

BIOFERTILISER PLANT DESIGN – FOOD WASTE TO BIOFERTILISER AND BIOGAS

Evans, T. D.¹; Boor, M.² and MacBrayne, D.³

¹ TIM EVANS ENVIRONMENT; ² EWB Designs; ³ Scottish Water Waste Services
Corresponding Author: Tim Evans, TIM EVANS ENVIRONMENT, Stonecroft, Park Lane, Ashtead, KT211EU tel: 00 44 1372 272 172; email: tim@timevansenvironment.com

ABSTRACT

This paper describes a plant that complies with Animal By-Products Regulations for Category II and III material. It will convert 30,000 tonnes food waste per year into bio-fertiliser, with a high degree of nutrient conservation, and biogas that will be used to generate electricity or could be processed to compressed natural gas, e.g. for automotive fuel. The design includes sustainable water management. The capital cost is approximately £7 million. The components have been selected and sized for reliability and longevity and to eliminate problems of litter, etc. that have plagued other plants. The annual operating cost is estimated at £0.86 million. The annual income from gate fees and electricity sales is approximately £2.6 million. The annual contribution is thus £1.8 million before taxes. Simplistically, this is a payback of approximately 4 years. In future, the capacity of plant could be increased readily at less than pro rata capital cost.

KEYWORDS

Anaerobic digestion, biofertiliser, biogas, CHP, Dewaster, food waste, recycling, renewable energy, resource conservation, thermal hydrolysis

INTRODUCTION

The European Union's Landfill Directive (CEC, 1999) obliges reductions in the amount of biodegradable municipal waste disposed to landfill compared with a reference year, which in the case of the UK is 1995. Composting used to be the method of first choice for treating biodegradable waste, but whilst it is suitable for carbonaceous greenwaste (yard waste); it is less suitable for food waste, which has a greater content of moisture, nitrogen and grease. These qualities make food waste more suited to anaerobic digestion. Whereas in the case of composting the moisture content and lack of structural strength mean that bulking agent is necessary to ensure air permeability and the nitrogen content means that additional carbon is needed if odours are to be avoided. The presence of physical contaminants (plastic, glass, rag and metal) has also proved to be an issue with source separated domestic and supermarket waste in most countries (Evans et al. 2002).

Location is always a critical issue for any new waste treatment facility. Scottish Water possesses a site from which a wastewater treatment works (WwTW) had been cleared, it is between two major population centres, close to a motorway junction, has a good access road, has a waste management site license and has no residential neighbours within sight. A modern WwTW is located on part of the site. There is at least 30,000 tonnes food waste per year (mainly industrial) in the vicinity. Within a reasonable haulage distance, there are ample areas of farmland and land requiring restoration on which the digestate can be used. The site has a supply of potable water and one of natural gas as a reserve supply for heating should the biogas fail. It has a connection to the electricity grid to export electricity. The site's only drawbacks are that the bearing strength of the ground is low so structures may need to be piled, there is a small area of Japanese knotweed (*Fallopia japonica*) and it is low lying, but site operators did not remember it ever flooding. Japanese knotweed is a highly invasive weed. Under Schedule 9 of the Wildlife and Countryside Act (WCA) 1981, it is an offence to spread Japanese knotweed. In addition, the Environment Protection Act (EPA) 1990 states that any material contaminated with Japanese knotweed must be classified as controlled waste, to which the duty of care applies. An offence under the WCA could face criminal prosecution and an infringement of the EPA could result in enforcement action that subsequently could lead to an unlimited fine. Eradication is difficult and lengthy but it is practicable using repeated application of [inexpensive] Glyphosate herbicide; a case of the sooner herbicide treatment starts, the sooner eradication will be accomplished.

SWWS commissioned TIM EVANS ENVIRONMENT (TEE) to produce a report on the technologies available, together with indicative process and civil and structural engineering designs for the most competitive of these. It was to include indicative ground engineering based on information provided by SWWS and approximate costs (CAPEX and OPEX) for a complete biogas plant capable of treating Animal By-Products Regulations Category III waste and preferably ABPR Category II waste. The plant is to treat food waste from factories, household kitchen food waste and fish waste. TEE partnered with EWB Designs for the project.

Perception of anaerobic digestion facilities by regulators has proved an issue. A composting plant produces 'compost' and use of this material on land is perceived as positive. When an anaerobic digestion facility is called a biogas plant, the biogas is perceived as the primary product and the digestate is perceived as waste, when the plant is called 'biofertiliser', the digestate is perceived as the product but biogas is so obviously beneficial that it is not stigmatised with the 'waste' designation. This is a case where there is a lot in a name: a biofertiliser plant is not a biofertiliser plant by any other name.

REGULATORY REQUIREMENTS

Waste Management Regulations classify the materials that are planned to be received and treated by the biofertiliser plant and the biofertiliser itself [digestate] as 'wastes' (SSI, 2003a). The site will therefore require a license; fortunately, it already has a license for 75,000 tonnes/year that permits it to operate 24 hours per day, 7 days per week. The biofertiliser would satisfy the conditions for exemption that when it is used on land it provides benefit to agriculture or ecological improvement for the purposes of paragraphs 7 and 9 of Schedule 3 to these Regulations. The locations of stockpiles on land where the biofertiliser is going to be used would have to be notified to SEPA (Scottish Environment Protection Agency). In essence, it would be very similar to land applying dewatered sewage sludge, but the regulatory pathway is more convoluted, bureaucratic and expensive than the Sludge (use in agriculture) Regulations, 1989. Policy makers and regulators have not taken on board that the Cross Compliance obligations of the Single [Farm] Payment Scheme requires compliance with most of the relevant control measures (Evans, 2005).

The Animal By-Products Regulations (SSI 2003b) would classify most of the input material Category III, but fish farming and processing waste could be Category II if it contained mortalities, i.e. fish that had died rather than having been harvested and killed for human consumption. The conditions for Cat III treatment are 70°C for 1 hour with particles not exceeding 6cm, but for Cat II the conditions are less clear. However, the conditions of Cambi thermal hydrolysis (CTH) [160°C for 30 minutes] after Dewaster® (which has outlet slots less than 1 cm opening) should satisfy whatever is considered necessary for Cat II.

PROCESS SELECTION AND DESIGN

The philosophy throughout was that equipment was sized to operate comfortably within its design specification to ensure reliability and longevity, and that there should be sufficient buffer, etc. capacity to cope with outages for maintenance or breakdown. Sizing equipment so that it operates close to its maximum is false economy.

RECEPTION

Deliveries will be via an automatic weighbridge, which will document the date, time and weight of material delivered; it will also give access to the site.

Physical contaminants are an issue. As far as possible, they should be excluded from the digesters; however, it is operationally desirable to avoid mechanical separation unless it is necessary. Depending on the size of truck, 30,000 t/y equates to only 6 to 12 deliveries per day, which is gradual enough to enable the driver of a mechanical shovel to examine received waste and discriminate whether a delivery is 'clean' or whether it needs screening.

Trucks delivering to the Waste Reception Hall (WRH) will reverse up a ramp to the delivery door, which will be a fast acting rising door. They will tip over a 0.3 m high threshold onto the floor of the WRH, which will be 1 m below the elevation of the top of the ramp. The door will be opened by the SWWS Reception Supervisor. The WRH will be maintained under negative

pressure at two air-changes per hour. When the door is opened, the air-changes will increase to four air-changes per hour. The air will be treated and vented through a stone/woodchip biofilter. The 1.3 m freeboard from the floor of the WRH to the top of the threshold will ensure that food waste does not come back around the wheels of a truck. It will also provide a confined, defined area in which the materials-handler [loading-shovel] can inspect the waste and deliver it to the appropriate reception hopper. The floor of the WRH will have capacity for 3 days' deliveries (360 tonnes) in order to accommodate non-availability of the first stage of treatment for any eventuality (maintenance or breakdown).

The cab of the materials-handler in the WRH will have air filtering, purification and conditioning so that its exhaust and the odour and bioaerosols from the input material are not a risk to the driver. No other personnel will be allowed in the WRH unless and until the atmosphere has been cleared by increasing the ventilation fans to 4 air-changes per hour.

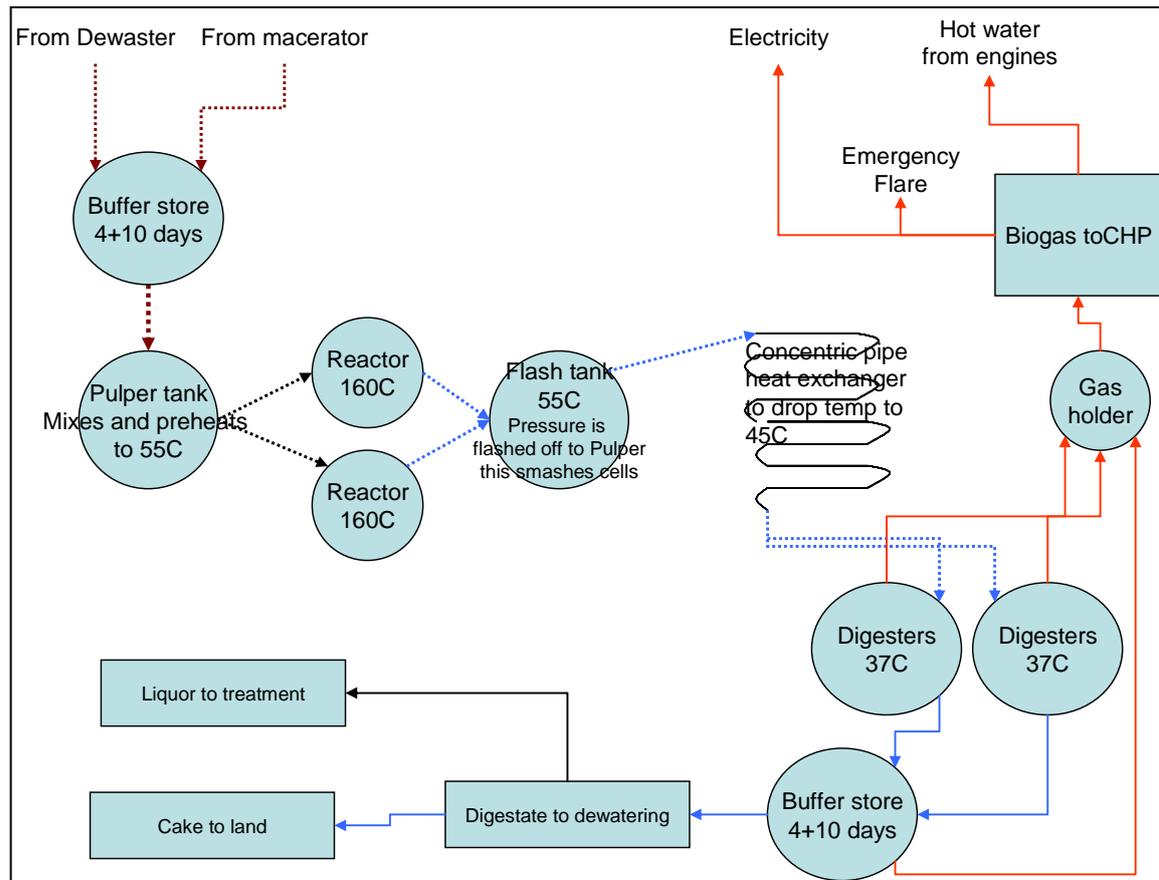


Figure 1 Schematic of the treatment process

FOG

Grease trap [interceptor] waste and used cooking oil etc. has a large biogas yield. It will be received into a heated tank, to keep it liquid, and metered into the first blend tank. FOG (fat, oil and grease) is a problem in sewers so providing a facility to treat it might facilitate separation at source and reduce sewer maintenance.

SCREENING AND SIZE REDUCTION

Physical contaminants (plastic, rags, metal, glass) are the bane of anaerobic digestion because it is difficult to get them out of a digester if they get in. Many operators have found that relying on separation at source is unsatisfactory so we gave attention to keeping them out. The WRH has been designed for visually checking each delivery to see whether it contains physical contaminants.

CLEAN WASTE

Loads that have no physical contaminants visible to the driver of the materials handler will be loaded into a hopper feeding a macerator (Mono Series F Muncher) discharging into a wide throat, 2-stage progressive cavity pump.

DEWASTER®

On a study tour of centralised co-digestion in Denmark (Evans et al., 2002) it was obvious that litter and contras in source-separated domestic and supermarket food waste was a significant operational problem for composting and for anaerobic digestion. The most elegant answer to this problem is the Dewaster® (Figure 2) which was developed in Denmark by EWOK and was bought by Hese Umwelt GmbH, Gelsenkirchen, Germany in about 2004. Hese has built a Cat III food-waste biogas plant with twin Dewaster® for 20,000 tonnes per year at Hamburg. The cost of the plant was reportedly €5.1 million.

EWOK had very successful applications of Dewaster® in Denmark treating source-separated and even whole MSW. The biopulp met the Danish quality standards for land application and was very digestible, but the political climate has changed in Denmark and organic matter recycling and biogas production have less priority than in the past; incineration is now considered fully acceptable. This change caused EWOK to sell Dewaster®.

The principle of Dewaster® is gentle bag opening and size selection/reduction followed by magnetic ferrous metal removal. A prime consideration of these early stages is not to damage the waste by, for example, smashing glass or opening batteries. The Dewaster® itself is a cylindrical/conical screen comprising longitudinal bars through which biopulp is forced by a screw conveyer. The gaps between the bars are <1cm. The pressure inside the screen chamber is about 100 psi; trash is discharged from the end of the Dewaster®, its moisture content is low because water is forced out through the screen in the biopulp. The process uses <14 kWh/tonne feed, which is <4% of the energy yield via biogas. Each Dewaster® treats 4 t/h. If 30% of the input is clean, i.e. contains no contras and therefore does not need to go through the Dewaster®, the remaining 70% will be handled by a twin Dewaster® installation.

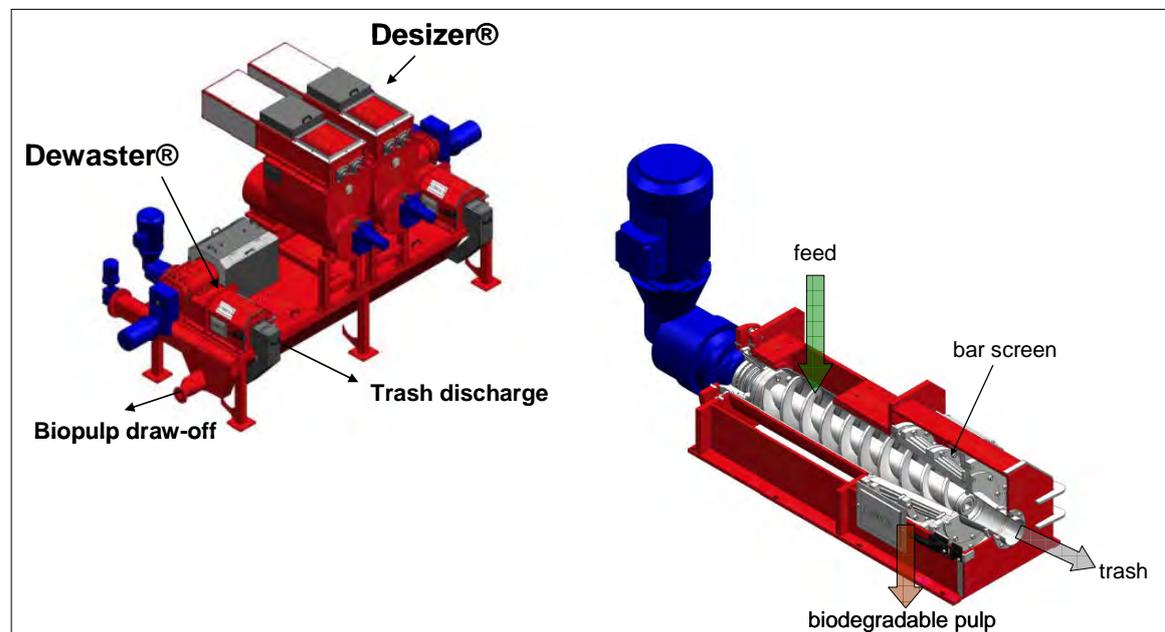


Figure 2 Schematic of a complete 4 t/hour Dewaster® unit and detail of the Dewaster

PUMPING AND BUFFER TANKS

Flooded-suction, two-stage, progressive cavity pumps (with dry-running protection) delivering to 150 mm PM 16 pipework were chosen. Pipework delivers to the operating depth range of the tanks, which have 4-days' operational HRT, they have an additional 10 days' capacity for buffer storage. By delivering to the 4-day depth, the delivery head is not unnecessarily high

during normal operations. Tanks are covered to prevent odour release and to exclude rainwater.

CAMBI THERMAL HYDROLYSIS

CTH was selected to meet the exacting requirements of ABPR and to maximise biogas production. CTH is a continuous batch process that pressure-cooks the feed at about 160 °C and 6.5 bar for 30 minutes. Dilution (process) water is added to the 'Pulper' tank, which is the first of the CTH vessels, to reduce the viscosity such that the feed is optimal for the rest of the process. Operational reliability of CHT is extremely good, except where ancillary components such as pumps have been undersized. CHT reduces the viscosity of the feed, which means that greater dry solids content can be fed to digesters without compromising their mixing. Using CHT halves the volume to digesters and other down-stream process units (i.e. the hydraulic loading) compared with 70 °C pasteurisation, etc. It also maximises biogas production and produces a digestate with acceptable odour that dewateres very readily; 34%DS cake from a belt filter press is typical. Compared with 70 °C pasteurisation, there will be a 35% saving in cake recycling (volume and cost) and 9% more biogas (volume and income). It eliminates the risk of pathogen reactivation and regrowth that has emerged as an issue in the wastewater biosolids sector.

ANAEROBIC DIGESTION

Input to the digesters from the CTH will be about 214 m³/day at 12%DS, i.e. two 3000 m³ mesophilic anaerobic digesters are required. Digester heating is not required (except as backup) because the hot feed from CTH provides the entire heat requirement. Draft tube mixing with propeller mixers was chosen for reliability. Big-blade mixers have proved problematic in operation because if material should accumulate on the blades differentially they are thrown out of balance requiring difficult and expensive repair. The choice of whether to use concrete or glass-lined steel is a matter of longevity and cost. The concrete have a longer life but are about 2 times the price of glass-lined steel. Glass-lined steel used to suffer from pinholes in the glass from which corrosion propagated resulting in eventual tank failure; however, improved manufacturing and modern electronic testing have improved reliability considerably. Permastore, the leading manufacturer, now has a 30-year design life on its digesters as a result of double coating and their high-voltage testing for flaws.

BIOGAS PRODUCTION AND STORAGE

The biogas production will be about 640 m³/hour. It will be approximately 65% methane and 34% carbon dioxide with around 1% of water, hydrogen sulphide and other gases. The energy value of methane is 37.78MJ/Nm³, therefore the energy value of the biogas will be 24.56MJ/N m³ i.e. 15,700 MJ/hour. At 40% electricity generating efficiency this is 1.75 MW_e/h of renewable electricity which at £90 /MWh including ROCs is an annual income of £1.4 million. To optimise the efficiency of using this biogas it is necessary to store the biogas; 3 hours' storage is considered acceptable to give good control. Double membrane gasholders have become the storage of choice for biogas in Europe. The PVC coated polyester membranes are impervious to biogas and to corrosion. The ultrasonic level sensor and target board give a continuous indication of the state of filling of the gasholder, which provides a signal to run the CHP engines (combined heat and power) or flare stack.

BIOGAS UTILISATION

GE Jenbacher generation sets have acquired a good reputation for reliability in Europe. The design includes two containerised 836 kW_e engine-generator sets. They include control panel and auxiliaries such as ventilation system, gas train and auto-top-up lubrication oil system all housed in an acoustic enclosure. The exhaust silencer and radiator are on the roof. The electrical control panel and switchgear are in a separate room at the end of the container. The factory manufactured and tested package simply requires gas and power connections on site, minimizing installation time and optimising versatility. Waste heat is recovered by integrating the appropriate heat exchangers in the cooling water and exhaust gas systems. The engine maintenance comprises:

- oil change at 1000 hours [depending on the quality of the gas]
- intermediate overhaul at 20,000 hours [2 ¼ years]
- major overhaul at 40,000 hours [4 ½ years]

The major overhaul can be accomplished by exchanging the engine with one from the factory so that downtime is minimised. If the gas proves to be especially dirty, or to contain unacceptable amounts of siloxanes, filters can be installed to clean it and lessen engine maintenance.

Burning biogas in engines to generate electricity has been practised for more than 70 years at WwTW. The best conversion that can be achieved is about 40% of the energy in the biogas to electricity, the rest of the energy is converted to heat, either in the exhaust gasses or in the water used to cool the engine and keep it at a safe operating temperature. The heat in the cooling water and from the exhaust can be used for space heating [or district heating] and heating process water for steam raising.

Some biogas installations pipe the biogas to off-site CHP engines close to a town, village or other development where district heating is easier. Fuel cells have been using sewage sludge biogas at WwTW in Germany and the USA.

An alternative is to remove most of the CO₂ from the biogas by molecular sieving such that the CH₄ content is >95% and then compressing the gas. The town of Linköping in Sweden has been a leading exponent of using this compressed natural gas to fuel municipal vehicles and also private vehicles. CNG has a lower NO_x and CO₂ index than diesel or ethanol. The revenue from CNG is more than double the revenue from the equivalent amount of biogas burnt in CHP engines even when there is revenue from district heating. Linköping produces 3.3 million m³ biogas per year, compared with the 5.6 million predicted for this biofertiliser plant. The environmental footprint of CNG is even better than CHP but the capital cost of Linköping's gas purification and compression was about €3 million. A prerequisite to using CNG is negotiating the infrastructure and facility to use CNG. In Linköping's case, this meant

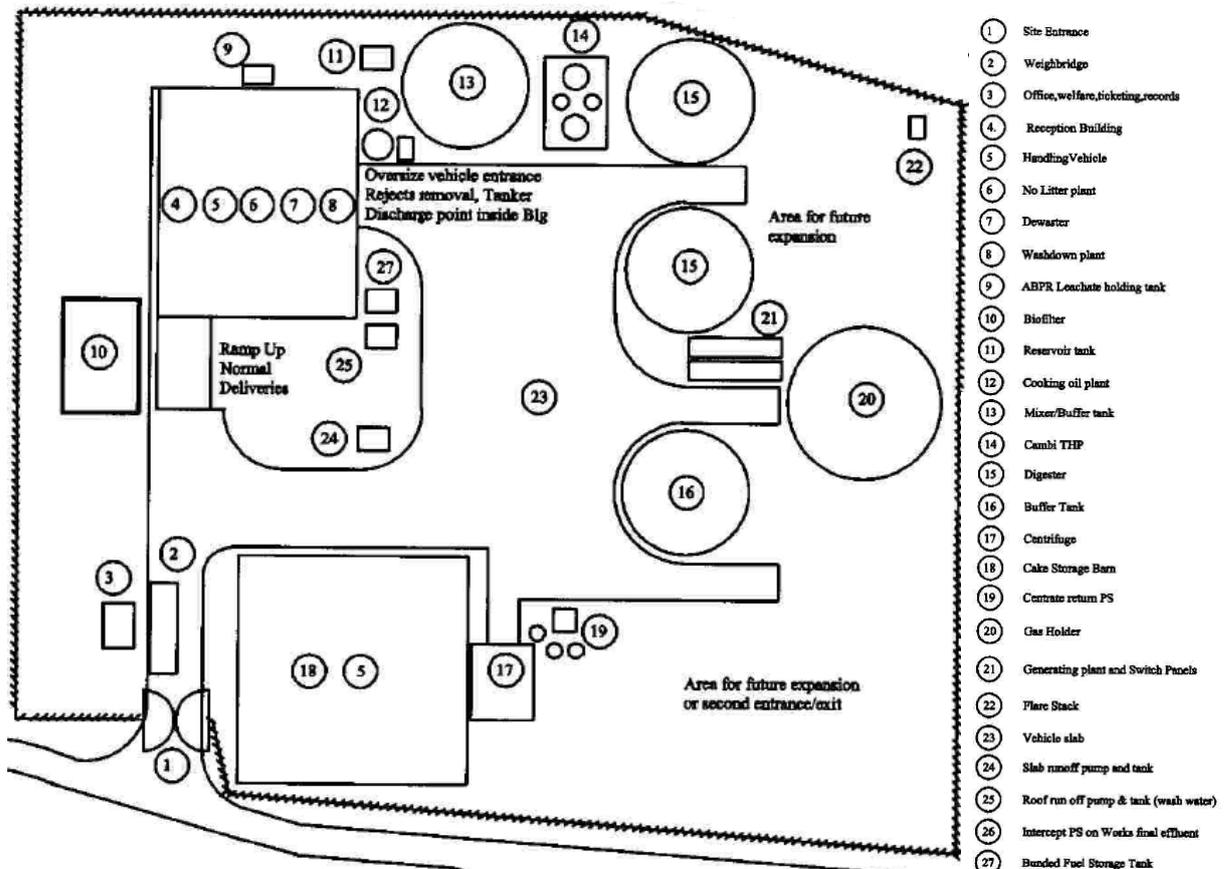


Figure 3 Biofertiliser plant site layout

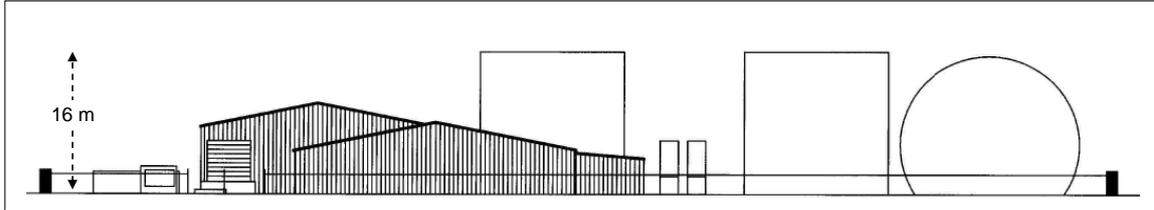


Figure 4 Site elevation viewed from the road

converting all the busses and municipal vehicles to carry CNG tanks, and CNG fuelling at their depots. In the towns where vehicles use CNG, the air quality is said to have improved. CNG could be a second phase development for this project.

POST DIGESTION

After the digesters, there will be a 3000 m³ blending and buffer tank, which has a capacity for 14 days' production. It will normally operate with only 4 days' volume, which will leave 10 days' buffer storage for any downstream non-availability through maintenance or breakdown. It will be mixed using a submersible mixer on a vertical guide rail. The tank will be covered and any biogas released from the digestate will be piped to the gasholder.

Liquid digestate will be dewatered and the cake recycled to land at approximately 34%DS.

WATER MANGEMENT

To improve the green credentials [as well as the Opex] of the project, it is important to minimise both the volume of potable water used, and the volume of wastewater requiring treatment. Biological treatment uses energy and has a climate change impact.

ABPR 'DIRTY' GREYWATER:

This comprises leachate/runoff from the input loads tipped onto the floor of the WRH, wash-down water from the floor of the WRH and any non-recirculated water generated by a wheel-wash associated with the WRH. The volumes will be small. It will go through the full treatment process including CTH.

RUNOFF AND WASH-DOWN WATER FROM THE CAKE STORAGE BARN AND CENTRIFUGE BUILDING:

This greywater is ABPR 'clean' because the only material it can have come into contact with is ABPR 'clean'. However, it might be considered as leachate by the regulatory bodies; therefore gullies serving these areas will drain by gravity to the tank serving the ABPR areas.

GREYWATER GENERATED BY DEWATERING:

The CTH plant at Lillehammer, Norway, which treats source separated domestic and commercial food waste, uses its dewatering liquor as makeup water and has experienced no nutrient/salt build-up problems in the digester. However, if ammonium and phosphate buildup proved to be a problem, they could be stripped physico-chemically and recovered as fertiliser at a fraction of the cost of the trade effluent charges that would be incurred if dewatering liquor were discharged to a sewer and a much better carbon footprint (Evans, 2006).

PLANT DRAIN-DOWN GREYWATER

When parts of the process are drained down for cleaning or maintenance, water drained down will discharge by gravity or partial pumping into the holding tank serving the ABPR runoff.

BLACKWATER

Toilet areas in the Reception Building and Office/Welfare block will generate small volumes of sanitary wastewater; this will be treated in a septic tank. The treated effluent will pass to the greywater system. The sludge can be removed periodically to the first blending/mixer/buffer tank in the process for treatment through the CTH and anaerobic digestion.

RAINWATER

Rainwater from the different parts of the site can be divided into 3 categories according to their ease of collect, cleanliness and likelihood of contamination. Circular roofs and minor structures will produce clean rainwater but it will not be worthwhile to collect it from their roofs.

However, the roofs of the WRH, Cake Storage Barn, and Centrifuge Building will produce large volumes of rainwater runoff. This clean rainwater is suitable for washing down and will be harvested into a washdown-water holding tank via gravity drains connected to the buildings' rainwater down-pipes. A pump will service a pressurised main that will supply a ring main with washdown points at key locations around the site. The holding tank will have a high-level overflow discharging into the road rainwater holding tank, and a connection from the neighbour WwTW's final-effluent pumping main, which will supply water to the holding tank during dry weather. First-flush diversion might be considered necessary if the harvested rainwater is to be used for the cleanest requirements, e.g. water for the steam-boiler, for which water treatment was included in the CTH package. First flush diversion is said to reduce the pollution load of roof runoff by 50% for each 1mm rainfall diverted.

Runoff from roads and other external surfaces will be serviced by road and yard gullies, which collect and carry the runoff via gravity drains through a silt trap and then an oil interceptor to a grey-water holding tank. This holding tank will be served by a pump and rising main that will supply the grey-water to the process-water reservoir tank. If both the grey water tank and the process-water reservoir tank are nearly full, and the greywater tank is still receiving incoming flow, the rising main will reroute and discharge into the adjacent treatment works high-level outfall chamber, where it will go to river.

If it is necessary to move dewatered biofertiliser from the covered store to stockpile storage outside, each stockpile will be covered with an Airbeam Roller Stockpile Cover. This will prevent re-wetting of the biofertiliser and also prevent erosion of particles and nutrients into the drains (Evans et al., 2006).

CIVIL ENGINEERING

The site of the proposed project was previously a WwTW, a replacement WwTW is located adjacent to this site and hence live services are readily available. The experience of the old works proves the site is suitable for development; however, there are several critical factors that require consideration. Ground investigations showed the ground has poor load bearing capability. All structures and plant producing heavy loading will require piling. Building and plant slabs will be of reinforced concrete construction, and may not require piling, however, movement joints, which will allow for some differential settlement, whilst maintaining the integrity of the slabs and buildings, will be required. Likewise all drainage and other services will require flexible joints where appropriate to ensure no failure takes place due to shear. External hard landscaped areas are less critical, and these will be of tarmac on a good sub base.

The site is low lying, close to a river estuary and behind a flood defence embankment. The embankment is stable and unlikely to be breached, but the area of the proposed development is not free draining and hence during periods of prolonged rain, water is liable to pond (though not to flood). It is essential that ABPR areas are not affected by surface water and therefore the slab of the reception building will be raised 200 mm above the surrounding level to avoid ponding surface water entering the building.

Although not as critical, the sludge cake store will also be raised. The storage area will be covered to protect the final cake from rainfall; the centrifuge will discharge directly onto the covered slab.

All below ground storage tanks will have covers raised above the surrounding ground level. An effluent draw-off pumping station will be constructed close to, and drawing off from, the WwTW final effluent outfall pipe. This chamber will be raised above flood level to avoid the danger of the river surcharging up the outfall and flooding the area behind the defences.

The machine operating in the reception building ('ABPR dirty') will also be used for 'ABPR clean' duties, i.e. to stockpile dewatered digestate (biofertiliser) and load collection lorries. The machine will require jet washing of its wheels and undersides when leaving the reception building before going to the 'clean' side of the site. Lorries collecting reject material will also require washing down when they leave the building. An internal draining wash-down bay is

located inside the WRH for these procedures. A wheelwash could be installed but regulators normally accept jet washing.

FINANCIAL

The capital cost of the scheme (including roads, fencing, groundworks, supervision) was estimated to be approximately £7 million (August 2006). The components were selected and sized for reliability and longevity. The operational cost was estimated to be £0.86 million per year and the income to be £2.62 million per year. The annual contribution is thus £1.76 million before taxes. Simplistically, this is a payback of about 4 years. If the quantity of foodwaste available/needing treatment increases, the plant has been designed so that its capacity can be increased readily at moderate additional cost (i.e. less than pro rata).

CONCLUSIONS

The paper describes a plant for converting 30,000 tonnes food waste per year into 13,765 tonnes biofertiliser that will be used for land restoration and on farmland to conserve organic matter and complete nutrient cycles. It will also generate 15,324 MWh_e/year electricity. The payback on capital will be about 4 years. As a second phase, methane could be extracted from the biogas and compressed; this compressed natural gas could be used as vehicle fuel.

The project will conserve resources and reduce global warming potential compared with the current methods for disposing this food waste. It is eminently buildable because of the location and nature of the site. Processes have been selected that avoid practical and operational problems observed at other sites. Components have been sized so that they are not stressed and will thus give long life and high reliability.

The conversion of foodwaste to biofertiliser and renewable fuel is so obviously environmentally virtuous that it is frustrating that the regulatory framework is not more encouraging and enabling. Perhaps the initiative of Quality Protocols will make things less difficult but policy makers have not had a good track record in this area.

ACKNOWLEDGEMENTS

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