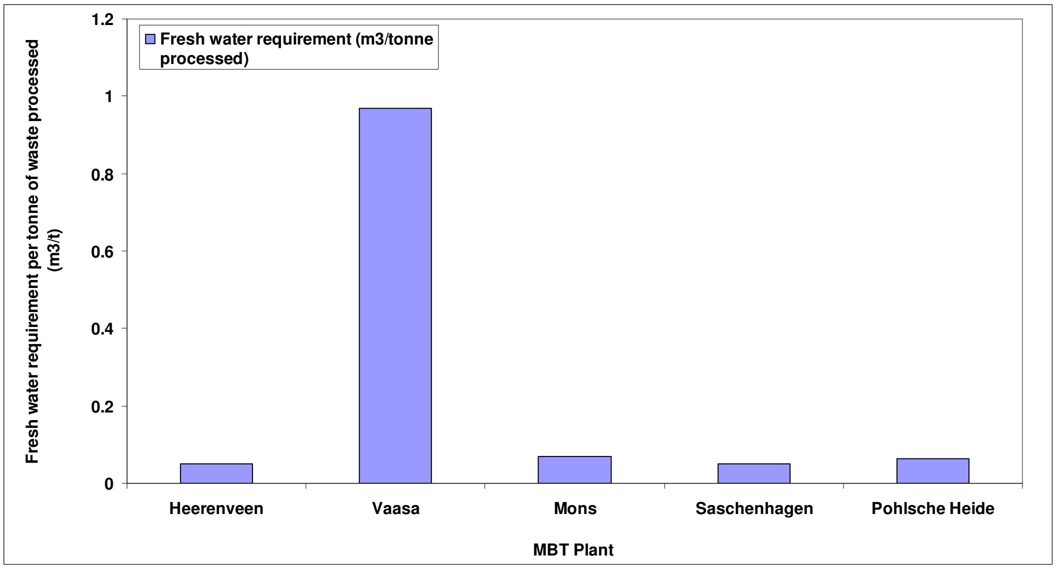

Figure 322 Fresh water requirements for MBT plants

The Buchen, Heilbronn and ZAK Ringsheim MBT plants have not been included in Figure 322 because exact values for water requirements were not made available. Fresh water requirements of the Buchen and Heilbronn sites was 'small', and could be covered entirely by the moisture content of the incoming wastes and by harvested rainwater (Kutterer, Personal Communication, 2006). At ZAK Ringsheim no figures for water usage were given. The incoming waste has a 40 - 50% water content, and the volume of water required in the percolators was not considered to be excessive (Gibis, Personal Communication, 2006).

The Vaasa plant uses 14,743 m^3/a of fresh water for pre-treatment, biological treatment, steam generation and in the offices, combined with a further 26,051 m^3/a that is pumped from an underground well and used in the biological treatment stages. Therefore, the total water requirement of the plant is 40,794 m^3/a (Pentinnen-Kalroos, Personal Communication, 2006). This corresponds to 0.97 m^3/t of waste processed, which is a very high water usage compared with the other processes, which are all less than 0.1 m^3/tonne. This figure also includes the water requirements of the parallel sewage sludge treatment plant, which would help to explain the extent of the difference between the Vaasa total and the water requirement at the other sites. The low water content of the incoming wastes stream could be another possible factor contributing to the high water requirement. As described in the case study the Vaasa site treats 'kitchen waste', containing combustibles, rather than residual wastes as in the majority of the other plants. Another reason for this very high water usage could be that the wet pre-treatment stages, in particular the mix separator, require a lot of water. Also, the plant was commissioned in 1991, and other parts of the process have been adapted and added on 'bit by bit' since then. This 'bit by bit' construction could mean that each technology or 'stage' was planned and built to operate independently from the other existing stages, with the benefits of co-engineering to recycle water being prohibitively expensive to retro-fit. The other MBT options shown in Figure

322 that were designed and built as one ‘unit’, and could therefore maximise the water recycling and re-use options to the fullest, from the start of operation. The other plants were also built much more recently (2000 – 2006), and could therefore benefit from more advanced technology and the advances in engineering experience since 1991. A further point to consider is the Finnish climate, with water economy afforded less importance than in other areas of Europe. The small population density in the region would also minimise the importance of the water usage.

At the Heerenveen site approximately 12,000 m^3 of fresh water is used on-site per year. This corresponds to approximately 0.05 m^3/tonne of residual waste processed. Process water is re-circulated as much as possible to minimise this usage. The Heerenveen site benefits from the economy of scale. Around 6000 m^3/a of water is needed by the Pohlsche Heide MBT process (Dippert, Personal Communication, 2005). This corresponds to approximately 0.06 m^3/tonne of incoming wastes. This is a low water requirement, although as well as residual MSW the plant accepts sewage sludge (12,500 tpa), commercial wastes (40,000 tpa) and other sludges (7500 tpa). These other waste streams may contain a high water content. The total water usage at the Mons site was given as 5500 m^3/tonne (Urbain, Personal Communication, 2006), which corresponds to 0.068 m^3/tonne of residual waste processed. Most of this fresh water use is by the anaerobic digestion system and composting systems which treat the 18,000 tpa of organic waste arriving from the mechanical separation stages of the plant. This corresponds to around 0.31 m^3/tonne of OFMSW processed. This water usage is primarily for steam and for daily washing of the plant. As mentioned above, a small proportion of the wastewater is re-circulated to dilute the waste stream to the right total solids content prior to digestion. Approximately 4500 m^3 of fresh water is used per year at the Saschenhagen plant (Kuhlmann, Personal Communication, 2006), which would be the equivalent of approximately 0.05 m^3 of fresh water per tonne of waste treated.

It can be seen from Figure 322 that except for the Stormossen plant at Vaasa, all of the water requirements provided are similar in terms of the volume of water required to process one tonne of residual waste. An interesting point to note is that the two processes based on dry anaerobic digestion systems (Mons and Pohlsche Heide) require more fresh water than the two MBT configurations based on wet anaerobic digesters (Heerenveen and Saschenhagen). It is possible that the lower water requirements are due to the high water contents of the incoming commercial wastes that are accepted at both Heerenveen and Saschenhagen.

Aside from the environmental advantages of being water efficient, economically it is particularly important that a plant is efficient in terms of water, because a plant will pay for the fresh water it uses, and again for the treatment of wastewater it produces. The volume of wastewater produced and how it is dealt with is shown in Table 78. In the majority of cases, the exact content and strength of the wastewater was not provided, and therefore can not be discussed.

Table 78 Wastewater production

Plant Capacity	Waste Treated	Waste Water (m^3/a)	Waste Water (m^3/tonne processed)	Wastewater Treatment Arrangement
Buchen 151,000 tpa	Residual MSW	Small	Small	• Dilution with rainwater and discharge to sewer
Heilbronn 88,000 tpa	Residual MSW	Small	Small	• Dilution with rainwater and discharge to sewer
Heerenveen 230,000 tpa	Residual MSW and commercial wastes	28,257 (1)	0.12	• Municipal wastewater treatment plant on site • Landfill leachate also treated • Effluent sent to the sewerage system
Mons 80,000 tpa	Residual MSW	9000	0.11	• Aerobically treated off site
Saschenhagen 55,000 tpa 30,000 tpa	Residual MSW Commercial wastes	2000 - 3000	0.022 – 0.375	• Content and water content of commercial wastes unknown • Municipal wastewater treatment plant on-site
Pohlsche Heide 40,000 tpa 40,000 tpa 12,500 tpa 7500 tpa	Residual MSW Commercial wastes Sewage sludge Other sludges	Small	Small	• Municipal wastewater treatment plant on-site • Landfill leachate also treated
Vaasa 42,000 tpa	Residual MSW	111,585	2.7	• Aerobically treated on-site, and discharged to sewerage system • Landfill leachate also treated
ZAK Ringsheim 100,000 tpa	Residual MSW	29,000	0.29	• Aerobic wastewater treatment plant on site • Then discharge to sewer

(1) Juniper (2005).

In line with its high fresh water usage, the plant at Vaasa produces considerably more wastewater per tonne of waste processed than any of the other plants for which data was made available. The wastewater treatment plant at Vaasa treated 111,585 m^3 of wastewater in 2005, although this total included landfill leachate and water de-watered from the sewage sludge treatment plant. As a breakdown of the sources of the wastewater was not available it is not possible to comment further. At the Buchen and Heilbronn MBT plants the small amounts of wastewater produced are diluted with rain water, which brings the effluents produced within standard consent limits for discharge to sewer. The exact volumes and compositions of the wastewater were not made available. The volume of wastewater produced at the ZAK Ringsheim plant was not directly made available, although the mass balance shows 'treated wastewater' to be 29% of the plants input by mass, which corresponds to over 29,000 tonnes, which equates to approximately 29,000 m^3 of treated wastewater per year. If this was the case, then the amount of wastewater produced per tonne of waste processed would equate to 0.29 m^3/tonne of waste processed. Although this figure is a factor of ten lower than the figure at Vaasa, it is higher than wastewater production figures for the other MBT plants for which data was available. Again, no information was available on the strength or content of the wastewater. The ZAK Ringsheim plant has a purpose built aerobic wastewater treatment plant as part of the MBT plant. After aerobic treatment the effluent is discharged to sewer. At the SBI Friesland plant in Heerenveen approximately 1 m^3 (or 1 tonne) of wastewater is produced per tonne of organic waste treated by the anaerobic digester. This equates to 100,000 – 120,000 m^3 of wastewater per year from the anaerobic digester. Much of this wastewater is re-used in the wet pre-treatment stage, although it is necessary to continuously replace some wastewater with fresh water to avoid the build up of nitrates and chlorides which could affect digester performance. Some of this replaced wastewater is also re-used in other parts of the process. The total volume of wastewater produced was reported to be 28,575 m^3 per year (Juniper, 2005). This corresponds to 0.12 m^3/tonne of waste processed. There is a wastewater treatment plant on site, to which the anaerobic digestion wastewater is sent (along with wastewater from other parts of the process and landfill leachate). The effluent from this wastewater treatment site is sent to the sewerage system. The Pohlsche Heide MBT plant only generates a small amount of wastewater because the concept provides for using any wastewater in the process itself (Pohlsche Heide Promotional Information, 2005). Water evaporated from the tunnel composting stages is recovered, and converted to steam with which to pre-heat and add moisture to the inflow of the Dranco digestion system. The digestate from the Dranco system is produced in the right quantity that when mixed with the residual OFMSW stream that was not anaerobically digested, contains a water content appropriate for tunnel composting. Very little wastewater is produced (exact volume and content was not disclosed) and therefore very little wastewater treatment is required. Wastewater produced is treated in the wastewater treatment plant that already existed on-site to treat landfill leachate.

The ITRADEC MBT plant at Mons produces 9000 m^3 of wastewater per year, which is treated elsewhere. This corresponds to 0.11 m^3/tonne of residual waste processed. Wastewater is aerobically treated off-site, for which ITRADEC pay €20/m^3 (plus €5/m^3 for transport. The introduction of an on-site wastewater treatment plant could improve plant economics. The Saschenhagen plant produces between 2000 – 3000 m^3 of wastewater annually. This would be the equivalent of 0.036 – 0.055 m^3/tonne of residual MSW processed, or 0.022 – 0.375 m^3/tonne of MSW and commercial waste processed. Without knowing the exact content of the commercial wastes treated it is not possible to comment on these figures. Wastewater is sent to the wastewater treatment works already on site before being discharged to sewer.

Wet digestion processes generally involve wet pre-treatment stages, and usually require more fresh water addition and produce more wastewater than systems based on dry AD processes (Vandevivere *et al.*, 2003), although this trend has not been apparent in the sites visited as part of this project. In both cases, MBT plants can be engineered to minimise water use, and to re-circulate and recycle as much as possible of the wastewater produced on site.

6.2.7 Comparison of space requirements for MBT plants

While it is always true that land-take is an important factor to consider, its importance in comparison to other process parameters varies between sites, usually as a result of the chosen location of the site. For example, if the MBT plant is to be built in an existing landfill complex, where ample room exists for new development (for example the MBT plants at Heerenveen, Saschenhagen or Vaasa) then the land-take assumes less importance. If however, the plant is located on a landfill site with limited available space (such as Buchen), or in an industrial area with only a specific (and small) area of land available (such as Heilbronn) then the ability to process the required volume of wastes in the space available becomes a crucial factor when choosing which MBT option to commission. Land-take is also particularly important in areas where land is expensive (or scarcely available). The footprint of each MBT plant visited (where available) is shown in Table 79.

Table 79 Surface area of plants

Plant Capacity	Total Area (m^2)	Tonnes Processed per m^2 per annum
Buchen 151,000 tpa	27,000	6.1
Heilbronn 88,000 tpa	20,000	4.4
Heerenveen 230,000 tpa	n/a	n/a
Mons 80,000 tpa	70,000	1.1
Saschenhagen 85,000 tpa	n/a	n/a
Pohlsche Heide 100,000 tpa	30,000	3.3
Vaasa 42,000 tpa	n/a	n/a
ZAK Ringsheim 100,000 tpa	8000 – 9000 (1)	11.1 - 12.5

(1) (Juniper, 2005).

As can be seen from Table 79, the total surface area required was not always made available. No data was available for Heerenveen, Saschenhagen or Vaasa. It should be noted that each of these three plants was built on an existing landfill site, where the availability of space was not a major issue, as the owning companies already owned the land on which the plant was to be built. As previously mentioned, the land-take is more important in some cases than in others, and different companies can engineer their respective processes reasonably flexibly to meet any existing requirements. It is also important to note that AD requires less space to treat the same OFMSW throughput than IVC. Therefore, MBT systems incorporating AD as a biological treatment will generally require less space/land than MBT processes incorporating only IVC. Figure 323 shows the tonnage of waste processed per square metre per year in a graphical form.

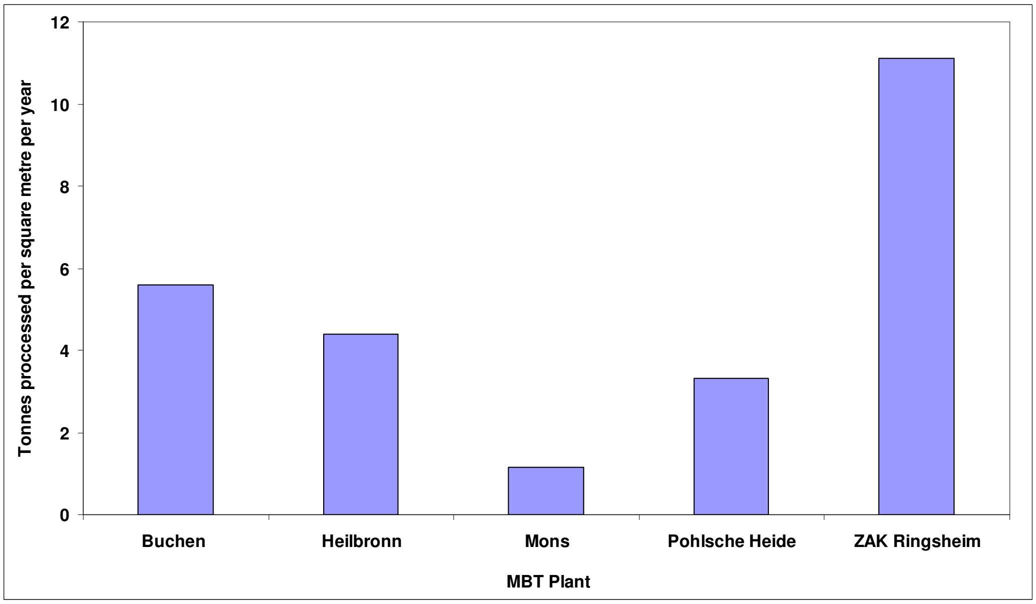

Figure 323 Tonnes of waste processed per square metre per year

From the surface area figures available, it can be seen that the processes in which a percolation stage is used prior to the AD of the liquid phase have higher throughputs per square metre than other plants. The ZAK Ringsheim plant has the highest throughput of all the processes visited (for which information was available). This is because of the percolation system, and because the solid fraction is biodried rather than composted for biostabilisation. Biodrying takes less time than composting, therefore the plant size required to treat a given volume of waste would be smaller. The ISKA MBT concept, which is also based on percolation, also processes more waste per square metre than the other processes that do not utilise percolation and for which data was available (6.1 tonnes/m^2/a at Buchen and 4.4 tonnes/m^2/a at Heilbronn, compared to 1.14 tonnes/m^2/a at Mons and 3.3 tonnes/m^2/a at Pohlsche Heide). As with ZAK Ringsheim, this high wastes throughput is partially due to the low throughput time, which is possible because of the percolation systems on which the ISKA plants are based. The low footprint was one of the main reasons behind the decision to choose ISKA as process suppliers at both Buchen (where there was limited space available at the landfill site) and at Heilbronn (where a limited space was available on the industrial plot on which the process was to be sited). The Mons site shows the lowest throughput per square metre of the plants visited (1.14 tonnes/m^2/a). The plant utilises both AD and in-vessel composting. The AD stage of the plant was operating well below capacity, and was operating on a high retention time (approximately 30 days) to maximise biogas production. The decision to maximise biogas production rather than minimise throughput time was the most economic mode of operation at Mons, given that the anaerobic digesters are operating at less than full capacity, and that plenty of space was available (Figure 216 in the Mons case study). It is assumed that the total footprint of the plant was not one of the most important factors governing the choice of process design for ITRADEC at the Mons site as the total area of the site was 170,000 m^2, of which only 70,000 m^2 is used. Footprints of other MBT plants reported in the literature are listed in Table 80.

Table 80 Processing capacity per square metre of MBT plants (data from Juniper (2005)

Plant Supplier Capacity	Biological Treatment	Tonnes processed per m^2 per annum
Tel Aviv ArrowBio 35,000 tpa	AD and IVC	7 - 8.75
Villacidro BTA 45,000 tpa	AD and composting	16.1
Leicester Hese 40,000 tpa	AD and IVC	6.1
Eastern Creek GRL 260,000 tpa	Percolation, IVC and AD	4.6
Tufino VKW 75,000 tpa	IVC	6.1
Durham Civic 90,000 tpa	IVC	18
Montanaso Ecodeco 60,000 tpa	Biodrying	22.2
Dresden Herhof 85,000 tpa	Biodrying	14.7
Rugen Nehlsen 20,000 tpa	Biodrying	1.2

The values quoted in Table 80 are case specific, and to compare them without first referring to the entire concept, background and aims of the plant would be unwise and potentially misleading. More information is available in Juniper (2005). Plants requiring windrow composting or maturation tend to have large land requirements. In general, the IVC of wastes requires more land than AD. This is not always observable in the figures as MBT plants based on AD often also require an IVC stage to fully biostabilise the output. The similarity between AD and IVC based systems can be seen in the figures. It is noticeable that biodrying processes have a considerably larger throughput per square metre than both AD and IVC based plants. This is because the biological stage of the plant is based on biodrying, which has a shorter residence time than both AD and composting. For example, the Ecodeco process shows a high throughput per square metre (22.2 $t/m^2/a$), the Herhoff process has a throughput of 14.7 $t/m^2/a$. Comparing the IVC systems, the Civic process stands out, with a throughput per square metre of 18 $t/m^2/a$). This high throughput per square metre is because the Civic system is based on vertical composting towers, which reduce the land required when compared to non-vertical composting systems. With regards to the AD plants, the throughput per square metre at the BTA plant in Villacidro (Italy) is very high (16.1 t/m^2/a). At the plant, de-watered digestate is composted, for full maturation, and it is assumed that the area required for composting is included in the total. The Hese plant at Leicester, the 6.1 t/m^2/a is only for the 'biological stages', not the mechanical stages. Also, the plant is based on two separate sites, and the land-take would be lower if the two parts of the process were integrated on the same site. The taller the process, the lower its footprint will be, but the greater its visual impact. The importance of the play-off between visual impact minimisation or land-take minimisation will be case specific, and highly dependent on the proposed location of the plant. The key point with regards to the surface area of the plant is that different areas have different priorities, and different MBT solutions will be ideal for different areas.

6.2.8 Comparison of residence times for MBT plants

The time taken to process residual waste is an important criteria for comparing the MBT options. It is reflected directly by many other factors, such as the concept, type and design of the MBT plant, the space required by the plant in comparison to throughput, and the overall performance of the concept. The residence time can usually also be manipulated in order to better or more economically treat the incoming waste stream, according to local conditions. For example, at Mons it is possible to keep the OFMSW in the AD stage for up to 30 days in order to try and recover more biogas, as the AD process operating well below capacity. Due to the different legislation applied in different European countries (particularly with regards to the extent of biostabilisation required prior to landfill) the residence times may be different in the UK, even if a similar process was employed. Figure 324 displays the total residence times in the MBT plants visited as part of this project.

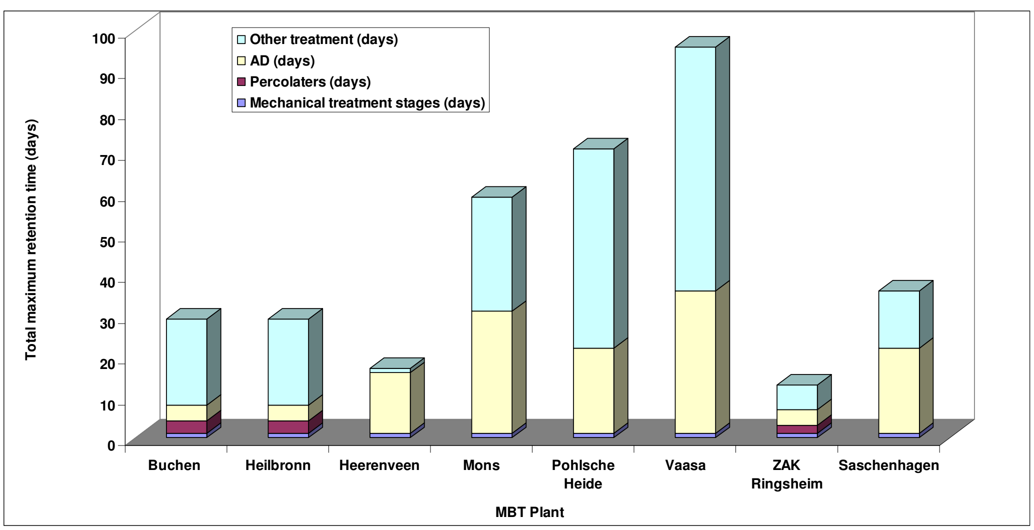

Figure 324 Total residence times in the MBT plants visited

In all of the cases considered above, time spent in the reception hall is not included in the total residence time. In all cases the time allocated to mechanical pre-treatment is given as one day, which should be the maximum time spent in the mechanical pre-treatment system. As the residence time is always variable, and can be manipulated to adapt to the specific conditions, many plants quote the residence times in different parts of the process in a range. For example at the Stormossen plant in Vaasa, retention time in the digester is given as 30 -

35 days, and at Mons, the post-AD composting stage was said to take 14 - 28 days. At Saschenhagen the retention time in the liquid maturation stage was quoted as 5 - 14 days, as required. In all of these cases the maximum residence time quoted has been used in Figure 324 to ensure consistency. Also, if the maximum values are compared, then it can be assumed that the actual average retention time is lower.

For Heerenveen the residence time in the 'immobilisation plant' was not given, but is assumed to be around one day, based on the short description of the process. It may be the case that the residence time in the 'immobilisation plant' is longer, and if so, this time should be added onto the total residence time in Figure 324. If the de-watered digestate is used as a substitute fuel then the digestate will not require this extra day, and the residence time will therefore be one day less. In the Saschenhagen plant the 21 days allocated to the anaerobic digestion stages includes the time spent in the hydrolysis and mixing tanks. In Vaasa, de-watered digestate is windrow composted for approximately 2 months after being de-watered. This figure can increase or decrease depending on the requirements of the neighbouring landfill sites for daily and permanent cover, and the space available at the windrow site. For the plants employing percolators (Buchen, Heilbronn and ZAK Ringsheim), the anaerobic digestion and the treatment of the solid phase (composting in the case of Buchen and Heilbronn and biodrying in the case of ZAK Ringsheim) occurs simultaneously, therefore the first four days of the 'other treatment' have been subtracted from the graph, to enable a more accurate comparison of the total throughput time. In reality, the residence time in the 'other treatment' section would be 4 days longer than is displayed in the graph.

It can be seen that the Heerenveen site, which has a low total residence time (of 17 days) due to the fact that there is no post AD composting of the digestate. The de-watered digestate is either used as a substitute fuel or is 'immobilised' (by mixing it with fly ash, sludges and water glass, sodium metasilicate), to produce a permanent landfill cover. The low residence time could be significantly increased if the residence time of the 'immobilisation plant' is higher than the assumed value of one day. For example, the post AD composting stages can have a residence time of between 2 and 8 weeks. If the digestate was composted for biostabilisation, then the total residence time would be significantly increased. It should be noted that aside from the Heerenveen residence time, which is based on an assumption, the three shortest total residence times are in the three systems that employ MBT plants based around percolation systems (ZAK Ringsheim, total residence time of 9 days, and Buchen and Heilbronn, both with a total residence time of 25 days). The percolation-based systems extract the majority of the organics from the mechanically treated residual waste stream into an easily pumpable liquid phase, which can be quickly and effectively treated in a conventional high rate anaerobic digester designed for liquid wastes. After percolation, the solid waste is simultaneously treated, by in-vessel composting at Buchen and Heilbronn, and by biodrying at ZAK Ringsheim. The considerably shorter residence time required to biodry the solid phase after percolation (6 days) compared to 21 days to biostabilise it for landfill by in-vessel composting is the reason why the residence time at ZAK Ringsheim is lower than at Buchen and Heilbronn.

At Saschenhagen and Pohlsche Heide it can be seen that the residence time in the anaerobic digesters is similar (21 days at each site). The main difference in the total residence times is due to the post AD treatment stage. In Saschenhagen 'liquid maturation' process is used, with a usual residence time of 14 days, compared with tunnel-composting at Pohlsche Heide (residence time of 7 weeks). At Vaasa windrow composting is employed (the de-watered digestate is windrow composted for up to 2 months). Clearly, windrow composting would be the cheapest option, as long as it meets the local legislation. It can be seen that the AD stage at Vaasa has the highest residence time (30 - 35 days), closely followed by Mons with a residence time of 30 days. The high retention time in the AD stage at Mons is possibly due to the fact that the plant is running at less than capacity, and the OFMSW can be digested for a longer period, to enable the maximum possible production of biogas.

6.2.9 Comparison of capital costs for MBT plants

MBT plants can incorporate a wide variety of technologies and combinations of technologies. As such, there are many different possibilities, and no two plants are exactly the same. The only way to obtain an accurate estimate of the potential cost of a system is to put the process out to tender. As for basic comparisons based on the costs of reference plants, these can only ever form a rough guide. The costs of plants vary for many different reasons, including type and quantity of waste to be treated, specific process aims or goals, local and national legislation, and local conditions or requirements. Also, some plant costs are quoted in different ways than others, for example some include land, finance, improvements and other costs, whereas others do not. Advances in technology, varying exchange rates and the historic value of the currencies also mean that the quoted converted financial figures shown will not be directly comparable with costs in the UK in 2006/2007. These factors must be considered alongside the information shown in Table 81, which displays a basic comparison of the capital costs.

The cost and the capacity figures in Table 81 are for the whole MBT plant, rather than just the biological (AD) part of the system. In MBT plants, the AD system itself represents only a small proportion of the total capital cost. It would be pointless to compare AD systems alone however, as MBT plants are a combination of processes designed to work together, and without the correct pre-treatment and post-treatment stages the 'system' could not function as planned. The capital cost/tonne waste throughput (over 20 year operating life) as displayed in Table 81 is a basic figure based on the total capital cost divided by the annual capacity multiplied by 20 years. No account of operating costs or the cost of finance was made. It should also be noted that many of the plants were deliberately oversized, in anticipation of increasing volumes of municipal wastes and the potential to win other wastes contracts. The winning of other wastes contracts could increase their income from gate fees, and boost their income from biogas production (if the waste was biodegradable). Therefore, any increases in throughput (which the owner/operators would usually welcome) would improve plant economics and positively change the figures considered above. These capital cost figures can also be observed in Figure 325, which shows the capital cost against the capacity of the plants.

The Pohlsche Heide capital cost figure takes into account the whole wastes stream (100,000 tpa), rather than solely the residual municipal wastes (40,000 tpa). It can be seen that the Vaasa system was very inexpensive compared to the other systems. The main reason for this would be that the plant was initially built in 1991, as compared to the other plants that were built much more recently, and no account has been made of inflation. The Vaasa plant was also built 'bit by bit', between 1991 and 2006, and made use of existing infrastructure which would also lower the capital cost. The ZAK Ringsheim and Buchen plants were the most expensive, reflecting the fact that they were the most recently built. Further comparisons should include the scale of the plant, which it is vitally important to consider as it has a large effect on the cost of the project.

Table 81 Capital costs for MBT sites visited

Plant Capacity	Waste Treated	Started-up	Total Capital Cost (Reference)	Capital Cost/ tonne waste throughput (over 20 year operating life)
Buchen 151,000 tpa	Residual MSW	2005	**€42 m** (1) £28.4 m	**€13.9** £9.4
Heilbronn 88,000 tpa	Residual MSW	2005	**€27 m** (1) £18.2 m	**€15.3** £10.3
Heerenveen 230,000 tpa	Residual MSW and commercial wastes	2002	**€40 m** (2) £27 m	**€8.7** £5.87
Mons 80,000 tpa	Residual MSW	2000	**€35.06 m** (3) £23.7 m	**€21.91** £14.8
Saschenhagen 55,000 tpa 30,000 tpa	Residual MSW Commercial wastes.	2006	n/a	n/a
Pohlsche Heide 40,000 tpa 40,000 tpa 12,500 tpa 7500 tpa	Residual MSW Commercial wastes Sewage sludge Other sludges	2005	**€26 m** (4) £17.6 m	**€13** £8.8
Vaasa 42,000 tpa	Residual MSW	1991	**€7.5 m** (5) £5.1 m	**€8.93** £6
ZAK Ringsheim 100,000 tpa	Residual MSW	2006	**€45 m** (6) £30.4 m	**€22.50** £15.2

An exchange rate of €1= £0.675 was used.
(1) Kutterer, Personal Communication (2006).
(2) Smink, Personal Communication (2006). Based on £25 m in 2002.
(3) ITRADEC Promotional Information (2006).
(4) AML, Promotional Information (2006).
(5) Akers, Personal Communication (2006).
(6) Gibis, Personal Communication (2006).

From Figure 325, it becomes clearer that although Vaasa was by far the cheapest plant in terms of capital costs, it also has the smallest capacity. The Heerenveen site has the largest capacity, which justifies its relatively high capital cost. A more valuable comparison, the capital cost per tonne of waste treated over the plant's estimated 20 year lifespan is shown in Figure 326. It must be noted that operational costs or incomes, finance costs or unforeseen maintenance costs are not considered in this figure. It must also be noted that different parts of different MBT plants have different guarantees with regards to 'operational lifetime'. Some MBT plants are designed with a longer 'working lifetime' in mind than others, while some are built with an added flexibility (sometimes at an extra cost) that would enable future changes to be made more easily. A well managed and maintained MBT plant may last considerably longer than a similar plant where less money is spent on maintenance.

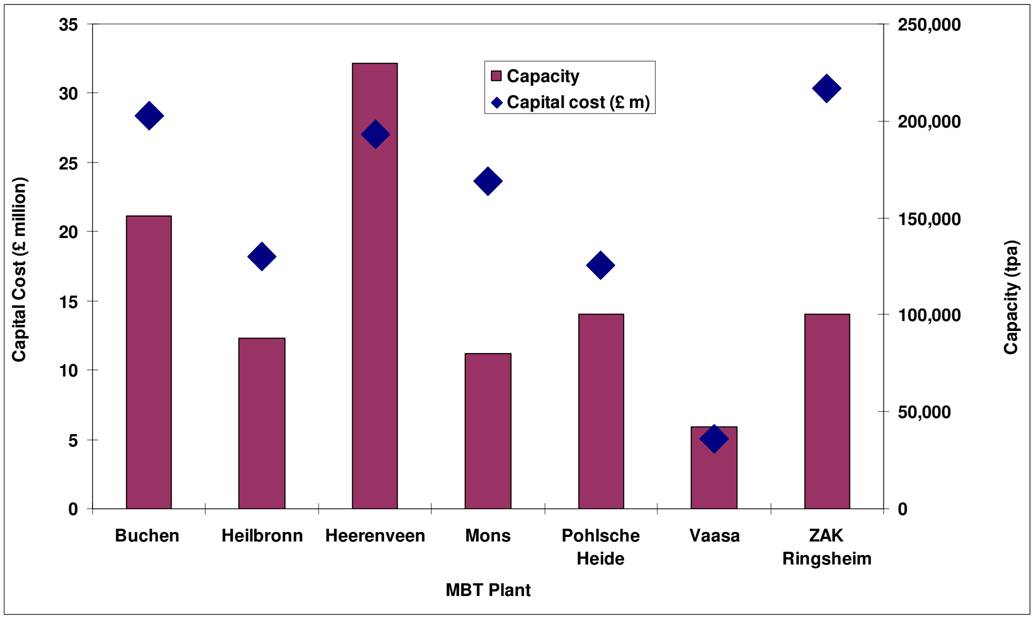

**Figure 325	Capital cost and capacity of MBT plants**

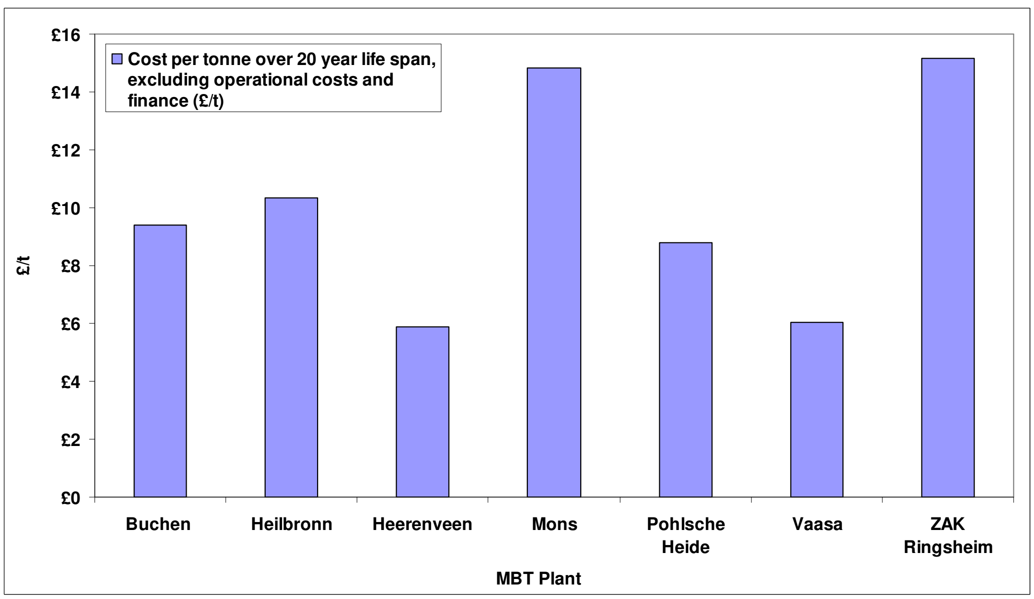

**Figure 326	Capital cost per tonne treated over 20 year life span of the plant**

The economy of scale can be noted when considering the cost/tonne at Heerenveen, as compared to the other sites. Heerenveen accepts around 230,000 tpa of wastes, approximately double that of the next biggest (in terms of throughput) plant visited (Buchen, 151,000 tpa). The relatively high capital cost of the ZAK Ringsheim plant reflects the fact that the digestate/solid output is upgraded and a solid recovered fuel produced. The technology required (throughout the plant) to enable the production of a quality-specified industrially usable fuel (from which an income will be received) represents considerable extra expense initially but will minimise ongoing RDF disposal charges. The high cost of the Mons plant could be indicative of the fact that the plant was designed considerably oversized. For example, only one of the two anaerobic digesters is currently required to treat the OFMSW. This extra capital outlay gives ITRADEC (the owner/operators) the option of accepting other non-municipal organic waste contracts, with which they can considerably improve their profit margins (by way of more gate fees and more biogas).

A point that must be made is that comparing these systems based on capital cost is of limited value, as each plant was judged by a panel of experts to be the best available option for the given circumstances of the specific area. For example, the throughput at Vaasa is small compared to the other plans, and capital costs per tonne processed, as well as operating costs would have been lessened if a larger plant had been built, the plant was built to deal with the available waste streams in the area, therefore a larger plant was not necessary. Another example is that the Heilbronn plant was built at a smaller scale than the Buchen plant to treat the lower local requirements. This resulted in increasing the costs per tonne processed when compared to the technically identical Buchen plant. It was also necessary to build the Heilbronn plant in a small area, which influenced the choice of MBT process. Other local factors such as the proximity of a river also influenced design and costs.

As well as local conditions, legislation plays a major part in the choice of systems. An example of this would be the fact that German air emission legislation is stringent in comparison to the legislation of other European countries. Clearly, to meet this legislation, the exhaust air treatment systems on German MBT plants must be considerably more effective than in other countries. This often represents a major extra expense. For example at the German MBT plants (Buchen, Heilbronn, Pohlsche Heide, Saschenhagen and ZAK Ringsheim) some form of thermal exhaust air treatment was necessary to meet legislation, whereas at Mons, Heerenveen and Vaasa only a biofilter unit was required.

6.2.10 Comparison of operating costs for MBT plants

The operating cost per tonne of waste processed is a key factor to consider when comparing different MBT approaches for residual wastes treatment. Unfortunately, detailed data on the economics of the plants was not made available. Where they were supplied, the operating costs given were often not well defined (in terms of exactly what they included or omitted). No data was available for the SBI Friesland plant at Heerenveen. The operating costs for Buchen, Heilbronn, ZAK Ringsheim and Saschenhagen all include the cost of finance. It is assumed that the operating costs supplied for Mons, Pohlsche Heide and Vaasa also include finance, although this was not stated. A basic comparison of the operating costs (where available) is shown in Table 82.

The operational costs above are displayed in Figure 327.

Table 82 MBT plant operating costs

Plant Capacity	Waste Treated	Operating Cost per tonne Input	Reference
Buchen 151,000 tpa	Residual MSW	**€35 – 55** (including finance) £23.63 - £37.10	(Kutterer, Personal Communication, 2006).
Heilbronn 88,000 tpa	Residual MSW	**€35 – 55** (including finance) £23.63 - £37.10	(Kutterer, Personal Communication, 2006).
Heerenveen 230,000 tpa	Residual MSW	n/a	
Mons 80,000 tpa	Residual MSW	**€100** (in 2006) £67.50	(Urbain, Personal Communication, 2006).
Saschenhagen 55,000 tpa 30,000 tpa	Residual MSW and commercial wastes	Not stated, but said to be close to 'normal MBT operating costs of **€60** With another €60 approx for finance £40.50 (+£40.50)	(Dippert, Personal Communication, 2006).
Pohlsche Heide 40,000 tpa 40,000 tpa 12,500 tpa	Residual MSW, Commercial wastes and sewage sludge	**€60** (excluding RDF disposal). £40.50	(Dippert, Personal Communication, 2006).
Vaasa 42,000 tpa	Residual MSW	**€84** (not including tax). £56.70	(Akers, Personal Communication, 2006).
ZAK Ringsheim 100,000 tpa	Residual MSW	**€70** £47.25	(Gibis, Personal Communication, 2006).

An exchange rate of €1= £0.675 was used.

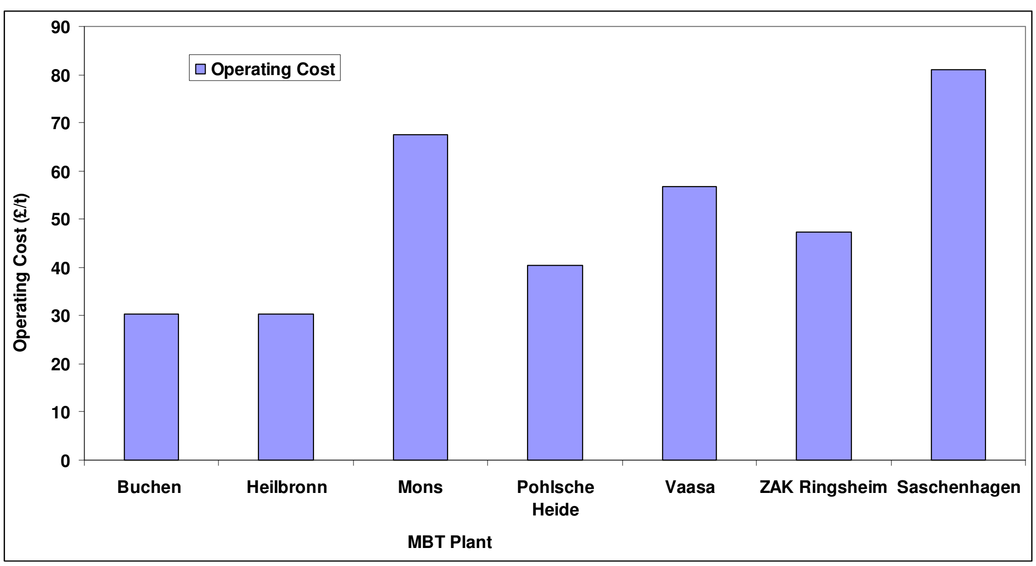

Figure 327 Operating cost comparison

As indicated above, for some of the plants it was confirmed that the operating cost included the cost of the finance, while for others whether or not the operational cost included finance was not made clear. For the Buchen and Heilbronn sites, operating costs were estimated at £23.63 - £37.10/t (€35 – 55/t), including finance. It was estimated that approximately half of the total operating cost at each site was spent on exhaust air treatment (Kutterer, Personal Communication, 2006). The Buchen plant is paid around £67.50/t (€100/t) of waste received (Kutterer, Personal Communication, 2006). At Mons the operating cost per tonne of incoming waste is £67.50 (€100). As the site is 100% publicly owned, the costs are passed on to the public, and the site gets a gate fee of £67.50/t (€100/t) from the municipalities. Wastewater treatment costs approximately £16.88/m^3. Around 30% of the operating costs of the plant are taken up by RDF disposal. It costs ITRADEC £47.25/t (€70/t) (including all taxes, but not including transport) to landfill waste. Therefore, the plant is more expensive than landfilling by £20.25/t (€30/t) at present. The Belgian Government plans to increase the landfill tax over the coming years to bring the price to around £67.50/t (€100/t) or above, which will close this gap. Operational costs (excluding RDF disposal) at Pohlsche Heide were stated as £40.50/t (€60/t), with the gate fee received being £84.38 - £97.88/t (€125 – 145/t). The low water usage and wastewater treatment requirement contributes to keeping the operational cost down. As the plant covers the vast majority of its energy requirements, energy costs will be low, although as no energy is exported, there is no income from the sale of excess electricity or heat from biogas production. The Stormossen plant running costs were said to be similar to the gate fee paid for 'kitchen wastes', which is around £56.70 (€84/t) without tax (Akers, Personal Communication, 2006). Operating cost per tonne of incoming waste is £47.25 (€70) including finance at the ZAK Ringsheim Plant (Gibis, Personal Communication, 2006). As the plant is publicly owned, the gate fee charged is slightly above £47.25/t (€70/t) (Gibis, Personal Communication, 2006). Operating costs for the Saschenhagen plant were not made available, but it was indicated that costs were 'similar to normal operating costs of MBT plants' at around £40.50/t (€60/t), with an additional £40.50/t (€60/t) of credit costs (Dippert, Personal Communication, 2006). It should be remembered that the Saschenhagen plant was also a pilot project, representing the suppliers first attempt to provide this type of plant. Therefore, costs should fall in subsequent projects.

Given the great differences between the plants, and the differences (or uncertainties) between how the operating costs were quoted and what they may or may not include, attaching importance or credibility to the comparison of the operating costs as displayed in this report is not recommended. A more detailed analysis would be required, based on a deeper level of financial information. Given that few companies are prepared to divulge detailed financial information, especially if it may be used in such comparisons, it may only be possible to compare operating cost forecasts based on detailed tenders produced by the process suppliers in response to an offer for bids for an actual project.

Considering the above paragraph, it can be seen that the ISKA plants, Buchen and Heilbronn appear to have the lowest operating cost per tonne of wastes throughput £23.63 - £37.10/t (€35 – 55/t), and the Saschenhagen plant the highest (although the exact operating cost was not quoted). More discussion of the costs of other MBT plants that do not incorporate AD can be found in Juniper (2005) and Eunomia (2002a and 2002b).

6.2.11 Summary of comparison of AD systems treating centrally separated OFMSW

Although the MBT plants visited were all primarily designed to process residual municipal waste (except Vaasa), each residual waste stream was different (depending on the waste strategy in the region, and what was included in the residual waste). The legislation that the plants were built to meet was different, as were the local conditions (*e.g*., remaining landfill capacity, incinerator capacity, proximity of industries that would accept RDF/SRF, climate, availability of existing wastewater treatment facilities or biogas utilisation facilities, space available, proximity to natural, agricultural or residential areas). The content of the residual waste depends on the wastes and recycling policy in the particular region, as well as many other factors. For example in some regions being served by the MBT plants compared in this section kitchen waste is collected as part of the residual waste stream (for example Mons, ZAK Ringsheim, Buchen and Heilbronn). In other regions kitchen waste is source separated and treated in a different plant (Heerenveen, Pohlsche Heide). In some plants (such as Pohlsche Heide, Saschenhagen and Heerenveen) commercial wastes and even sewage sludge are also accepted, therefore these sites can not be considered solely as municipal residual wastes processing and treatment facilities.

The ZAK Ringsheim concept diverts over 90% of the residual waste from landfill. The Saschenhagen MBT plant diverts around 40% of the incoming waste from landfill (although the plant accepts a high proportion of commercial wastes, the contents of which was not revealed). Buchen, Heilbronn, Heerenveen, Mons, Pohlsche Heide and Vaasa all divert between 60% and 72% of the wastes from landfill (minimum values), assuming all RDF is incinerated and all CLO is landfilled. In all cases, if the digestate/CLO was to be incinerated rather than landfilled, the energy recovery would increase and the volume of waste being landfilled would be decreased.

The costs of plants vary for many different reasons, including type and quantity of waste to be treated, specific process aims or goals, local and national legislation, and local conditions or requirements. Also, some plant costs are quoted in different ways than others, for example some include land, finance, improvements and other costs, whereas others do not. Advances in technology, varying exchange rates and the historic value of the currencies also mean that the quoted converted financial figures shown will not be directly comparable with costs in the UK in 2006/2007.

It can be seen that the processes in which a percolation stage is used prior to the AD of the liquid phase have higher throughputs per square metre than other plants. The ZAK Ringsheim plant has the highest throughput of all the processes visited. This is because of the percolation system, and because the solid fraction is biodried rather than composted for biostabilisation. The ISKA MBT concept, which is also based on percolation, also processes more waste per square metre than the other processes that do not utilise percolation and for which data was available. The taller the process, the lower its footprint will be, but the greater its visual impact. The importance of the play-off between visual impact minimisation or land-take minimisation will be case specific, and highly dependent on the proposed location of the plant. The key point with regards to the surface area of the plant is that different areas have different priorities, and different MBT solutions will be ideal for different areas. Process suppliers can work flexibly to meet clients requirements.

Wet digestion processes generally involve wet pre-treatment stages, and usually require more fresh water addition and produce more wastewater than systems based on dry AD processes (Vandevivere *et al*., 2003), although this trend has not been apparent in the sites visited as part of this project. Whether AD is wet or dry, MBT plants can be engineered to minimise water use, and to re-circulate and recycle as much as possible of the wastewater produced on site.

The biogas production figures for Pohlsche Heide, Buchen, Heilbronn and Heerenveen are all very similar (57 – 72 m^3/t, 55 m^3/t, 50 m^3/t and 55 m^3/t, respectively). It is interesting that the Pohlsche Heide plant shows a slightly higher biogas production per tonne of waste throughput, despite only 70 – 80% of the organic waste being anaerobically digested. This could be due to the commercial wastes that the plant co-digests alongside OFMSW, or the fact that anaerobic digestion is 'dry'.

The average biogas production per tonne of OFMSW anaerobically digested in the six fully operational MBT plants visited is 133 m^3/t. The biogas produced per tonne of organic waste processed through the anaerobic digestion system at Mons is very high compared to the other values recorded (231 m^3 per tonne of waste throughput, based on a total biogas production of 4,160,000 m^3 from 18,002 tonnes of OFMSW). The average volume of biogas produced per tonne of OFMSW anaerobically digested in the other plants was 113 m^3/t (although some of the other plants also co-digested other organic wastes). Not considering energy from the thermal treatment of RDF or SRF, all of the MBT plants (with the exception of Heilbronn and Pohlsche Heide) cover their on-site requirements and produce exportable electricity from the biogas they produce. Heilbronn and Pohlsche Heide almost completely cover all on-site requirements. All of the MBT plants produce enough heat to cover all their own uses and produce an exportable excess. In some (but not all) cases it has been possible to find a beneficial use or even an income for this excess heat (for example, ZAK Ringsheim where the heat is used in a district heating scheme, and Vaasa where heat is exported to an indoor sports complex and another neighbouring industry).

All of the plants represent a viable and economic option to divert biodegradable and otherwise recoverable municipal wastes from landfill in their respective countries and regions.

7.0 POSSIBILITIES FOR BIOLOGICAL TREATMENT OF BMW IN RCT CBC AND SOUTH WALES - UK

This section aims to analyse the various possibilities for biological treatment of BMW in RCT CBC as well as for the South Wales area. For the purposes of this report the term South Wales Urban Conurbation (SWUC) has been used to describe the South Wales local authority areas between Newport and Swansea, and extending northwards through the valleys towards Merthyr Tydfil. Approximately 60% of the Welsh population live in these areas (Welsh Census, 1999), at a population density of 500 people per square kilometre, twice the UK National average (WAG Public Statistics for Wales website, accessed June 2006). Table 83 shows the kitchen waste arisings in the SWUC local authority areas in 1999/2000 (WAG, 2002). These figures only represent municipal kitchen waste, and do not include garden waste or other organic fractions of MSW (such as paper and card). It is likely that the total MSW produced has increased since 1999/2000. The implementation of a biological waste management system is looked at in terms of having a source separation scheme as well as being part of a MBT system. Included is also a comparison of the performance of the two forms of BMW treatment (*i.e.* AD and IVC).

Table 83 Kitchen waste arisings in SWUC

SWUC Region	Total MSW (1999/2000) (tpa)	Total Kitchen Waste (1999/2000) (8% of MSW) (tpa)
Blaenau Gwent CBC	41,348	3,308
Bridgend CBC	56,864	4,549
Caerphilly CBC	80,192	6,415
Cardiff CC	167,694	13,416
City of Swansea C	131,031	10,482
Merthyr Tydfil CBC	30,457	2,437
Neath Port Talbot CBC	89,968	7,197
Newport CBC	62,043	4,963
Rhondda Cynon Taff CBC	**107,168**	**8,573**
Torfaen CBC	47,807	3,825
Vale of Glamorgan CBC	53,841	4,307
Total for SWUC	**868,413**	**69,473**
Total for Wales	**1,622,107**	**129,769**

Commercial wastes (including from institutional kitchens), industrial and agricultural organic wastes, all of which are available (and must be treated) in large quantities in the South Wales region are also not included. Sewage sludge, which is available in each LA area is similarly not included. In addition to those wastes, there was also a total of 165,207 tpa of solid organic wastes (consisting mainly of slaughterhouse waste and paper waste sludge) spread to land in the SWUC area between 1995 and 2001 (WAG, 2002), which included 18,433 tonnes in RCT (WAG, 2002). Therefore, there is a considerable organic resource from different sectors in the South Wales region that could potentially supplement source separated BMW in AD facilities, boosting gate fees, and increasing income from biogas and renewable energy targets. The anaerobic digestion of a proportion of these organic wastes could significantly assist progress towards waste treatment and landfill diversion targets, improve soil quality by the addition of organics, and help farmers meet nitrates protection Directives and save on inorganic fertilizers. Integration and collaboration between LAs, the industrial sector, the agricultural sector and private investors would need to be developed and maximised to make the most of potential AD opportunities in the region. As it can be seen from Table 83, most LA areas would need to consider a biological treatment plant capacity around 10,000 tpa. There are significant number of anaerobic digestion and in-vessel composting reference plants around this size throughout Europe. It is estimated that the potential capital cost for an in-vessel composter treating 10,000 tpa would be between £1 – 3 million (see Section 2.3.2.3). A similar scaled AD plant would probably cost in the region of £2 – 5 million (see Section 2.3.2.3 and Table 63), based on similar scaled plants in continental Europe, with the exact cost depending on the characteristics and role of the plant. It should be noted that UK conditions and legislation are different from those in Europe and these costs may not be representative of a similar plant in the UK.

Both an in-vessel composting facility and an anaerobic digester could be expected to divert 100% (minus contaminants which could be expected to be less than 5%) of the incoming source separated kitchen waste from landfill provided the CLO quality could be assured. AD systems would require less space to treat the same throughput of wastes. The major advantage of AD systems over IVC systems is the positive energy balance. This advantage can be clearly seen for a 10,000 tpa plant where the energy difference could be as much as 7000 MWh/a in favour of anaerobic digestion (based on a difference of 700 kWh/t as quoted by Edelmann *et al*., 2001).

Calculations based on figures from a Kompogas plant were performed just as an example. It does not represent an endorsement of Kompogas systems over and above the AD systems of other AD suppliers. According to the Kompogas website [c] (accessed January 2006) the amount of biogas produced by a 10,000 tpa unit is approximately 1,054,000 m^3/a, which produces 2078 MWh/a of electricity. Approximately 290 MWh (14%) of this is used on site every year, leaving an annual electrical power surplus of 1788 MWh/a (all figures from Kompogas website [c], accessed January 2006). At current UK prices, this biogas would be worth £192,210 if sold as renewable electricity (after on-site electricity had been provided). The same plant would produce approximately 3240 MWh/a of heat energy, of which approximately 1,650 MWh/a would be used on site, leaving an exportable excess of around 1320 MWh/a (Table 84). It is noted that these figures are variable as a function of plant design and waste composition.

Table 84 Exportable energy from a typical Kompogas AD plant (Kompogas website, accessed January 2006)

Energy	Exportable Energy in a 10,000 tpa plant (MWh/a)	Exportable Energy in a 100,000 tpa plant (MWh/a)	Exportable Energy/tonne Waste Treated (kWh/t)
Electricity	1788	17,880	179
Heat	1320	13,200	132

Despite the fact that Kompogas systems usually treat kitchen and garden wastes (~80%) and industrial organic wastes ~20%) this biogas production (105.4 m^3/t) can be considered as a reliably achievable gas production from AD systems treating kitchen waste alone. Other AD systems (provided by other suppliers) treating kitchen waste have reported biogas productions of 110 – 170 m^3/tonne of source separated kitchen waste (see Table 19 and Table 21). As the Kompogas system is modular, a scale up to 100,000 tpa would be possible. It can be assumed that the biogas production figures can also be scaled up by a factor of 10 (approximately) to give an income from biogas of approximately £1,922,100 if sold as renewable electricity. At this larger scale it can be assumed that the cost (per tonne of waste treated) of the biogas enriching plant, transport fuel infrastructure or CHP plant would be significantly lower due to the economy of scale. Conversely the transport distances to and from the site would be increased. All other AD suppliers (whether the systems are modular or not) are able to supply various plant sizes, and the cost per tonne of waste treated always decreases the larger the scale of the plant.

It is assumed that it will not be possible to receive an income from the heat energy, unless the site is constructed near an existing or planned user. The calculations in Table 85 are based on figures quoted on the Kompogas website [c] (accessed July 2006) and are therefore representative only of one Kompogas system that was put forward as an example. Current economic projections from Greenfinch also predict a potential income from electricity sales of £20/t of food wastes treated (Chesshire, Personal Communication, 2007). Similar figures of biogas and electricity production are observed in plants supplied by most major AD suppliers treating the same waste stream.

Table 85 Potential income from biogas from BMW (after on-site electricity requirements of 14%)

Biogas Use	10,000 tpa	15,942 tpa (As available in RCT, in 1999/2000)	100,000 tpa	Income/tonne Waste Treated
Electricity	£192,210	£306,421	£1,922,100	£19.20
Heat	n/a	n/a	n/a	n/a

Note:

- The RCT figure of 15,492 tpa represents kitchen and garden waste, whereas the figure of 8573 tpa quoted in Table 83 represents only kitchen waste (both from WAG, 2002).
- It can be assumed that a centralised plant treating kitchen wastes from the whole South Wales region would be around 100,000 tpa capacity (depending on feedstocks for co-digestion).
- It may also be possible to recover revenue (or definitely savings on site) from the heat produced in electricity production, but that will depend on neighbouring industries/public buildings and is therefore case specific.
- The exact amount of gas produced vary according to waste and process characteristics.

Table 86 summarises the capital and operating costs as well as landfill diversion and energy balance of an AD system compared to an IVC for treating 10,000 tpa of BMW/kitchen waste.

Table 86 Summary of comparison of 10,000 tpa IVC and AD plants

Parameters	IVC	AD
Capital Cost	£1 - £3 million (1)	£2 – 5 million (1) £2 – 3 million (2)
Operating Cost (£/t)	£20 – 30 (1) £24 – 36 (3)	£3 (1) (inc. income from biogas) £13 – 17 (3)
Landfill Diversion	>95%	>95%
Energy Balance (per tonne of wastes treated)	Negative -50 to -75 kWh_e/t (4) -73 kWh_e/t (5)	Positive +75 to +150 kWh_e/t (4) +102 kWh_e/t (5)

(1) DEFRA website (accessed October 2005)
(2) Table 63 of this report.
(3) Eunomia (2002b)
(4) Verma (2002)
(5) van Zanten (Accessed 2005)

It must be noted that there are many different IVC and AD technologies on the market, and the figures in Table 86 may not be representative of all systems. In-vessel composting remains the cheaper biowastes treatment option in terms of capital cost, nevertheless capital costs for more recent AD systems are comparable to IVC. In terms of operating cost most comparisons agree that AD is cheaper than IVC. Both technologies will divert a similar percentage of source separated BMW from landfill, and it is assumed that the surface area required by an AD plant would be smaller than that required by an IVC plant. The most significant difference between the two technologies becomes apparent when considering their respective energy balances. Several studies have attempted to quantify the difference in energy balances between AD and aerobic composting. Verma (2002) stated that aerobic composting required 50 – 75 kWh of electricity per tonne of MSW input, compared to AD producing around 75 – 150 kWh of electricity from methane per tonne of MSW input. Resulting in a difference of 125 – 225 kWh of electricity per tonne of waste treated. A Dutch study, comparing the treatment of biowaste by and anaerobic digester and an in-vessel composter found that the anaerobic digestion plant produced 366 MJ (102 kWh) of net energy per tonne of (garden food and vegetable) waste, whereas the composting plant consumed 261 MJ (73 kWh) per tonne of biowaste. This represents a difference of 627 MJ or 175 kWh per tonne of biowaste treated (van Zanten, Accessed 2005). Taking into account the primary energy for construction and running of the plants, *i.e.* including all losses from the moment of extracting crude oil or uranium, as well as the substitution of nuclear and fossil energy by renewable biogas, Edelmann *et al.* (2001) calculate an energy difference as large as 700 kWh/tonne in favour of anaerobic digestion over fully enclosed tunnel composting.

Therefore, operating in-vessel composting plants will carry a considerable cost, whilst operating AD plants will return a significant income from the sale of renewable energy. The importance of energy issues is ever more important, considering climate change concerns, security of supply issues and increasing fossil fuel prices. Therefore, it can be assumed that the operating costs of IVC systems will increase over time, and the income from the sale of renewable electricity from AD plants will increase over time, making the treatment of BMW/OFMSW by AD even more attractive.

It can be seen from Table 86 and Table 87 that although AD and IVC remain excellent options for diverting organic wastes from landfill, they represent significant capital expenditure. The South Wales area, although governed by 11 LAs, represents a small land area, and houses a population of 1,672,100 (Welsh Census, 1999). If the 11 neighbouring LAs listed in Table 83 were to co-operate, and commission one centralised anaerobic digester to treat all kitchen waste arisings, then significant cost savings may be realised. Further cost savings and income could be generated by co-digesting any of the other organic wastes available in the region. Although each local authority must prepare its own detailed plans for managing municipal wastes in line with the national strategy, it is clear that significant advantages could be realised by the co-operation of neighbouring LAs. The Welsh Local Government Association (WLGA) recognise that partnership between LAs is critical in ensuring the success of local government to meeting the landfill targets. The WLGA 'accept that '*it is neither feasible, sensible nor affordable for each local authority to have their own hierarchy of waste facilities. Therefore partnership and regional working will be critical*' (WLGA website, accessed June 2006). Co-operation should bring economies of scale for authorities, allow for larger contracts and thereby appearing more attractive to the private sector for investment whilst also allowing LAs to retain control of services. This is important as it will be LAs, if they fail to meet targets, which will pay the fines imposed for non-compliance with the Landfill Directive.

The total kitchen waste arisings (from Table 83 were 69,973 tonnes in 1999/2000. Assuming all of this amount could be made available for biological treatment, a plant of 100,000 tpa capacity could be commissioned. This larger figure is to allow for growth, or the potential to co-digest other organic wastes at the same facility (for example organic industrial waste from food and beverage industries, abattoir wastes, sewage sludge, or even agricultural waste). Also, more reference data is available for plants of 100,000 tpa capacity. Depending on the exact characteristics and aims of the plant, the capital cost would probably be in the region of £10 – 25 million based on similar scaled plants on continental Europe. It should be noted that UK conditions and legislation are different from those in Europe and these costs may not be representative of a similar plant in the UK. Eunomia (2002a) estimated the cost of a 100,000 tpa anaerobic digestion plant treating BMW in the UK would have a capital cost of approximately £21 million. If for easiness of calculation here, an even split would be considered between the 11 local authorities of the £10 - £25 million, this would equate to £0.9 - £2.3 million for each of the LAs contribution towards the capital cost of the AD plant. Instead of an equal split, this division would most probably be based on population and waste arisings. Each LA would then need to contribute the equivalent of one small IVC system. Operational costs and payback periods would be much lower within a centralised AD system (see Section 2.3.2.3).

Both an in-vessel composting facility and an anaerobic digester could be expected to divert 100% (minus contaminants which could be expected to be less than 5%) of the incoming source separated kitchen waste from landfill.

As before, Table 87 summarises the capital and operating costs as well as landfill diversion and energy balance of an AD system compared to an IVC for treating 100,000 tpa of BMW/kitchen waste.

Table 87 Summary of comparison of 100,000 tpa IVC and AD plants

Parameters	IVC	AD
Capital Cost	£8 – 15 million	£10 – 25 million
Operating Cost (£/t)	£20 – 30 (1)	£3 (1) (inc. income from biogas)
Landfill Diversion	>95%	>95%
Energy Balance (per tonne of wastes treated)	Negative -50 to -75 kWh_e/t (3) -73 kWh_e/t (4)	Positive +75 to +150 kWh_e/t (3) +102 kWh_e/t (4)

(1) DEFRA website (accessed October 2005)
(2) Eunomia (2002b)
(3) Verma (2002)
(4) van Zanten (Accessed 2005)

It must be noted that there are many different IVC and AD technologies on the market, and the figures in Table 87 may not be representative of all systems. In-vessel composting remains the cheaper biowastes treatment option in terms of capital cost. In terms of operating cost most comparisons agree that AD is cheaper than IVC. Both technologies will divert similar percentage of source separated BMW from landfill, and it is assumed that the surface area required by an AD plant would be considerably smaller than that required by an IVC plant. As with the 10,000 tpa plant, the real difference between the two technologies becomes apparent when considering their respective energy balances. Comparing anaerobic digestion with fully enclosed tunnel composting, assuming the energy difference of 700 kWh/tonne quoted in the LCA study by Edelmann *et al.* (2001) is accurate, then a 100,000 tpa anaerobic digestion plant could be expected to have an energy advantage over an in-vessel composting plant of the same scale as large as 70,000 MWh/a. Even considering the less extreme quotes from the other two studies (a difference of 175 kWh/tonne quoted by van Zanten (Accessed 2005), and a difference of 125 – 225 kWh/t quoted by Verma (2002), the energy advantage offered by the AD plant amounts to between 12,500 – 22,500 MWh/a. As the scale of the plant increases, so will the energy costs of the IVC plant, in contrast, as the scale of the AD plant increase, so will the income from renewable energy production.

With regards to MBT plants treating residual MSW, it can be seen from Table 83 that the approximate scale of MBT plant required in RCT would be 100,000 tpa. Assuming a scale of 100,000 tpa, and depending on the exact characteristics and aims of the plant the capital cost would probably be in the region of £15 – 35 million based on the capital cost of similar scaled plants on continental Europe. It should be noted that UK conditions and legislation are different from those in Europe and these costs may not be representative of a similar plant in the UK. The average landfill diversion potential from a MBT plant accepting residual wastes would be between 60% and 90%. The exact landfill diversion potential would be dependent on the characteristics of the incoming residual waste, the presence of an industry/incinerator/thermal treatment plant to accept the RDF or SRF produced, and the intended end use for the digestate (landfilling, daily or permanent landfill cover, or SRF production). The average biogas production from the anaerobic digestion of OFMSW (which is estimated to make up at least 40% of residual MSW) from the plants visited as part of this project is ~130 m^3/tonne digested (or ~50 m^3/tonne of residual waste accepted through the MBT plant). If a more conservative figure of 100 m^3/tonne anaerobically digested is used, then the expected biogas production would be in the region of 4 - 5 million m^3. Assuming a methane percentage of 60%, an electrical conversion efficiency of 30% and an on-site requirement of approximately 1/3 of this electricity (this figure varies greatly depending on MBT plant design), then approximately 4400 – 6000 MWh/a of electricity should be exportable. At current UK prices this would be worth £473,000 - £645,000 per year.

Assuming the co-operation of neighbouring local authorities, the potential exists to build a centralised MBT plant with a capacity considerably larger than 100,000 tpa. As can be seen from Table 83 the total MSW available in the SWUC region is 868,413 tpa. This total is subject to change, as the introduction of source separation of recyclables (including kitchen waste) would significantly reduce the volume of residual MSW. In addition, despite the trend for increasing volumes of municipal wastes, the introduction of source separation in other European countries has led to a decrease in the total mass of waste collected (due in part to a change in the attitudes of its citizens). The MBT plant in Heerenveen in the Netherlands is a good example of a large scale MBT plant. The plant, which had a capital cost in the region of £25 million (€40 million) in 2002, accepts around 230,000 tpa of residual MSW from approximately 650,000 residents in the surrounding region. Approximately 100,000 – 120,000 tpa of OFMSW is anaerobically digested along with local organic industrial wastes (which make up ~10% of input), producing 11 million m^3 of biogas which powers 14,000 Dutch homes (Smink, Personal Communication, 2006). The exportable electricity is estimated at 14,000 – 15,000 MWh/a based on the quoted figures. In the UK, this would currently provide an income of £1.5 – 1.6 million/a. The plant also produces enough heat energy to cover all on-site requirements and produce a considerable excess. The plant diverts approximately 70% (approximately 161,000 tpa) of the incoming residual waste from landfill. Considering that recyclables (including BMW) are collected at source in the region, the overall percentage of municipal wastes landfilled is small.

Assuming a biogas production potential of 100 – 120 m^3/tonne of kitchen waste digested, and taking the total tonnage of kitchen waste in the SWUC to be 69,473 tpa, if all of the kitchen waste in the SWUC area could be collected and anaerobically digested, approximately 7 – 8.3 million m^3 of biogas could be produced. Assuming a 60% methane percentage, a 30% electrical conversion efficiency and an on-site requirement of 20%, then theoretically approximately 10,000 – 12,000 MWh/a of renewable electricity (with a current market value of £1,075,000 - £1,290,000, based on £107.50/MWh) could be exported. This figure would be considerably increased if garden waste was included, and further increased if other organic wastes were co-digested. Assuming all 868,413 tonnes of the residual waste in SWUC could be sent to a MBT plant incorporating AD, and assuming a biogas production potential of 50 m^3 of biogas per tonne of MSW accepted, or 40% of the residual MSW being OFMSW and 100 m^3/tonne of OFMSW anaerobically digested, then approximately 34 - 43 million m^3 of biogas could be produced. Assuming a 60% methane percentage, a 30% electrical conversion efficiency and an exportable excess of 10% (which should be possible depending on the MBT system design and goals), then theoretically approximately 6125 – 7746 MWh/a of renewable electricity (with a current market value of £658,438 - £832,695 per year) could be exported. This figure would be considerably increased if other organic wastes were co-digested. The on-site electricity requirement would be considerably higher in a MBT plant than in an AD plant treating source separated biowastes due to the more intensive mechanical pre-treatment required. SWUC figures have been used rather than national figures due to the fact that the collection of BMW in rural areas may not prove worthwhile if transport emissions are considered, whereas the SWUC region is densely populated and the collection (and distribution to a centralised AD facility) of a high percentage of the available organic wastes should be possible. It can be seen that the AD of both waste streams (source separated kitchen wastes and residual waste) can make a considerable impact in terms of diverting organic wastes from landfill and in renewable energy production. The incomes from this considerable biogas resource can be maximised if the biogas was upgraded and utilised as a vehicle fuel.

7.1 Examples of the potential for biogas as a transport fuel in AD systems treating 10,000 tpa and 100,000 tpa of kitchen wastes

Kitchen wastes can usually be expected to produce 100 – 120 m^3 of biogas per tonne of waste anaerobically digested. This corresponds to about 70 litres of petrol (Kompogas website [c], accessed January 2006). Kompogas estimate that 1 kg of kitchen waste can power a car for 1 km (Kompogas website [d], accessed January 2006). This corresponds to 1000 km of travel provided by 1 tonne of biowaste. The following example is given on the website:

> '*A Kompogas plant with an annual processing capacity of 20,000 metric tonnes of biogenous waste will supply the energy needed by about 2000 passenger cars travelling about 10,000 kilometres a year. This translates into about 20,000,000 (20 million) environmentally-friendly kilometres by car*'.

Other anaerobic digestion systems treating the same wastes could expect to produce similar volumes of biogas, which could be upgraded and used in the same way. If these Kompogas figures are assumed for the scales of plant considered in this work, then the benefits of biogas as a transport fuel for RCT or the South Wales Region are shown in Table 88. Calculations by the Waste to Energy Research Group, from Cork Institute of Technology (Murphy, 2005) show that:

- 1 tonne of OFMSW produces an average of 130 m^3 of biogas.
- 1 m^3 of biogas produces 0.57 m^3 of enriched/upgraded biogas (97% CH_4, 37.8 MJ/m^3).
- 1 m^3 of enriched biogas can power a Volvo V70 for 10 km.
- 1 tonne of OFMSW = 74 m^3 upgraded biogas.
- 1 m^3 of upgraded biogas replaces 1 l of petrol.
- 1 m^3 of biogas replaces 0.57 l of petrol.
- 1 tonne of OFMSW = 740 km in a Volvo V70.

To summarise these figures:

1 tonne of OFMSW = 130 m^3 biogas = 74 m^3 upgraded biogas = 74 litres of petrol = 740 km in a Volvo V70.

Differences between the figures calculated by Murphy (2005) (1 tonne waste = 740 km in a Volvo V70) and Kompogas (1 tonne waste = 1000 km in a mid-sized passenger car) may be due to differences in the waste treated, in the reactor used, in the efficiencies of the biogas upgrading facility, or simply that the Volvo V70 is a larger and more powerful car than the 'mid-sized passenger car' used in the Kompogas calculations.

Table 88 Savings on petrol from using biogas as a transport fuel

Scale of Plant (tpa)	**Average Passenger Car Travelling Distance** (km)	**Saving on Petrol (litres)** (based on 70 litres/tonne waste)	**Saving on Petrol (£)** (based on £0.88/ litre) (3)	**Using Reference**
10,000	10,000,000	700,000	£616,000	(1)
10,000	7,400,000	740,000	£651,200	(2)
100,000	100,000,000	7,000,000	£6,160,000	(1)
100,000	74,000,000	7,400,000	£6,512,000	(2)

(1) Using figures from Kompogas website [d] (accessed January 2006).
(2) Using figures from Murphy (2005).
(3) Average UK petrol price of £0.88/litre (What Price website, accessed January 2006)

These values do not take into account biogas used for electricity and heat on site, or finance/operating costs on the infrastructure required to set up biogas enrichment plants, biogas/natural gas filling stations, or any duty/incentives that may be imposed on this type of fuel.

According to the Kompogas website [c] (accessed January 2006) the amount of biogas produced by a 10,000 tpa unit is approximately 1,054,000 m^3/a, which produces 2078 MWh/a of electricity. Approximately 290 MWh (14%) of this is used on site every year, leaving an annual electrical power surplus of 1788 MWh/a (all figures from Kompogas website [c] (accessed January 2006). At current prices this biogas would be worth £616,000 as transport fuel before on-site electricity costs (based on savings from petrol purchase), or £192,210 if sold as renewable electricity (after on-site electricity had been provided). As the Kompogas system is modular, a scale up to 100,000 tpa would be possible. It can be assumed that the biogas production figures can also be scaled up by a factor of 10 (approximately) to give an income from biogas of approximately £6,160,000 as transport fuel (based on savings from petrol purchase), or £1,922,100 if sold as renewable electricity. At this larger scale, it can be assumed that the cost (per tonne of waste treated) of the biogas upgrading plant, transport fuel infrastructure or CHP plant would be significantly lower due to the economy of scale. Conversely, the transport distances to and from the site would be increased.

Table 89 Potential incomes from biogas from food waste/OFMSW (after on-site electricity requirements of 14%)

Biogas Use	**10,000 tpa**	**15,942 tpa** (As available in RCT, in 1999/2000)	**100,000 tpa**	**Income/tonne Waste Treated**
Electricity (1)	£192,210	£306,421	£1,922,100	£19.20
Transport fuel (2)	£616,000	£982,027	£6,160,000	£61.60

(1) Based on £107.50/MWh (NFPO website, accessed July 2006). These figures are after on-site electricity requirements have been met.
(2) Based on 70 litres petrol equivalent per tonne of waste treated, and average petrol price of £0.88/litre (What Price website, accessed January 2006). These figures do not include on-site electricity use, therefore approximately 290 MWh/a of electricity would need to be purchased for a 10,000 tpa plant, and approximately 2900 MWh/a of electricity would need to be purchased for a 10,000 tpa plant.

Note:
- The RCT figure of 15,492 tpa represents kitchen and garden waste, whereas the figure of 8573 tpa represents only kitchen waste (both from WAG, 2002).

- It can be assumed that a centralised plant treating kitchen wastes from the whole South Wales region would be around 100,000 tpa capacity (depending on feedstocks for co-digestion).
- It may also be possible to recover revenue (or definitely savings on site) from the heat produced in electricity production, but that will depend on neighbouring industries/public buildings *etc*. and is therefore case specific.
- The exact amounts of gas produced vary according to waste and process characteristics.
- These figures are basic calculations and take no account of the finance required to put infrastructure in place.
- These figures do not consider tax burdens/relief for transport fuel, only the savings on petrol purchase.

If all of the municipal kitchen wastes in the SWUC area could be collected and anaerobically digested, then a total of approximately 7 – 8.3 million m^3 of biogas could be produced. Similarly, if all of the 868,413 tonnes of residual MSW in SWUC could be sent to a MBT plant incorporating AD, then approximately 34 - 43 million m^3 of biogas could be produced. These biogas potential figures are shown in Table 90. The incomes from electricity sales shown in Table 90 are from excess electricity (after on-site requirements have been met), whereas the incomes and benefits from using the biogas as a transport fuel do not take into account meeting the electricity and heat requirements of the plant itself. If the biogas was used as a transport fuel then these electricity and heat requirements would represent an extra expense.

Table 90 Potential incomes from biogas from kitchen waste/OFMSW in SWUC

Parameters	SWUC total from kitchen waste (69,473 tpa)	SWUC total from MSW (868,413 tpa MSW, of which 40% is OFMSW)
Total biogas potential	7 – 8.3 million m^3	34 - 43 million m^3
Potential exportable electricity	10,000 – 12,000 MWh/a	6125 – 7746 MWh/a
Income if sold as electricity (1)	£1.1 – £1.3	£658,000 – £833,000
Average passenger car travelling distance (2)	40 – 47 million km	194 – 245 million km
Annual saving on petrol (based on 1 m^3 biogas = 0.57 litres petrol) **(3)**	4 – 4.7 million litres	19.4 – 24.5 million litres
Annual financial saving on petrol (4)	£3.5 - £4.1 million	£17.1 - £21.5 million
Carbon dioxide emission saving from petrol substitution (5)	9440 – 11,092 tpa	45,748 – 57,820 tpa

(1) Based on £107.50/MWh (NFPO website, accessed July 2006).
(2) Based on 1 m^3 of enriched biogas can power a Volvo V70 for 10 km (Murphy 2005).
(3) Based on 1 m^3 biogas = 0.57 litres petrol (Murphy 2005).
(4) Based on an average petrol price of £0.88/litre (What Price website, accessed January 2006).
(5) Based on 1 litre of petrol producing 2.36 kg of CO_2 (Skanetrafiken, 2006).

These figures are provided as a guide to the possibilities as quantities of wastes would have changed since the year 2000. In addition, it can be assumed that other organic wastes can be co-digested, which will further increase the volume of biogas produced. As a rough guide to the potential capital costs of biogas upgrading infrastructure, the biogas upgrading plant at the Västerås biogas plant upgraded a volume of approximately 3 million m^3 of biogas per year (from the biogas plant and the sewage sludge digestion plant), and had a capital cost of €1.7 million (£1.2 million) (Persson, Personal Communication, 2006). The facilities at the bus station (high pressure compressors, high pressure gas storage, back-up LNG store, buildings and pipework, and the re-fuelling facilities for buses and cars) cost €1.4million (£1 million) (Persson, Personal Communication, 2006). More details are available in the Västerås case study (Section 5.1.8) and in Section 2.6.1.8.2. It is expected that a larger biogas upgrading facility would lower the cost per cubic metre upgraded due to the economy of scale.

Considering the information above, considerable potential exists to convert wastes collection fleets (or other public service vehicles like buses) to biogas. This would reduce infrastructure costs in that only one centralised 'biogas filling station' would be required, compared to the many required if publicly owned vehicles were converted to biogas. Utilisation of biogas from the anaerobic digestion of wastes is technically proven and favourable environmentally. In addition, it can be seen that the use of biogas as a transport fuel could produce significant economic benefits in terms of savings of petrol/diesel. A more detailed economic analysis of the infrastructure costs required would be necessary to further evaluate economic potential.

8.0 LESSONS LEARNED AND CONCLUSIONS

8.1 Lessons learned from European experiences

This section aims to provide a summary of the lessons that can be learnt from European experiences of anaerobically digesting biodegradable municipal wastes. Most lessons learned concern the anaerobic digestion of source separated BMW, rather than the anaerobic digestion of OFMSW as part of a MBT plant. It is hoped that similar problems and faults may be avoided when AD systems are commissioned in the UK. Due to its importance in the context of the project, the reader is referred to the Agropti-Gas Workshop presentation by Carl Magnus Pettersson (Production Manager of the Växtkraft Project), titled 'Lessons Learned' (in the Västerås case study, Section 5.1.8 and Appendix 1). The lessons learned from this and other AD of BMW/OFMSW projects are summarised here. They have been sub-divided into the following groups:

A. Wastes collection, source separation and public education
B. Planning/legal issues
C. Technical issues
D. General lessons learned

A. Wastes collection, source separation and public education

A high quality biowaste is essential for the realisation of digestate quality standards, which are key to project goals and finances. The achievement of a high quality source separation and therefore a high quality biowaste is fundamental for the success of any project aiming to use the digestate on land. Many European nations have struggled to eliminate contaminants from source separated biowastes. Even in societies with well developed source separation procedures, and a population experienced in the source separation of wastes, contaminants still enter the kitchen waste stream. The lack of contaminants in the waste source separated by the Swedish population provide the primary reason why the Västerås project has been successful, as compared to similar schemes in other countries where the quality of source separation has not been so good (e.g. Denmark, Finland and Germany). Lessons can be learned from the Swedish source separated biowaste collection strategies as described in the Västerås case study.

It has been noted that ***'A source separated high quality biowaste is achievable but calls for massive efforts, for example information and education activities towards the households'*** (Pettersson, 2006). To achieve a high quality biowaste public co-operation is essential. Householders should be aware of the motives behind the source separation, and know why they are being asked to do it. Ongoing public education is key to efficient source separation. Any source separation scheme should be simple, easily understood and actioned, and should not cause the householder nuisance (e.g. odours and flies). A smaller degree of contaminants is observed when the householders have a choice of whether or not to source separate (see Västerås case study, Section 5.1.8 and Appendix 1), as opposed to being told that they must. When results of source separation schemes are regularly reported to householders, a sense of community pride can be fostered leading to further improvements (see Västerås case study). Pettersson (2006) also notes that regular quality control of the biowaste is necessary, and that any faults should be corrected by 're-education' in a positive atmosphere (rather than fines). It is unrealistic to expect citizens to 'instantly' provide a source separated biowaste suitable for AD. The source separation of biowastes should be established well before the AD plant is scheduled to come online. This provides two main benefits:

1. The population gets used to source separation, and the percentage of contaminants decreases.
2. The exact characterisation in terms of quantity, content and contaminants of the waste stream can be established.

In many cases source separated biowaste was treated by IVC as an intermediate measure, while the AD process was being planned. In this way there was a viable 'product' to show the public from the start. This also meant that the public did not lose interest in source separation, and let their standards slip, as may have happened had they realised that their source separated biowaste was being incinerated/landfilled with the residual waste anyway.

Trials in Sweden and Denmark have concluded that paper bags are superior to plastic bags for the collection of kitchen wastes, for two main reasons. Firstly, they are biodegradable and do not contaminate the CLO, and secondly they act as a constant reminder not to add non-organic wastes. Public relations (PR) and public awareness are very important. Waste treatment sites will always encounter some local opposition, but a well-run (and open/transparent) PR campaign can reduce problems. An example is the Greenfinch plant in Ludlow (UK) where the plant went through planning in a short period of time (Chesshire, Personal Communication, 2006). Other positive examples are the ETVO biowaste treatment site in Lisbon (with the poster campaign, see Figure 291, Figure 292 and Figure 293), and the Salzburg site (with the 'organic waste hotlines' and the interactive visitor centre). Visitor centres promoting public education (as observed in Zurich, Salzburg and Västerås) are a very important component of any waste management strategy. An attractive and informative visitor centre would be an important addition to any planned AD facility in the UK. A visitor centre is in construction at Ludlow. Visitor centres are key factors in public education, as well as the promotion of the technology. With regards to further improving organic waste treatment systems it has been noted in several nations that '***further improvements can be made not with technology but with the help of individuals***'. It has also been stated throughout Europe (e.g. Sweden, Finland, Germany and Portugal) that major ongoing investment in public education and PR are worthwhile and justified.

B. Planning/legal issues

Fundamental to the success of a project is to '*Identify the important key organisations and involve them in the project in an early planning phase*'**.** All of the project partners are key to its success in different ways, because of what they can bring to the table. Ideally '*a company should be formed to make key decisions and manage/realise the project*'**.** '*The key stakeholders should be part owners of the company, so they have active roles in the project with focus on their specific fields of competence*'. Considering this it is important that responsibilities, boundaries and aims are clearly defined. '*It is key that the company does not compete with any of the owning companies*'. Potential conflicts could arise if these pre-conditions are not met.

An established company with a good reputation and with good working reference plants should always be used. An important point that has been re-iterated in personal communications with numerous sources throughout Europe is that where possible, one company should be contracted to supply a turnkey project, or at least to manage the overall project, and therefore organise and manage their own sub-contractors. This point was backed up by Pettersson (2006) who stated '*Get one main contractor for each plant, co-ordinating sub-contractors. This makes life easier for the purchaser*'. Co-ordinating contractors for large projects involving so many technologies can be extremely problematic and time consuming. AD plants (particularly those operating as a step in MBT plants) have many different facets, or stages, many of which can be supplied by different companies. The use of different companies to supply and build different parts of the process should be avoided where possible, even when cost savings can apparently be made. Conflicts can arise and delay the project. There have been many examples of problems and delays caused by non-compatible equipment and problems with technology integration. Unclear boundaries of responsibility can slow down work and cause problems.

'*Reduce the amount of tenderers to a few reliable suppliers, capable of successfully finalising the project. They must have sufficient experience, competence, size and financial strength*' (Pettersson (2006). Only accept tenders from four or five 'major players'. Do not ask for applications from anyone and everyone. Tenders for full plants (or parts of plants) represent huge amounts of work (for those who will submit them, and for those who must evaluate them). The use of suppliers with existing reference plants and a proven track record in the field is highly recommended. It was stated (as it has been repeatedly throughout this project) that 'corners should never be cut' for short term financial gains, and extreme care should be taken if considering awarding contracts to an un-proven supplier. The financial strength of the suppliers should always be analysed, as there have been problems in the past of projects running into major difficulties because the suppliers (or some sub-contractors) have gone bust.

Where possible, contract the supplying company to run the plant for a period of at least one year after start-up. Start-up periods can be problematic, and most plants (however well designed and built) can experience 'teething problems'. These problems are to be expected and can normally be dealt with by the suppliers, with their specific knowledge of the technology. Also, a period of knowledge transfer will be necessary from suppliers to operators and this is best done 'hands-on'. There have been cases of the compost/CLO not reaching the required standards for agricultural use, after an agreed period of operation. This can result in a considerable disposal expense. Contracts must be watertight with regards to the quality of the outputs, and responsibilities for meeting quality targets.

The security of supply of organic wastes is crucial. Organic waste streams should be secured for as long as possible in legally binding contracts. Technically sound plants have become economically unviable because they have lost the contracts to receive the waste stream they were designed to treat.

The siting of AD plants can be crucial to their viability. New-built AD plants should be built as close as possible to where the waste originates, and where possible near existing infrastructure, with good transport links. Existing wastewater treatment plants, landfill sites, electricity grid-links or gas utilisation plants can help reduce initial costs. AD plants should also be sited near a user for the excess heat, or planned in tandem with another industry/facility/residential estate that can use the heat.

Effort should be made to develop markets for the CLO prior to the plant being constructed. As with all products, quality is key to marketability. The image of the 'product' is also important if an income is to be generated or no additional costs are to be incurred. As food producers may not want to introduce waste based compost to their land (even if quality standards were met), the use of the CLO on forestry land or marginal land used for energy crop production is seen as an ideal future market/route for CLO that can not be sold.

C. Technical issues

As it is possible that there will be more organic wastes available in the future, it is wise to build at a capacity significantly larger than you presently require, so as to accommodate the extra waste. It is easier to fill up to capacity than to expand. In addition, if operating below capacity AD plant operators have the potential to increase the retention time in the digester, which should result in an increased biogas production (up to a point).

If co-digestion with industrial organic wastes is planned, it is good practice to install two (or more) industrial wastes reception tanks. The idea behind having two industrial wastes reception tanks is that higher energy wastes will be stored in one, and lower energy wastes in the other. This will give the plant operators a greater control of the feed mixture going into the reactor. This could be used to manipulate the organic (and nutrient) loading rates, to increase, decrease or regulate the rate of biogas production.

Moving parts within the digester should be avoided where possible. If the digester contains moving parts (for example mechanical mixers/paddles, ensure the design is tried and tested with years of uninterrupted operation. Pumps and other vital equipment should be as easily accessible as possible. For example, in some AD systems treating wet wastes, pumps are submerged in the wastes reception/storage tanks which makes cleaning/maintenance difficult.

Experienced, qualified operators should always be employed. Alongside the automatic control systems provided, AD plants require qualified and experienced personnel on site, perhaps more so than other processes as AD is a 'living process'.

The importance of the mechanical separation and pre-treatment stages should not be underestimated. Sub-optimal pre-treatment can have severe knock-on effects later on in the plant. Even organic waste streams in countries with long-established source separation procedures can contain surprising contaminants. The pre-treatment stage should always be robust enough to deal with any contaminants that may arise. With municipal, waste streams, this could be *anything*. Worst case scenarios must be assumed, as insufficient pre-treatment will cause knock-on effects through the whole plant.

Sand (and other fine inerts) in the waste stream can cause severe problems for some wet AD systems. There have been several examples of sand removal stages being retro-fitted to plants, and several examples of sedimentation leading to expensive digester downtime. Sand/fine inerts can be present in all waste streams, particularly garden waste and the organic fraction of residual MSW.

The anaerobic digester treating vegetable, fruit and garden wastes in Tilburg (Netherlands) was shut down around 2001/2002. The reasons given were: '*A combination of economics and insufficient pre-treatment (i.e. sand and stones were insufficiently separated) from the so-called VFG (vegetables, fruit and garden) waste from households. The digested material was difficult to reuse because of environmental standards. Also the tariff for the biogas was not enough for an efficient exploitation. Also the scale was relatively small (about 20,000 to*

35,000 tpa input), not very positive for the economics' (Notenboom, Personal Communication, 2006). The failure of this plant highlights several points. Firstly, the importance of efficient pre-treatment (especially sand removal in wet AD systems). Secondly, the importance of meeting the necessary quality standards with regards to digestate, and thirdly, the importance of Government support and 'market distorters' aimed at increasing the tariffs available for the renewable energy provided.

D. General lessons learned

There are many other 'easier' organic wastes to anaerobically digest. In the 1980s and 1990s BMW was accepted in many Danish co-digestion plants, but is no longer accepted at most. Initially, removing non-organic contaminants such as plastics from the source separated waste streams was problematic and costly. Digestate quality problems were also experienced, and the necessity of retro-fitting a pasteurisation stage also detracted from the viability (in existing AD plants). All of the technical problems were overcome, but only a few Danish plants still accept source separated kitchen wastes. Aside from problems achieving the required quality of source separation, a major reason that the Danish plants stopped accepting BMW was the availability of many other organic wastes. There are plenty of easier, lower risk organic wastes that they can treat instead. The manager of the LinkoGas Biogas Plant (Denmark) was asked if the plant would consider accepting BMW, the response was; '*Why*?.... *There are plenty of other organic wastes to choose from'*. The opinion was that it was not worth the risk, as any contamination on a plant of this scale (200,000 tpa) could lead to massive digestate disposal problems and costs. Another barrier would have been the introduction of upfront mechanical separation processes, which are simply not necessary when liquid industrial and agricultural wastes are treated. According to Bruno Sander Nielsen (Secretary of the Danish Biogas Association); '*The main reason why the development has stopped is that the [Danish] Ministry of Environment has made a report where they concluded that there may be advantages using organic household waste in biogas plants but it is very expensive to have parallel collecting systems. Therefore almost all municipalities have only one line and all the waste is incinerated. A few municipalities still have source separation and a minor volume is supplied to biogas plants. The plants that receive household waste now have no technical problems. In the past there were problems due to unsolved problems in the pre-treatment resulting in the reactor being filled with plastics etc. Some of the waste is currently supplied to a traditional AD biogas plant with manure as the main biomass resource'* (Nielsen, Personal Communication, 2006). Despite most Danish municipalities no longer collecting source separated kitchen waste from individual homes, food waste from restaurants and other institutional kitchens is still collected and treated in biogas plants (Nielsen, Personal Communication, 2006). Portuguese studies by Valorsul have also highlighted kitchen waste from restaurants and institutional kitchens as an ideal and more easily collectible and controllable source of organic waste for AD systems than kitchen waste from individual households.

Universities should be brought on board at an early stage to monitor the full scale process as part of research projects (Christiansen, Personal Communication, 2006). With anaerobic digesters 'knowledge is power', and the more data you have the more you know about your process and the more you can 'tweak' things to optimise performance. Along the same theme, having 'partner universities' to perform laboratory scale trials and experiments is very beneficial, as it is very difficult to experiment at full scale. There are plenty of minor amendments a manager may want to try, and laboratory-scale processes are necessary to test these. University research projects can bring benefits by the closer monitoring of the process, and in terms of laboratory scale testing, which enables risk-free trials of major and minor processing changes (Christiansen, Personal Communication, 2006).

It has been mentioned on several occasions that people building new plants still make the mistake of not 'learning from experience' and not taking on board advice from experienced operators. Experienced operators are regularly asked for advice or comments on the design of new plants. Often well intentioned advice is ignored, for the sake of short term cost-savings.

Competitiveness depends on the taxation system in your particular country (Nilsson, 2006). The positive financial results observed for plants in Sweden are a direct consequence of the Swedish Government's taxation and development policies, aimed at promoting renewable energy provision. Government support was key in Sweden. Without top-level Government support, Sweden would not have any biogas plants. It is unknown if similar positive economics would be possible in a similar UK based system. This would require further economic study based on more detailed economic information than was made available.

A recurring theme and 'lesson learnt' from conversations with European AD operators and decision makers is that '*you can not do things by halves with AD-based systems*', and '*if you cut corners, you will fail*', or '*Do not be tempted to go for quick-fixes or cut corners*'. AD plants represent a major investment, and should be operational in excess of 20 years. A basic but vitally important lesson is 'if you do it, do it right – do not cut corners'. Aside from this, two key lessons learned are that an established company with a good reputation, and good working reference plants should always be used, and where possible one main contractor should be employed to oversee the design, construction and commissioning of each plant.

8.2 Conclusions

Many LCA studies identify AD as the most environmentally sustainable biowastes treatment option. The main reason for this is that AD is energy positive due to the production of biogas, while aerobic composting requires energy addition. The electricity difference has been quantified (in three independent studies) as 125 – 235 kWh/tonne of waste treated in favour of AD over IVC. With regards to the organic fraction of residual MSW, Fricke *et al.* (2005) confirm that with the rising relevancy of climate change and the utilisation of renewable energies AD for the treatment of OFMSW has a high potential for further development. This view is echoed by Juniper (2005) which concluded that the MBT configurations that appear most attractive in a UK context include those geared towards the production of biogas.

Given current electricity costs and potential revenues from renewable electricity sales, for a 10,000 tpa biowastes treatment plant this difference equates to an energy cost difference of approximately £161,000/a (£16.10/t treated) in favour of AD in 2006. For a 100,000 tpa biowastes treatment plant this difference equates to an energy cost difference of approximately £1.6 million/a in favour of AD in 2006. The effect of predicted rises in the cost of electricity and the price of renewable electricity were calculated, and it was estimated that in 2010 the energy cost difference would equate to £185,000 - £190,000/a for a

10,000 tpa plant (£18.50 - £19/t treated) and £1.85 million to £1.9 million/a for a 100,000 tpa plant.

In addition to financial benefits, the use of AD rather than IVC will result in considerable carbon dioxide emission savings from fossil fuel substitution. The average carbon dioxide emission per kWh of electricity produced in the UK is 0.47 kg, after taking into account the different methods of electricity generation (Carbon Calculator website, accessed October 2006). Therefore assuming a difference of 125 – 235 kWh/tonne of waste treated in favour of AD over IVC, a 10,000 tpa AD plant would reduce carbon dioxide emissions by 588 – 1105 tpa, and a 100,000 tpa plant by 5875 – 11,045 tpa as compared to treating the same wastes by IVC.

On the basis of the financial information available, the capital costs for AD are likely to be higher than for IVC processes at current UK price. No exact figure can be given based on the lack of transparent economic data particularly for AD of BMW/OFMSW in the UK. The extra capital cost of AD systems is primarily associated with biogas collection and utilisation. The operating cost of AD systems is generally smaller than that of IVC systems once the income from biogas is taken into account. Therefore, AD systems may prove to have shorter payback periods than IVC systems. The continued upward trend in energy prices will further support AD implementation. The financial viability of AD projects increases with plant capacity, due to increased income from gate fees and increased income from biogas production.

The success of source separation is crucial to the realisation of a quality compost/CLO that can be used on land, and good continuous public education is key to achieving this. Experiences in other countries have shown that the recovery of a good quality source separated organic fraction is possible with significant and continuous expenditure on public education. It has been observed across Europe that the quality of source separation improves with time (as long as public education is ongoing). At the sites visited, the percentages of non-organic contaminants in source separated BMW ranged from less than 0.5% in Västerås (Sweden) to around 10% at Ludlow (UK), although source separation at Ludlow was in the early stages and quality was expected to improve. As long as the quality of the source separation is maintained, the CLO from AD will be suitable for land application in the UK. Therefore landfill diversion can be considered to be 95 – 99%, or 100% minus contaminants. AD will produce a similar quality and volume of 'compost' to IVC systems (assuming the same wastes are treated), and will therefore incur/generate similar disposal costs or revenues as a similar volume of IVC output. AD has a shorter retention time (even when aerobic post-treatment is required) and therefore requires less space than in-vessel composting to treat the same throughput of wastes.

An income from CLO from the AD (or IVC) of BMW may be possible in the UK, but a sustainable income may be unrealistic due to the increasing volumes of CLO available and image concerns over waste based composts (irrespective of quality). Markets/disposal routes for CLO should be identified and developed at an early stage in process planning. Forestry land, or the emerging energy crops market may provide beneficial disposal routes for (quality) digestates/CLOs where alternative markets can not be found.

Status of AD of BMW/OFMSW in Europe

European countries are world leaders in the use of AD for the treatment of municipal biowastes. A total of 168 anaerobic digestion facilities that currently treat either BMW or OFMSW have been identified, with a total capacity of 6,226,000 tpa (although this capacity includes many co-digested wastes). Of these 168 plants, 48 treat centrally separated OFMSW and 120 treat source separated BMW. Anaerobic digesters treating source separated kitchen and/or garden waste are employed at a smaller scale on average (29,835 tpa) than those treating centrally separated OFMSW (56,094 tpa). Systems treating centrally separated OFMSW tend to be part of large, centralised MBT plants, whereas systems accepting BMW can be smaller and more localised as the expense required for mechanical pre-treatment is considerably less. Over 50 companies have been identified which have built one or more AD system treating BMW or OFMSW. The top ten suppliers in terms of installed capacity are:

Supplier	Number of Plants	Total Capacity (tpa)
Valorga	15	1,034,700
Linde	17	820,000
Kompogas	25	462,500
Ros Roca	11	411,500
BTA	13	402,500
Haase	8	396,000
OWS Dranco	14	341,500
CiTec	8	243,000
Krüger	4	230,000
Alkane Biogas	2	225,000
Total	**117**	**4,566,700**

Based on a total installed capacity of 6,226,000 tpa, the top ten supplying companies have a market share of 73% (4,566,700 tpa) of the total installed capacity. Kompogas have installed the most plants (25), followed by Linde (17), Valorga (15) and OWS Dranco (14).

The use of AD to treat BMW/OFMSW has grown considerably in recent years. Although there are anaerobic digesters treating OFMSW that have been running successfully and continuously since the late 1980s (Valorga digester in Amiens, France, and the CiTec digester at Stormossen, Finland), the majority of the development of AD systems accepting BMW or OFMSW has been recent. The total increase in installed capacity since 2000 is around 3,500,000 tpa. In terms of capacity installed since 2000 three companies stand out (Ros Roca with an installed capacity of 622,500 tpa, Valorga with an installed capacity of 560,500 tpa and Linde with an installed capacity of 542,000 tpa). These three companies together have installed 51% of the total AD of municipal organic wastes capacity since the year 2000. In terms of activity in the municipal wastes field in the past six years five companies stand above the rest of the suppliers. These companies are Kompogas (12 plants built), Ros Roca (11 plants built), Linde (9 plants built), OWS Dranco (7 plants built) and Valorga (7 plants built). All of these companies are currently involved in commissioning new AD of BMW/OFMSW projects, mainly in Europe.

Of the 75 plants installed since the year 2000, 35 of these (47%) have been for the treatment of source separated biowastes, and 40 of these (53%) have been for the treatment of centrally separated OFMSW from residual MSW (as part of MBT plants). This even spread of applications underlines the flexibility of AD systems, and their suitability to treat either source separated organic municipal wastes (to produce a usable compost) or to biostabilise the organic fraction of residual wastes prior to landfill/thermal treatment.

Of the 35 plants installed to treat source separated BMW since 2000, 12 of these (34%) treat only municipal biowastes, while 23 plants (66%) co-digest BMW with other organic wastes. The main wastes co-digested are OIW (co-digested at 10 plants), agricultural wastes (co-digested at 4 plants) and sewage sludge (co-digested at 2 plants). The more recent trend is more in favour of co-digestion plants. In 2004, 2005 and in the early parts of 2006 (before the report was published) the total number of plants treating source separated BMW installed was 19. Of these, 14 (74%) also treated other organic wastes, while only 5 (26%) treated BMW alone.

Of the 35 anaerobic digesters treating source separated municipal biowaste that have been installed since the year 2000, the plants have been evenly split between wet digestion systems (18) and dry digestion systems (17). This even distribution mirrors the fact that both wet and dry AD systems have been proven over time to operate successfully. BMW/OFMSW can be treated successfully in both wet and dry systems, but the other available organic wastes (specifically their water content) may prove to be decisive factors in choosing one type of digester over the other.

A total of 75% (30 of the 40) of digesters installed since the year 2000 treating centrally separated OFMSW do not co-digest centrally separated OFMSW with other organic wastes. This is due to the trend towards large centralised MBT plants, particularly in Germany (treating residual municipal waste) and Spain (treating unsorted ‘black bag’ waste). In the 10 (out of a total of 40) plants installed since the year 2000 that do treat other organic wastes, the most common waste co-digested was sewage sludge (co-digested at 5 plants). Of the 40 anaerobic digesters treating centrally separated OFMSW installed since 2000, 29 are ‘wet’ AD systems and 11 are ‘dry’ AD systems.

Irrespective of whether they treat BMW or OFMSW 58 (77%) of the 75 plants built since 2000 operate in the mesophilic temperature range, and 17 (23%) in the thermophilic temperature range. Of the 40 plants installed to treat OFMSW, 36 (90%) operate in the mesophilic temperature range, and 4 (10%) in the thermophilic range. The domination of processes treating OFMSW operating in the mesophilic temperature range is due to the fact that the majority of plants treating OFMSW are wet digestion processes. The lower the total solids content, the more energetically unfavourable it is likely to be to operate in the thermophilic range, due to the larger volumes of water that would need to be heated to the higher digestion temperature. With regards to systems treating BMW more digesters still operate in the mesophilic temperature range (22 digesters, or 63%) than in the thermophilic range (13 digesters, or 37%). The higher incidence of thermophilic digesters treating source separated BMW than treating OFMSW (37% compared to 10%) is due to the increased importance attributed to pathogen reduction in systems treating source separated BMW, as the solid output is usually intended for land application, as well as decreased retention time attained with improved bacterial activity rate. The high number of thermophilic plants treating source separated BMW is mainly due to Kompogas plants, of which 13 have been built since the year 2000.

Germany and Spain have the highest installed AD of BMW/OFMSW capacities (2.29 million tpa and 1.43 million tpa, respectively). Between them their installed capacities make up 59% of the total installed capacity in Europe, which is 6,266,000 tpa. The majority of the anaerobic digester capacity in which source separated biowastes are digested is in Germany (1.8 million tpa of the European total of 3.5 million tpa, which constitutes 51% of the total). Significant digestion capacity has also been installed in Sweden and Switzerland. Spain has the highest installed capacity to treat OFMSW (1.43 million tpa, or 52% of the European total), due to its many large scale centralised MBT plants that incorporate an AD stage. Spain has 18 MBT plants incorporating AD treating OFMSW, with an average capacity of the anaerobic digestion stages of 67,400 tpa.

Income from biogas

The average income currently available from renewable electricity from biomass projects (including AD) in the UK is £107.50/MWh (NFPA website, accessed December 2006). In the past five years this price has steadily increased (from £18.50/MWh in February 2001) and the price looks set to continue to rise as targets for renewable electricity provision increase. The income from the biogas can be enhanced if it is used as a transport fuel. The use of biogas/natural gas as a transport fuel is proven and developed. Further implementation is more a question of marketing and industrialisation than of research and development (Biogas as a Vehicle Fuel, A European Overview, 2003). LCA studies by Biogas West (2006) and NSCA (2006) comparing all renewable transport fuels have identified biogas as the best environmental option in terms of carbon dioxide emission reduction. Biogas also compares well with other renewable transport fuels in terms of noise emissions, safety, and local availability. Kompogas estimate that 1 kg of kitchen waste can power a car for 1 km (Kompogas website [d], accessed January 2006). This corresponds to 1000 km of travel provided by 1 tonne of biowaste. Murphy (2004) calculated that:

1 tonne of OFMSW = 130 m^3 biogas = 74 m^3 upgraded biogas = 74 litres of petrol = 740 km in a Volvo V70.

Based on NSCA (2006) calculations the total biogas potential from AD in the UK is around 7.4 billion m^3 of methane (of which 2.5 billion m^3 is from domestic food waste, and 2.1 billion m^3 from commercial food waste). This is equivalent to 263,000 TJ of energy or 6.3 million tonnes of oil equivalent. If all of this energy were used for transport it would replace around 16% of current UK road transport fuel demand (NSCA 2006).

Based on the biogas from an AD plant treating kitchen waste, the potential petrol saving if the biogas produced was used as a vehicle fuel would be approximately £61.60/tonne of waste treated (based on a petrol price of £0.88/litre). This figure does not take into account on-site electricity and heat requirements, the cost of biogas upgrading infrastructure, or the effects of finance or tax on the income available from the biogas transport fuel.

Careful siting of new AD projects can have a major impact on plant economics. Capital and operating costs can be minimised by siting new AD projects close to existing infrastructure (such as landfill sites, wastewater treatment plants, or thermal treatment plants), and close to potential users for the excess heat produced.

RCT/South Wales possibilities

An AD plant treating 10,000 tpa of BMW (such as may be implemented in RCT-CBC or other Welsh local authority) could produce in the region of 1788 MWh/a of exportable renewable electricity and up to 1320 MWh/a of exportable renewable heat. The renewable electricity would generate an income of approximately £192,210 (or £19.20/t) at present prices. Landfill diversion would be 100% minus contaminants provided digestate/CLO quality could be assured. The minimum economic scale for an AD plant treating BMW (and other organic wastes) is likely to be 15,000 – 20,000 tpa in the UK at present, therefore co-operation between local authorities may be necessary for smaller local authority areas to realise AD of BMW projects. A centralised South Wales plant treating 100,000 tpa of BMW could produce in the region of 17,880 MWh/a of exportable renewable electricity and up to 13,200 MWh/a of renewable heat. The renewable electricity would generate an income of £1,922,100 (or £19.20/t) at present prices. Again, landfill diversion would be 100% minus contaminants provided digestate/CLO quality could be assured, and a market/beneficial disposal route could be found.

A MBT plant treating 100,000 tpa of residual wastes could produce in the region of 4400 – 6000 MWh/a of exportable electricity. At current UK prices this would be worth £473,000 - £645,000. Landfill diversion would be 60 - 90% depending on whether the CLO is landfilled, used as a daily or permanent landfill cover or upgraded to SRF and used as a fossil fuel substitute.

Plants visited/case studies

In total twenty AD sites were visited in nine European countries, and detailed case studies included in the report. Seven treated OFMSW as part of a MBT plant. Ten plants treated source separated kitchen wastes, either alone or co-digested with other organic wastes. Of the ten major plant suppliers in terms of capacity, at least one site from each supplier was visited, with the exceptions of Linde, BTA, Haase and Alkane Biogas. As it was not possible to visit Linde, BTA and Haase sites, literature based case studies from plants designed and built by these companies have also been included.

The average biogas production per tonne of OFMSW anaerobically digested in the six fully operational MBT plants visited was 133 m^3/t, although other wastes were co-digested in several plants. The mean biogas yield at the AD plants treating kitchen waste was 103 m^3/t (or 110 m^3/t for the plants accepting primarily kitchen waste). Other organic wastes were co-digested in most plants.

For the seven MBT plants visited the minimum landfill diversion potential (assuming sufficient incinerator capacity exists to accept RDF) was between 60% and 90%, depending on the end use of the digestate/CLO. Systems where the digestate/CLO is converted to SRF show the highest landfill diversion (as well as providing an extra income from the sale of SRF). These systems would be more expensive initially, and would require markets for the SRF to be developed prior to the plant being built. The next highest landfill diversions are observed in plants in which the CLO is used as a permanent landfill cover. In all cases, if the digestate/CLO was to be incinerated rather than landfilled, the energy recovery would increase and the volume of waste being landfilled would be decreased.

Simplified comparisons of the systems visited can be misleading due to the different wastes being co-digested. Considering this, key conclusions from the comparison of AD systems treating BMW were:

- Dry AD processes produce more biogas per tonne of wastes treated, due to their higher %TS (and therefore %VS).
- Wet digestion systems on average produce more biogas per tonne of total solids throughput than dry AD systems, although this could be attributed to differences in the wastes treated. The average biogas production per tonne of total solids treated in

the dry AD systems visited is 390 m^3/tonne TS, compared to an average biogas production per tonne of total solids treated in the wet AD systems visited of 663 m^3/tonne TS (although the figures for Västerås, Jonkoping and Ludlow are not yet proven). The only proven figure for a wet AD system (Grindsted) compares favourably with all of the dry AD systems visited (553 m^3/tonne TS).
- No significant advantage was observed (in terms of biogas production) from operating in the thermophilic range (although benefits should be observed in terms of pathogen reduction and decreased throughput time).
- Given that there is usually no end use for excess heat, heat requirements for both thermophilic and mesophilic processes can be easily covered by excess heat produced on-site.
- Dry AD systems require less land than wet AD systems, but the land required by the anaerobic digester itself is small in comparison to the land required by wastes reception areas, mechanical treatment areas and post-AD composting areas.
- For most plants treating source separated biowastes little fresh water addition is required.
- On most sites treating source separated biowastes no wastewater is produced, as excess process water is of the required standard to be spread on land. In systems where the required standards for land application are not met, wastewater can be treated in municipal wastewater treatment plants.
- All of the AD plants visited produce exportable renewable energy.

General Conclusions

The main conclusions from this study are:

- A good quality source separated BMW fraction is achievable with continuous public education.
- AD is superior to IVC environmentally (due to the renewable energy it produces).
- Although more expensive initially, payback periods may be shorter for AD systems than for IVC systems particularly as the scale of the system increases.
- All of the AD plants treating source separated BMW visited produced net electricity and heat.
- Income can be maximised by upgrading the biogas for use as a transport fuel (although the initial cost of infrastructure will be higher).
- Careful siting of new AD projects can have a major impact on plant economics.
- **The AD of source separated BMW (or centrally separated OFMSW) is technically possible (and economically viable in other European countries) in many different technical configurations.**
- The optimum configuration is case specific, and dependent on the amount and characteristics of the wastes to be treated, the aims of the project, and local legislation and circumstances.
- The availability and characteristics of any wastes that could be co-digested is an important factor to consider when choosing between systems configurations.
- Co-digestion should be maximised where possible, as should the co-operation of neighbouring local authorities to achieve the benefits of the economy of scale.
- An established company with a good reputation and with good working reference plants should always be contracted.
- Where possible, one company should be contracted to supply a turnkey project, or at least to manage the overall project, and therefore organise and manage their own

sub-contractors. Co-ordinating contractors for large projects involving so many technologies can be extremely problematic and time consuming.

The upward trend in the commissioning of AD projects is set to continue as Landfill Directive targets approach. The economics of AD projects will become more and more favourable (especially as compared to IVC) as energy costs increase. The anaerobic digestion of source separated BMW and centrally separated OFMSW is a reliable, proven and economic waste treatment technique as can be evidenced by the many successfully operating plants around Europe. Due to its many positive impacts, anaerobic digestion must be considered as a key technology in terms of the movement towards a more sustainable society.

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APPENDIX 1

Agropti-Gas Project 'Lessons Learned' (Pettersson, 2006)

Lessons learned – Sum up

- ✓ The overall aim is achievable
- ✓ Strong will, ambition and endurance
- ✓ A high quality biowaste is essential !!
- ✓ A multidisciplinary project covering several fields of competence
  - A strong local project organization
    - different fields of competence represented
    - consensus and mutual understanding
  - Overall system view/perspective
- ✓ Don't underestimate the time needed !!
- ✓ Yes, we would do it again and almost in the same way

AGROPTI-GAS

Lessons learned - Organizing the project Initial phase

- ✓ Identify important key organizations and involve them in the project in the early planning phase
- ✓ Specify the preconditions for the realization of the project
- ✓ Prepare the financing of further planning activities, preparatory works, feasibility studies etc

AGROPTI-GAS

Lessons learned - Organizing the project

Preparatory / Pre-study phase

- Form a strong project organization:
  - Waste Management
  - Energy
  - Agriculture
  - Public transports
- Try to solve any upcoming problems/-conflicts as soon as possible:
  - Cost effective
  - Gives the organizations possibilities to influence the design of the project
- Keep other key organizations etc continuously informed (reference group)
- Don't change the preconditions if not absolutely necessary

AGROPTI-GAS

Lessons learned - Organizing the project

Realization of the Project

- ✓ Form a company for the realization of the Project – Practical and formal reasons
- ✓ Make the Partners (Key organizations) owners of the company
- ✓ Give the Owners active roles in the operation with focus on their specific field of competence.
  The company should not "compete" with the Owners.
- ✓ Specify the interfaces between the Company and the Owners in separate long-term Agreements

AGROPTI-GAS

Lessons learned - Organizing the project

- Focus on the basic criteria's decisive for the long term outcome of the Project:

  Economy: - Biowaste
  - Utilization of biogas

  Environment: - Digestates/Fertilizers

  Meanwhile prepare the financing of the realization of the project.

- Don't run into technical details.
  The planning of the Biogas plant etc should be a consequence of that the basic preconditions are fulfilled.

AGROPTI-GAS

Lessons learned – Procurement process

Procurement of:

- Biogas plant for co-digestion of organic waste and crops
- Gas upgrading plant with tank stations etc.
- Gaspipes connecting the sewage treatment plant, the biogas plant and the bus depot
- Storage facilities for silage and liquid digestate

AGROPTI-GAS

Lessons learned – Procurement process

The contractual form (functional all-in one contract, ABA 99) has been successful

- The Purchaser specifies the preconditions, the technical and functional requirements etc.
- The Contractor is free to come up with technical solutions, although they have to be approved by the Purchaser
- The contractor is alone and fully responsible
- Everything is included to make the Plant fulfill the requirements stated in the Contract
- Just one main contractor for each plant, coordinating a subcontractors, makes life easier for the Purchaser

AGROPTI-GAS

Lessons learned – Procurement process

- International EU procurement processes are recommended for technical complicated processes
- Technical and functional requirements should be distinct specified and easy to control
- Specify the amount and composition of the input material (Biowaste etc) within wide margins.
- If possible, establish the source separation of biowaste well before the purchase of the biogas plant to get the proper data on the amount and composition of the biowaste

AGROPTI-GAS

Lessons learned – Procurement process

- Reduce the amount of the Tenderers to a few reliable suppliers capable to successfully finalize the project (sufficient experience, competence, size and financial strength)
- Specify in detail the interfaces regarding the undertakings of the Contractor(-s) and the Purchaser
- Most suppliers of Biogas plants are rather small companies with limited financial strength.
  In most cases they are owned by bigger companies (Mother Companies).
  Always demand Mother Company guarantees and first class bank guarantees

AGROPTI-GAS

Lessons learned – Biowaste

- A source separated high quality biowaste is achievable but calls for massive efforts e.g. information and education activities toward the households etc
- Introduce the source separation as early as possible.
  Should be done before the procurement of the biogas plant.
  Necessary to specify the amount and composition of the biowaste.

AGROPTI-GAS

Lessons learned – Biowaste

- Focus on the quality of the biowaste - Essential for a high quality digestate.
  Restrict to food waste.
- The source separation should be introduced step by step during a certain period of time
- It should be easy and comfortable to participate.
  The households should only have to follow the instructions.
- The handling should not cause any nuisances (odour, flies etc).

AGROPTI-GAS

Lessons learned – Biowaste

- The motives for the separate collection of biowaste should be well known.
  The households should know why.
- Any extra costs should be motivated
- The households should be offered alternatives for the handling of biowaste.
- The results of the separate collection should be reported to the households.

AGROPTI-GAS

Lessons learned – Biowaste

- Regularly quality control of the biowaste is necessary.
  Any mistakes should be adjusted immediately.
  Adjustments should be done in a positive atmosphere.
  Punishment should only be used when absolutely necessary.

- Important for the credibility that the biowaste is used for the purpose intended already from the start.
  Start by composting the biowaste.

AGROPTI-GAS

(Pettersson, 2006).

APPENDIX 2

MASS BALANCES OF EACH MBT PLANT VISITED

BUCHEN

Approximately 151,000 tpa of residual MSW (including kitchen waste) is accepted at the Buchen MBT plant. The incoming waste usually has a total solids content in the range of 50 – 53%. The mass balance of the process outputs is shown in Figure 328.

Table 91 Buchen MBT plant mass balance

Products/Outputs	(tpa)	(%)	End Use/Destination
CLO	57,380	38	Biostabilised for landfill
'Disturbal substances'	3,020	2	Landfilled
Metals	4,530	3	Recycled
RDF	30,200	20	Incinerated
Mineral substances	7550	5	Re-used or landfilled
Water	27,180	18	Used in composting process
Biologically degraded	13,590	9	Treated with exhaust gases
Biogas	7,550	5	Electricity and heat production
Total	**151,000**	**100**	

Information from ISKA Promotional Information (2006).

The mass balance above includes the in-vessel composting part of the MBT plant, which was not supplied by ISKA. This in-vessel composting stage is labelled 'Post-cur' in Figure 328, and is highlighted in green. Therefore these figures represent the final outputs from the MBT plant. 'Disturbal substances' are items in the waste stream removed in the initial mechanical separation stages, usually at the wastes reception and crane picking stages.

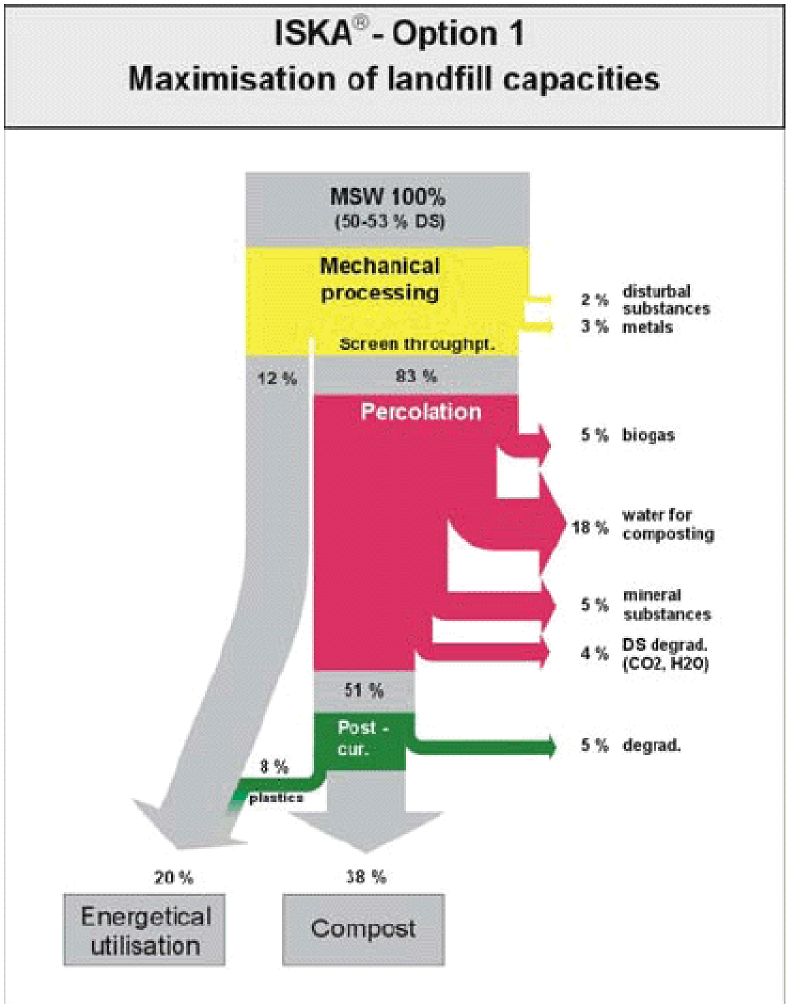

Figure 328 Mass balance of ISKA process (Environmental Expert website [b], accessed June 2006)

In the mass balance above, the pink section labelled 'Percolation' incorporates both percolation and anaerobic digestion. It can be seen that 5% of the incoming residual waste (by mass) is converted to biogas. Around 18% of the incoming waste stream by mass comes out of the percolation and AD stages as wastewater. A proportion of this wastewater is re-used in the in-vessel composting stage, later in the process. This re-use minimises the volume of wastewater that needs treated. The information in Table 91 and Figure 328 is shown as a pie chart in Figure 329.

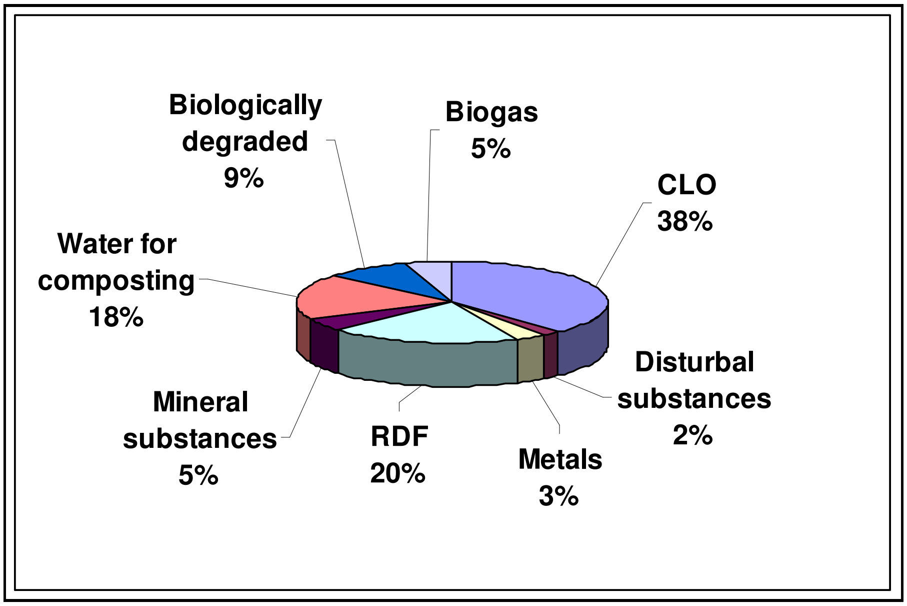

Figure 329 Buchen MBT plant mass balance outputs

The RDF, of which there is usually around 20%, is sent to an incinerator, which is also owned by U-Plus UmweltService AG, the parent company of ISKA. The CLO at Buchen is fully biostabilised output for landfill. Presumably the majority of the 'disturbal substances' are landfilled, although it is possible that some are recycled. In the following comparison it is assumed that all 'disturbal substances' are landfilled. Therefore if the CLO (38%) and the disturbal substances (2%) are landfilled the total landfill diversion under normal circumstances is around 60%.

HEILBRONN

The mass balance for the system is identical to that at Buchen, due to the processes treating similar wastes in the same area with the same process. Approximately 88,000 tpa of residual MSW (including kitchen waste) is accepted. The incoming waste usually has a total solids content in the range of 50 – 53%. The mass balance for the system is identical to that at Buchen, due to the processes treating similar residual municipal wastes in the same area, with the same process. The mass balance is shown in Figure 328.

Table 92 Heilbronn MBT plant mass balance

Products/Outputs	(tpa)	(%)	End Use/Destination
CLO	33,440	38	Biostabilised for landfill
Disturbal substances	1,760	2	Landfilled
Metals	2,640	3	Recycled
RDF	17,600	20	Incinerated
Mineral substances	4,400	5	Re-used or landfilled
Water	15,840	18	Used in composting process
Biologically degraded (CO_2 and H_2O)	7,920	9	Treated with exhaust gases
Biogas	4,400	5	Electricity and heat production
Total	**88,000**	**100**	

Information from ISKA Promotional Information (2006).

Please refer to Figure 328 and Figure 329 and the discussions above, regarding Buchen, as the same figures and comments will apply to the Heilbronn MBT plant.

HEERENVEEN

Table 92 shows the average content of the residual MSW received at the SBI Friesland MBT plant at Heerenveen.

Table 93 Average content of residual MSW brought to SBI Friesland site

Type of 'Waste'	Percentage of Residual MSW (%)
Metals	3
High calorifics (paper and plastic)	16
Organic fraction	40
'Rest waste' (everything else)	41

A mass balance of the process outputs in terms of percentages of the input were calculated by Juniper, as part of the Juniper MBT report (2005) and are shown in Table 94.

Table 94 Heerenveen MBT plant mass balance

Products/Outputs	(tpa)	(%)	End Use/Destination
Digestate	48,000	16	Sent for landfill after 'immobilisation', to be used as landfill permanent cover
Ferrous metals	9,000	3	Recycled
Coarse inerts	18,000	6	May be recycled, but may be landfilled
Fine inerts (sand)	15,000	5	May be recycled, but usually landfilled
RDF	120,000	40	Sent for incineration as secondary fuel
Rake fraction	9,000	3	Sent for incineration as secondary fuel
Paper and light plastics	48,000	16	Used as a co-fuel in cement kilns and CHP plants
Wastewater	15,000	5	Treated and discharged
Biogas	18,000	6	Electricity and heat production
Total	**300,000**	**100**	

Percentages sourced from Juniper MBT Report (2005).

For the purposes of comparison below, the rake fraction, and the paper and light plastics have been considered as part of the RDF stream as they are thermally treated for energy recovery.

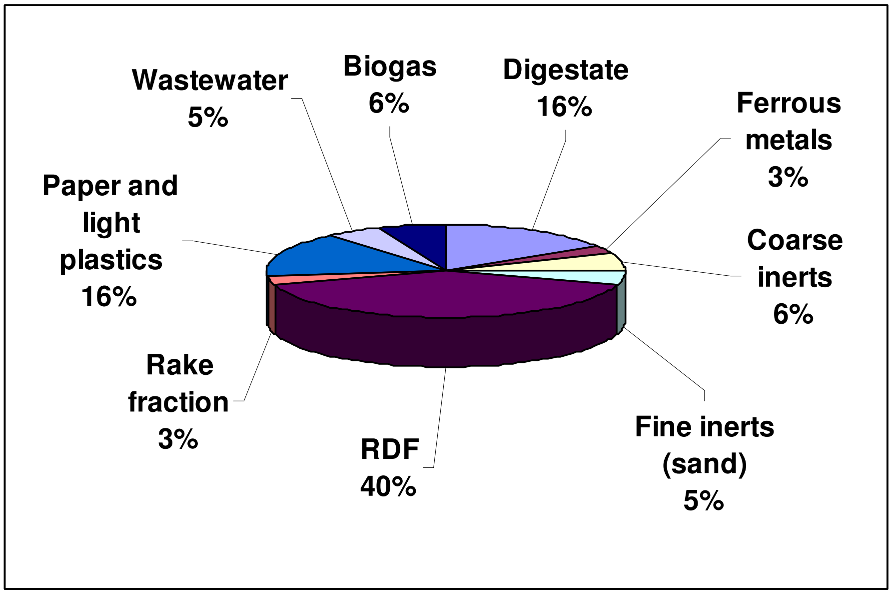

Figure 330 Heerenveen MBT plant mass balance outputs

In Table 94 and Figure 330 the wastewater has been included as 5%. In the actual process, it is necessary to add in another 9% of fresh (or recycled) water/steam to treat the waste stream. The wastewater produced is then 14% by mass, out of a total of 109% by mass. An undisclosed proportion of the 48,000 tonnes of digestate produced annually in Heerenveen is transported to a German energy from waste (EfW) installation, where it can be used as a secondary fuel to supplement coal combustion for energy production. This is the preferred option economically (Smink, Personal Communication, 2006). Digestate not transported to Germany, is sent to an 'immobilisation plant' on site, where it is mixed with fly ash, sludges and sodium metasilicate to produce a permanent landfill cover. In the Netherlands (as in the UK) use as a permanent landfill cover counts as 'recycling' as long as the ABPR is met. The RDF (40%) and the 'rake fraction' that is removed from the top of the digester (3%) are sent for incineration, while the 'paper and light plastics' (16%) are used as a fuel substitute at cement kilns and CHP plants. Therefore 59% of the incoming wastes are thermally treated for energy recovery (not counting the digestate proportion). All that is usually landfilled is the coarse inerts (*e.g.* stones), and the fine inerts (*e.g.* sand). Therefore only approximately 11% of the incoming waste stream is landfilled, and 89% can be considered diverted under normal circumstances.

MONS

The residual waste that arrives on-site, of which there is approximately 80,000 tpa, is separated into 4 main fractions (ITRADEC Promotional Information, 2006):

- Organic 30%
- Ferrous metal 2 – 3%
- Mineral fraction 15%
- Combustibles 50%

The organic fraction is digested anaerobically and composted for use as a landfill cover. The ferrous metal content is sold to a ferrous metal recycling company, the mineral fraction is landfilled and the combustible fraction (which contains paper, plastics and textiles) is accepted by a cement kiln or landfilled. The mass balance is shown in Table 95.

Table 95 Mons MBT plant mass balance

Products/Outputs	(tpa)	(%)	End Use/Destination
CLO	25,014	31.0	Landfilled/landfill cover
Ferrous metals	1,845	2.3	Recycled
RDF	39,292	49.0	Sent for incineration/landfill
Glass, stones and mineral content	8,750	10.9	Sent for landfill
Biogas	3,269	4.0	Electricity and heat production
Miscellaneous	1,858	2.7	Miscellaneous
Total	**80,000**	**100**	

ITRADEC Promotional Information (2006).

Figure 331 displays the outputs from the ITRADEC MBT plant at Mons.

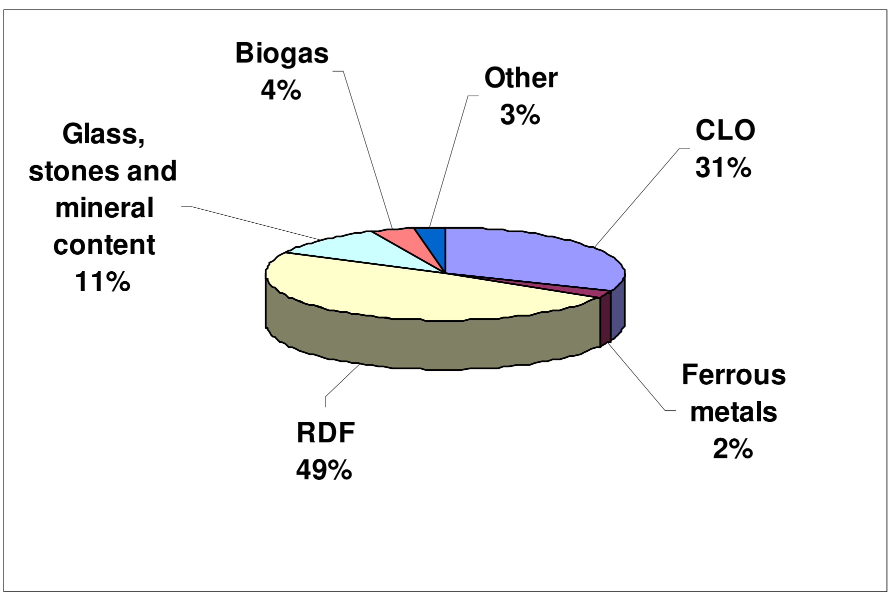

Figure 331 Mons MBT plant mass balance outputs

Ideally, all of the RDF should be incinerated (or used as a fuel/thermally treated in some way), however due to a lack of incinerator capacity and suitable industrial customers for the RDF in Belgium, the vast majority (38,520 tonnes, 98%) of the RDF was landfilled. Only 772 tonnes (2%) of the RDF was utilised as a secondary fuel in a cement works. Finding a customer for the RDF is a priority for ITRADEC, and would prove beneficial economically, in terms of landfill diversion and in terms of fossil fuel avoidance. In 2005 approximately 11% (8749 tonnes) of the input by mass was glass, stones and mineral content. Of this 11% (8749 tonnes) 3337 tonnes were landfilled (glass and stones) and 5412 tonnes was incinerated. For the purposes of Figure 331, these respective percentages of inerts have been added to the RDF total (for incineration) and the CLO total (for landfill). CLO, which makes up approximately 31% of the incoming mass was landfilled, alongside 3337 tonnes (4.2%) of the 8749 tonnes (11%) of glass and stones. The destination of the 3% of 'other' wastes is unknown. It is possible that some of these 'other' wastes are re-used or recycled, but for the purposes of calculating the total landfill diversion of the Mons plant it will be assumed that all 3% is landfilled. As 98% of the RDF that makes up 49% of the plants output is also currently landfilled, the landfill diversion provided by the Mons plant in 2005 was only 14%. If the RDF that is landfilled was incinerated, then the total percentage by mass of the incoming waste that is landfilled would be 38%, leaving a landfill diversion of 62%. The mass balance of the anaerobic digestion system in 2005, as provided by ITRADEC, is shown below.

IN	**Amount (tpa)**
Organic waste introduced	18,002
Process water (Steam)	675
TOTAL	**18,677**
Re-circulated process water	9441
TOTAL IN	**28,118**

OUT	**Amount (tpa)**
Biogas Production	3269
Digestate	25,014
TOTAL OUT	**28,283**

In 2005 around 18,002 tonnes of OFMSW was biologically treated. The re-circulated process water dilutes the incoming waste to the preferred total solids content, transfers heat to the waste stream and mixes anaerobic bacteria through the organic waste. Steam is added to further boost the temperature prior to adding the waste to the anaerobic digester.

SASCHENHAGEN

A mass balance for the Saschenhagen MBT plant is shown in Table 96 and Table 97. Incoming wastes are shown in Table 96, and outgoing materials in Table 97.

Table 96 Saschenhagen MBT plant input

Input Waste	**Amount (tpa)**
Residual MSW	55,000
Commercial wastes	25,000 – 35,000
Total	**80,000 – 90,000**

Table 97 Mass balance of the Saschenhagen MBT plant output (based on residual MSW only)

Products/Outputs	**(tpa)**	**(%)**	**End Use/Destination**
Stabilised residue for landfill	33,000	60	Landfill
Metals	5,000	9.1	Recycled
RDF	10,000	18.2	Incinerated
Losses by AD	7,000	12.7	Biogas used for electricity and heat production Exhaust gases treated and released
Total	**55,000**	100	

Saschenhagen Promotional Information (2005).

The 30,000 tpa of commercial wastes also treated at the Saschenhagen MBT plant are not included in the mass balance of the outputs in Table 97 and Figure 331.

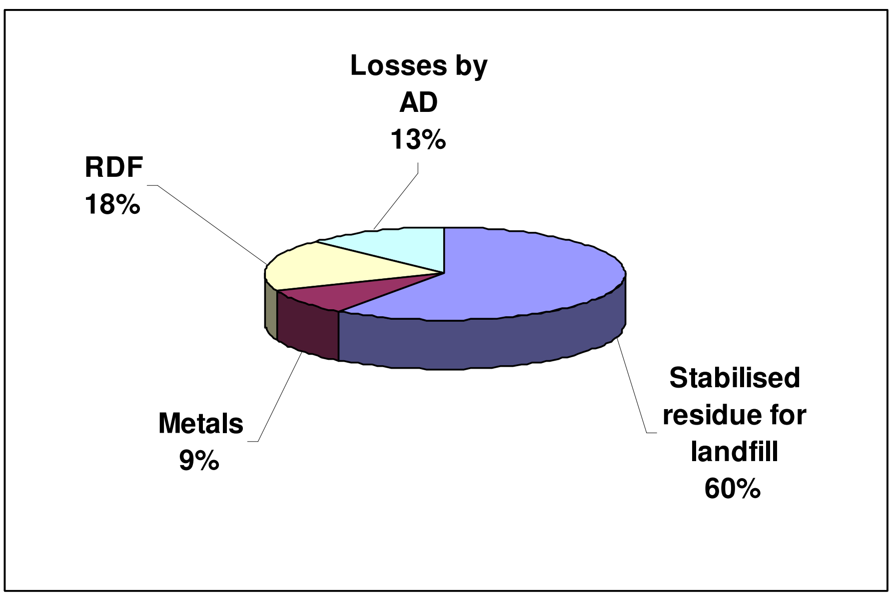

Figure 332 Saschenhagen MBT plant mass balance outputs

The Saschenhagen MBT plant recovers a lot less of the waste stream as RDF than other plants (see Table 73 and Figure 314). This could be due to the content of the incoming waste stream, as a reflection of the local wastes collection strategy. For example, 'combustibles' may be collected separately at source in the region and sent directly for energy recovery. A high proportion of the incoming wastes stream is shredded, pulped and sent through the biological treatment stages. The waste stream passing to the biological treatment stages contains a high (but undefined) proportion of inorganics. These inorganics are not recovered after the biological treatment stages (as they are at some other plants), and are landfilled. Approximately 9% of the mass recovered are metals. This is a high proportion compared to other systems, and it is assumed that this is a reflection of the wastes collection strategy rather than the MBT process.

After mechanical separation, approximately 40,000 tpa was treated biologically (Saschenhagen Promotional Information, 2005). This 40,000 tpa contains not only OFMSW but also a proportion of the commercial wastes stream. Approximately 33,000 tpa of CLO/solid output remains after the digestion and aerobic treatment of the combined waste stream. If the organic content of the commercial waste stream (which was not defined) is not considered, then 82.5% of the mass of waste put into the biological treatment system is biostabilised and landfilled. Therefore the percentage landfill diversion of the whole MSW stream (55,000 tpa) provided by the biological treatment system (AD and aerobic treatment) is around 17.5%. Around 13% is allocated to losses from AD (Saschenhagen Promotional Information), which will include biogas. Therefore approximately 4.5% of the incoming mass is attributed to degradation by the aerobic treatment stage. When the total mass balance is considered (rather than only the organic fraction) it can be seen that 40% of the total residual MSW input to the MBT plant is diverted from landfill. Furthermore, if the entire waste stream entering the plant is considered (total input is 80,000 – 90,000 tpa) then 59 - 63% can be considered to be diverted from landfill. Without further details of the contents of the 25,000 – 35,000 tpa of incoming commercial wastes it is not possible to comment on this figure.

POHLSCHE HEIDE

The flow of materials entering the plant can be observed in Table 98, and the materials leaving the plant can be observed in Table 99.

Table 98 Materials accepted at Pohlsche Heide MBT plant

Input Waste	Amount (tpa)
Municipal residual waste	40,000
Commercial waste	40,000
Sewage sludge	12,500
Other sludges	7,500
Total	**100,000**

Table 99 Approximate mass balance of the output

Products/Outputs	(tpa)	(%)	End Use/Destination
CLO	33,500	33.5	Landfilled
Recovered metals	2500	2.5	Recycled
RDF	32,500	32.5	Incinerated
Digestion losses	6700	6.7	Biogas used for electricity and heat production
Composting losses	16,500	16.5	Exhaust gases treated and released
Miscellaneous	8300	8.3	Miscellaneous
Total	**100,000**	**100**	

Pohlsche Heide Promotional Information (2005).

Figure 333 displays the outputs from the plant.

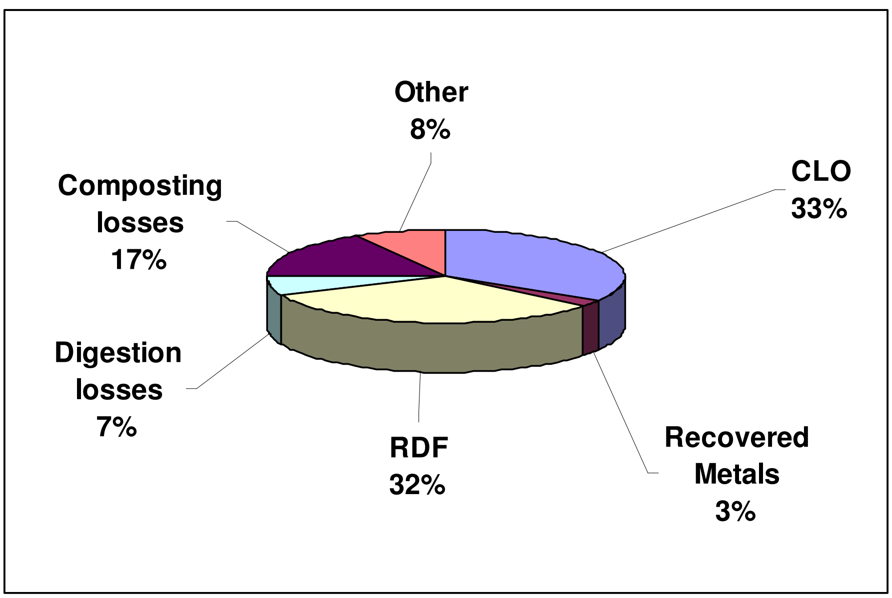

Figure 333 Pohlsche Heide MBT plant mass balance outputs

The operation of the biological treatment stages of the plant involves the combination of a Dranco anaerobic digester and Horstmann composting tunnels. The anaerobic digester does not receive all of the organic waste stream, only around 70 - 80% of the OFMSW. This set-up means that when the digestate is mixed with the remaining 20 – 30% of the waste stream, it contains enough organic material to enable a fast and efficient aerobic degradation. This set up also means that the total solids content of the digestate mixed with 'fresh' OFMSW is closer to the optimum for composting. Therefore the digestate does not need to be de-watered prior to composting, as it does in other system configurations. This saves the capital and ongoing expense of de-watering. Wastewater treatment costs are also saved. The plant separates 32% by mass from the wastes stream as RDF, which is sent for incineration. Metals, which make up around 3% of the incoming mass, are recovered and recycled. Pohlsche Heide categorise 8% of the incoming wastes by mass as 'other'. These 'other' wastes could be re-used, recycled, incinerated or landfilled, but for the purposes of calculating the minimum possible landfill diversion it will be assumed that they are landfilled. Around 33% by mass is landfilled as biostabilised CLO, which when combined with the 8% of 'other' wastes leaves a landfill diversion potential of at least 59%.

VAASA

The waste stream entering the Stormossen MBT plant at Vaasa is significantly different from the residual waste streams treated in the other MBT plants compared here. As described in the Vaasa case study (Section 5.1.7) the waste arriving at Stormossen is known as ‘kitchen waste’, although due to wastes collection policy the kitchen waste stream contains not only organics but also ‘combustibles’ such as paper and plastics (see Figure 134 in the Vaasa case study, Section 5.1.7). It can also contain other contaminants which people put in their kitchen wastes bin. Recyclables and hazardous wastes are collected separately, as are wastes destined for landfill. This ‘landfill bin’ would contain much of the wastes contained in residual waste streams arriving at the other MBT plants discussed here. Therefore in theory the plant should receive only combustible wastes and organic waste, and separate these into RDF and an organic fraction for biological treatment/landfilling. In practice, many contaminants are present in the municipal kitchen waste.

Table 100 Approximate mass balance of the output

Products/Outputs	(tpa)	(%)	End Use/Destination.
CLO	6,000	14.5	Landfilled/landfill cover
Rejects	5,880	14.0	Landfilled
Recovered Metals	420	1.0	Recycled
RDF	21,000	50.0	Processed into pellets and used as fuel in paper mill
Digestion and composting losses	6,000	14.5	Biogas used for electricity and heat production
Biogas	2,520	6.0	Exhaust gases treated and released
Total	**41,820**	**100**	

Akers, Personal Communication (2006).

In 2005, ‘kitchen waste’ arriving on-site, 14% (by mass) was classed as ‘rejects’ and was landfilled, 50% was recovered as RDF and used as a fuel to substitute fossil fuel use, 1% was metals that are recycled and 35% was treated anaerobically (Akers, 2006). Of the anaerobically digested waste, 6% by mass was recovered as biogas and a further 14.5% was attributed to digestion and composting losses. The Stormossen plant has noticed a change in the volume and contents of waste arriving at the site between 1999 and 2006, with slightly more packaging and less organics in 2006 than in 1999. As the plant has the flexibility to cope with variations in the content of the incoming wastes, the system has continually provided a high percentage of recycling and re-use. Figure 334 displays the outputs from the plant.

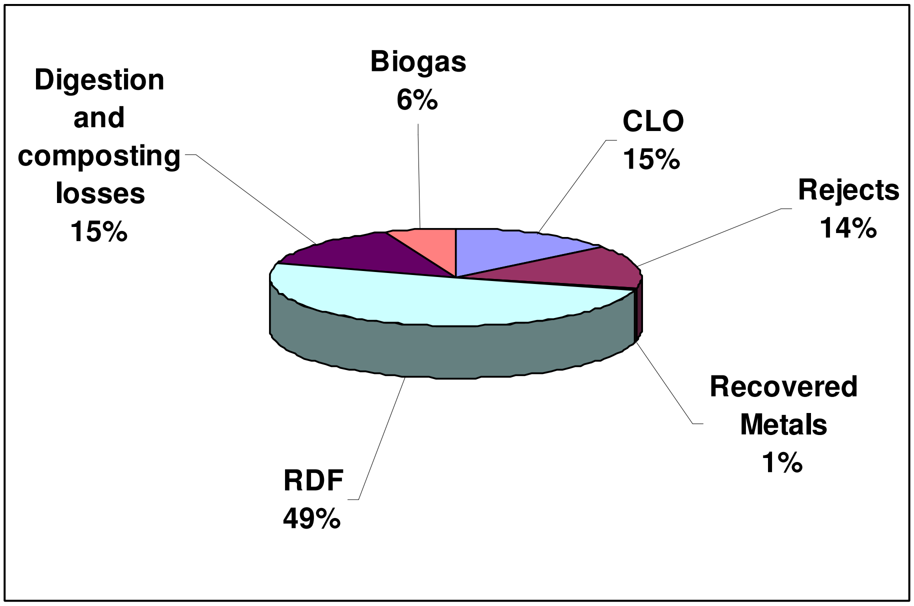

Figure 334 Vaasa MBT plant mass balance outputs

As mentioned before, the Stormossen MBT plant should not be directly compared with the other MBT plants due to the different wastes arriving on site. The wastes separated as RDF and sent to the Pietersaari Pellet plant for conversion to fuel-substitute comprises 49% of the incoming waste by mass. The low percentage of metals recovered (1%) reflects the fact that the waste stream is 'kitchen waste' rather than residual waste, with a high proportion of 'rejects' (14%), which the plant separates but was not intended to process. This high proportion of 'rejects' could be due to the wastes collection strategy, in which citizens pay less to dispose of 'kitchen waste' than to dispose of 'landfill waste', and could therefore be tempted to dispose some non-suitable items in the cheaper bin kitchen wastes bin. Some of these rejects could be recycled, but it will be assumed that they are all landfilled for the purposes of comparison. Only 15% of the incoming wastes by mass end up as CLO, which is used as daily cover for the adjacent landfill sites (after windrow composting). CLO is also being stockpiled for final cover for one of the sites two landfills, which is approaching the end of its lifespan. As use of CLO as a daily landfill cover would not count as 'recycling' or 'landfill diversion' in the UK, the CLO will not be included in the final landfill diversion figure in this case, although it should be considered that a proportion of the CLO produced will be used as a permanent landfill cover, which would count as 'recycling' or 'landfill diversion' in the UK. Assuming all of the CLO and all of the rejects are landfilled (neither of which will be the case) then a maximum of 29% of the incoming waste by mass is landfilled. Therefore the landfill diversion (from the 'kitchen waste' stream) is at least 71%.

ZAK RINGSHEIM

The ZAK Ringsheim MBT Plant and Landfill Site accepts 100,000 tpa of residual waste. Recyclates are separately collected and sent elsewhere for processing or recovery. Kitchen waste is not source separated and is included in the residual waste stream. No further details of the exact content of the incoming waste stream were available. The approximate mass balance of the outputs (ZAK Promotional Information, 2006) is shown in Table 101 and Figure 335.

Table 101 Approximate mass balance of the output

Products/Outputs	(tpa)	(%)	End Use/Destination
CLO	0	0	n/a
Ferrous metals	1,000	1	Recycled
SRF/RDF	35,000	35	Used as fuel/incinerated
Minerals	10,000	10	Landfilled/re-used.
Water losses	15,000	15	Treated in exhaust gas treatment system
Treated wastewater	30,000	30	Treated on-site and released to sewer
Composting Losses	5,000	5	Treated in exhaust gas treatment system
Biogas	6,000	6	Electricity and heat production
Other	<5,000	<5	
Total	**100,000**	**100**	

Information from ZAK Promotional Information (2006).

Before considering the mass balance in more detail it should be stated that the plant was not yet fully operational (in June 2006), and therefore the mass balance is 'expected' based on calculations made in the planning stages, rather than proven on actual observed data. Figure 335 displays the outputs from the plant.

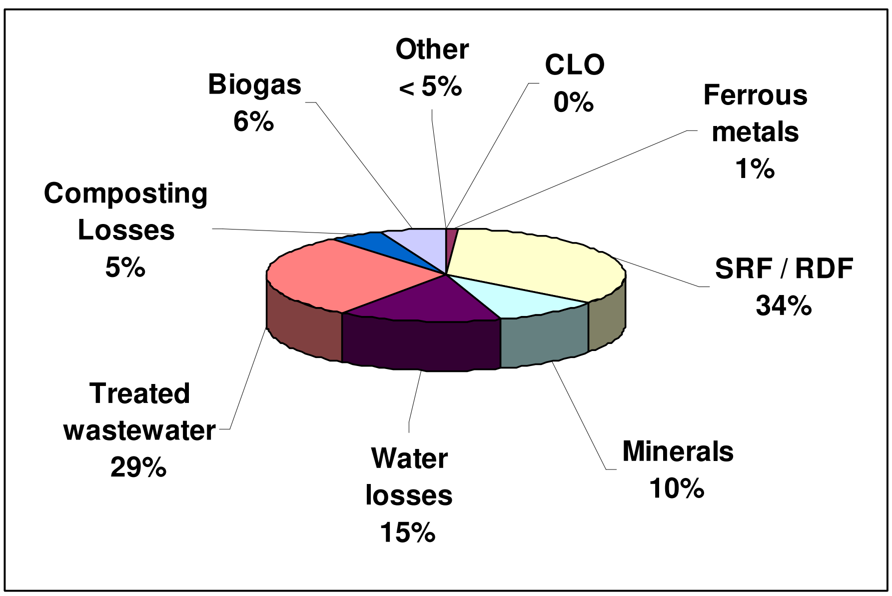

Figure 335 ZAK Ringsheim MBT plant mass balance outputs

The innovative MBT configuration at the ZAK Ringsheim plant aims to produce different grades of quality SRF from the solid fraction of the percolated waste stream. This is achieved by biodrying the solid fraction to drive off moisture, and then mechanically sorting the waste stream into different grades based on size and weight. The water losses from biodrying are given as 15,000 tonnes in Table 73. This water vapour is treated by the exhaust gas treatment system prior to being released to atmosphere. SRF can be made to order and sold as a 'product' as a quality guaranteed fuel substitute, as opposed to RDF, which is unspecified in terms of quality and content, and which the plant must pay to get rid of. Energetically, the calorific values of the RDF and different grades of SRF were not made available, but in terms of the waste hierarchy and landfill diversion, SRF can (usually) be classed as 'recycled' (as the SRF has a beneficial use) and the RDF can be considered 'recovered'. It was not possible to verify the contracts for the thermal treatment of the SRF. If contracts were not secured, it is assumed that the SRF would be incinerated. This would change the percentages recycled/recovered *etc*, but would have no effect on the landfill diversion. The employment of the ZAK Ringsheim concept relies heavily on available incinerator (or other thermal treatment process) capacity, and the presence of industries that can use the SRF. The ZAK Ringsheim plant only landfills stones and other inerts, of which it can produce 6 grades, ranging from a maximum size of 1mm up to rubble. These products are currently landfilled, but it is hoped that (construction-based) markets can be found in the future. For the landfill diversion potential comparison it will be assumed that all of these inerts (<5% of the input by mass) will be landfilled, although in the future a proportion of these may be re-used. The landfill diversion can be considered to be >90%.



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