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A review of waste solids processing with energy capture technologies

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Executive Summary

The scope of this study was to identify and provide information about waste to energy technologies and assess their likely suitability for solid wet wastes generated by the red meat processing industry, as an alternative to current waste management practices such as conversion of edible parts to meat and bone meal for animal feed, and composting of non-edible materials.

One of the aims of this study was to provide a basis for action for the meat industry if these practices become unsustainable at some time in the future, due to concerns about the possible spread of BSE.

A range of technologies used for meat processing wastes or similar wet organic materials have been examined from a technical perspective, and a practical viewpoint. Overseas examples of their use have been listed (where available) and major equipment suppliers have also been identified. Indicative unit costs have also be obtained where possible although such information is unreliable.

Costs from overseas plants are sometimes not applicable to the local situation, since such costs depend largely upon the scale of the plant and the local conditions such as labour costs, costs of other alternatives for waste disposal, costs of disposing of residuals to landfill and the market value of any energy generated.

It is noted that waste to energy technologies are unlikely to provide an economic advantage over current practices such as rendering at present, since meat and bone meal (MBM) and tallow are valuable commodities at present. Information provided by MLA indicated that market prices for MBM are of the order of $350-400/tonne and tallow can fetch up to $500/tonne at present. Typical costs of rendering are of the order of $80/tonne according to industry sources. On this basis most rendering operations are relatively profitable at present.

In contrast, the capital and operating costs of most waste to energy processes exceed the possible revenues obtained from the electricity generated and sold. They are at best marginally profitable, and in most cases, unprofitable in the conventional sense.

Typical operating costs range from $180-260/tonne for incineration type plants and $80-170/tonne for gasification and pyrolysis type plants. These normally only process relatively dry wastes, as a large amount of energy is needed to drive off water. Wastes with moisture contents of less than 60% are required to obtain a positive energy balance, where energy generated from combustion exceeds energy required to drive the process.

Financial viability of conventional waste to energy plants is normally accomplished through fees paid to plant operators by waste generators for disposal of wastes, due to other waste disposal options (such as landfilling) being equally or more expensive. Without such fees, most conventional waste to energy plants are not economically viable, as revenues from sale of electricity are not sufficient to cover the costs of producing and distributing electricity. Such revenue simply reduces the gate fees that need to be charged for wastes received at these plants.

Therefore there appears to be no economic incentive at present to cease current practices such as rendering and production of meat and bone meal, while such materials can still be used as animal feed. Production of biodiesel from tallow produced by rendering plants is the only waste to energy process that is likely to be economically viable in the current climate, as biodiesel has a market value of the order of 90c/L, and typical production costs of about 25-40c/L excluding raw material costs.

From this investigation it appears that the one of the most practical alternatives for individual meat processing plants in the event that there is a significant decline in the market for meat meal (due to BSE concerns) would be for them to continue operating their rendering plants, but for the MBM to be transported to coal fired power stations for blending with coal. Transport costs would depend upon the distance of meat processing plants from existing power stations, but could prove to be quite expensive for remote operators.

Also the acceptance of meat wastes as an alternative fuel source for the power industry would need to be determined by discussions with existing operators. However MBM is already being used as substitute fuel in German power plants and in cement kilns. Trials with local operators would be the best way of assessing the conditions under which MBM could be used to supplement existing fuels.

The current high demand for renewable energy by electricity retailers and current government schemes for encouraging its use mean that renewable energy certificates (RECs) are able to be issued to coal fired power stations that use MBM as a supplementary fuel. These RECs effectively provide a minimum subsidy of $40/MWh for such renewable energy sources. Whether this scheme continues is a subject of a current review of the MRET scheme being undertaken by the Commonwealth Government.

Meat and bone meal possesses many of the characteristics of current fuels such as coal, as it is reasonably homogeneous, has a calorific value approaching coal, and can be stockpiled and stored if necessary. The stable nature and the relative dryness of meat and bone meal suggests that it could also be used as feedstock for a number of other waste to energy processes, including pyrolysis, gasification, existing coal fired steam boilers and as fuel for existing cement kilns.

As mentioned already, conversion of tallow from rendering plants into biodiesel is also a feasible alternative to current food-related uses of tallow, in the event of a BSE scare. Major rendering plant operator AJ Bush is planning a biodiesel production facility at its Bromelton Rendering Plant in Queensland, to utilise the tallow from its rendering plants. The profitability of this type of operation would depend upon the market price of biodiesel at the time and the possibility of use of some or all of the biodiesel produced for powering transport vehicles owned by an abattoir or rendering plant operator.

Raw meat wastes are putrescible, wet (requiring considerable amounts of energy to dry them prior to energy recovery) and are not suitable for direct input to boilers and other existing processes due to their non-homogeneous nature. However, wet meat wastes appear to be suitable feed stocks for waste to energy processes such as anaerobic digestion with or without thermal hydrolysis, thermal pressure hydrolysis and thermal depolymerisation.

Anaerobic digestion is the simplest waste to energy option for raw meat wastes, as an alternative to rendering or composting. Typical costs quoted for anaerobic digestion are of the order of $70-$150/tonne. Gas production can be enhanced by pre-processing of wastes by thermal hydrolysis however could this add approximately $90/tonne to the cost of the process, and the revenues from electricity generation are unlikely to cover such costs. Neither anaerobic digestion nor digestion combined with thermal hydrolysis would be suitable in the event of a BSE scare, as the temperatures associated with such processes do not appear to be high enough to destroy the BSE prion.

Thermal pressure hydrolysis offers great promise for wet meat wastes, with grinding of wastes to less than 50mm size the only preparation required. The process has been developed in Europe specifically to deal with meat wastes and minimise the likelihood of BSE transmission. The only drawback at present is that there is no full scale plant at this stage, therefore likely costs of operation are not able to be defined.

Another technology that is applicable to wet meat wastes is thermal depolymerisation and chemical reforming, the process being developed by Changing World Technologies. This offers the possibility of being able to convert wet meat wastes directly into fuel. A full scale plant has been built in the US but no data on costs of operation are currently available.

As mentioned above, incineration is not a suitable waste to energy technology for wet meat wastes. Conventional gasification and pyrolysis processes also require feedstock fuels to be relatively dry, due to the large amount of energy required to drive off water from the fuel before chemical conversion processes take place. These processes are therefore only suitable for dried meat wastes such as MBM.

Whether rendered or non-rendered wastes are considered, the potentially high capital costs associated with waste to energy plants suggest that on site processing of either types of wastes is not financially viable for most small to medium scale meat processing facilities. There are large information gaps associated with the potential application of waste to energy technologies to meat wastes, particularly in relation to costs and specific application to meat wastes.

The most significant areas where primary factual data is absent or weak, is about the suitability of existing technologies such as pyrolysis and gasification for processing MBM and anaerobic digestion and emerging technologies such as thermal depolymerisation for processing non rendered meat wastes.

There are relatively few overseas examples of these practices being applied specifically to meat wastes, and little information on the costs of such processes that can be used to estimate costs in an Australian context. However more information on the suitability of thermal pressure hydrolysis and thermal depolymerisation, which offer the greatest promise in terms of processing wet meat wastes and eliminating the BSE prion, is likely to be available within the next 1-2 years, as a full scale plant is currently being either built or commissioned.

Future work undertaken to strengthen areas where information is absent or weak could include some practical trials involving disposal of MBM in existing facilities, such as existing power stations and cement kilns. With the technical difficulties currently being experienced at the SWERF gasification/pyrolysis plant at Wollongong, trials using MBM are unlikely to be possible, although MBM would be a less problematic fuel than the domestic garbage that it has been designed to process.

Additional work could be undertaken to investigate the likely costs of waste to energy technologies for typical individual meat processing facilities, as there are a number of local factors that affect the economic feasibility of waste to energy technologies.

These include the costs of operating rendering facilities (since it has been suggested by industry sources that many abattoirs may not understand their actual costs), proximity of other meat processors that could be involved in a joint waste to energy facility, distances to existing power stations and cement kilns, acceptance of MBM as fuel by existing operators, and their willingness to pay for such feedstock (as opposed to charging a gate fee for disposal).

Application of the newer technologies for wet wastes such as thermal depolymerisation and thermal pressure hydrolysis also warrants more detailed investigation, including formal liaison with the technology providers and site visits, although this should probably be delayed until their full scale plants are properly commissioned and operational.

An overview of waste to energy technologies assessed in the scope of this study is provided in Table 1. Technologies utilising biofuels are summarised in Table 2.

Table 1 Overview of waste to energy technologies applicable to meat wastes

Technology	Advantages / Disadvantages	Cost	Application	Technology Suppliers	Operational Sites
Thermal Processes					
Incineration	Well suited for combustion of MBM, but not suitable for wet meat wastes due to energy required to drive off water High potential for energy recovery from dried meat wastes High level of environmental controls required	\$180 - \$260/t plus the cost of rendering to produce MBM (approx \$80/t)	Medium to large scale offsite facilities would be expected, since most meat processing plants would not operate incinerators. Combustion of MBM in Europe is currently practised for up to 85,000 t/a (at one facility) - as a disposal method for MBM, rather than for energy production.	Howden 3Ts International Ltd (UK), Segers Keppel Technology Group (Belgium)	UK, Germany, France
Coal-fired power stations	Suited to dried meat wastes Not suitable for tallow or wet meat wastes Co-combustion of coal with MBM can improve combustion and lead to decreased levels of carbon and carbon monoxide as well as lower ash production	Cost of transporting MBM to power station (could be \$20/t for 100km round trip), preparing fuel for boiler (ie crushing) and the cost of rendering to produce MBM (approx \$80/t)	Transport to existing power stations required. On site applications unlikely. Power stations likely to accept small to large quantities of MBM and may pay operators for fuel or cover transport costs (due to high demand for renewable energy).	Power station, Lunen, Germany (MBM only)	Europe
Cement kilns	Possible supplementary fuel for cement plants,	Cost of transport to existing facility (could be \$20/t for 100km round	Transport to existing medium to large scale offsite facilities		France, Switzerland,

Technology	Advantages / Disadvantages	Cost	Application	Technology Suppliers	Operational Sites
	which are very energy intensive Integrity of cement clinker can be affected if large quantities of solid waste are introduced Undesirable build up of alkali chlorides where waste contains high levels of chlorine	trip) plus the cost of rendering to produce MBM (approx $80/t).	expected. In 2001 in Germany 245,000 tonnes of MBM and fat were burnt in cement kilns.		Germany
Boiler fuel	Tallow has lower sulphur content than either gas or fuel oil Use of meat wastes as boiler fuel is still not commonly carried out	Cost of rendering to produce MBM (approx $80/t) plus cost of fuel preparation.	Most meat processing plants would not operate coal fired boilers, and installation of new boilers would be necessary.-	Energy Equipment Australia Pty Ltd (green waste only)	Green waste to energy plants in NSW, Tasmania, WA, Qld, and Vic.
Biological processes					
Anaerobic digestion	Well established process for most wet wastes Production of biogas and compost Unlikely to destroy BSE prion in meat wastes Pre-treatment of wastes required High capital costs	Estimates of $70-150/tonne typically reported. New technology such as ORT claiming costs as low as $55 / tonne.	Capacity depends on digestion/co-digestion process and mix of waste types. Small plants are feasible but best economies of scale are achieved for larger plants. Current digestion plants can be up to > 100,000 tonnes/year gross input.	Earthpower, ORT, BTA, Valorga International, Haase Energietechnik	Many plants in operation throughout Europe. Earthpower digestion plant in NSW currently being commissioned for food wastes
Thermochemical Processes					
Thermal hydrolysis	Production of biogas and compost Pathogens and spores are eliminated	Costs estimated to be $90/t in Norway for thermal hydrolysis plant. Additional costs of anaerobic	Wide range of plant sizes possible, with plants from 1200t/yr up to 36,000t/yr already	Cambi AS	Norway

Technology	Advantages / Disadvantages	Cost	Application	Technology Suppliers	Operational Sites
	Best suited to wet wastes. Provides greater speed of digestion, increased production of biogas and better dewatering properties than conventional anaerobic digestion alone. May not destroy the BSE prion, therefore not suitable if BSE is an issue	digestion ($70-150/t) need to be added to this	operating. On site operations, combined with existing or new anaerobic digestion plants is possible.–		
Thermal pressure hydrolysis	Can accept almost all waste as feed stock Pre treatment to grind particle size < 50 mm required Solid residues from processing meat wastes are only approximately 20% of feed stock of existing pilot plant. Biogas and solid products are used in further thermal processes. , High biogas yield and high methane content (70-77%) of biogas compared to normal digestion process Minimises quantity of solid residuals requiring disposal	Process not yet fully developed and operational – therefore costs not known	In process of planning full scale 50,000 t/a plant. Economics of small versus large plants not able to be assessed at present.	ATZ Evus	Pilot plant in Bavaria
Gasification & Pyrolysis	Processes have high energy requirements Higher overall efficiency than other thermochemical and biological processes when	$80 - $170 / tonne quoted in literature plus cost of rendering to produce MBM (approx $80/t).	Due to high capital costs and energy requirements, generally better suited for medium to large scale plants. On site plants likely	Brightstar Environmental (use or MSW), Environmental Solutions International (Enersludge),	Operational plants in Japan, South Korea, Norway, UK and other areas of Europe.

Technology	Advantages / Disadvantages	Cost	Application	Technology Suppliers	Operational Sites
	energy recovery is taken into account Suited to dry meat wastes High capital costs/uncertainty about possible application to meat wastes		to be uneconomic, with larger centralised facilities more feasible.	Compact Power (UK), Organic Power (Norway)	Brightstar Plant still in commissioning in Wollongong. Enersludge plant in Subiaco WA has closed due to being uneconomic to operate.
Thermal depolymerisation	Capable of processing variety of feed stocks Process has low energy requirements Well suited for wet wastes Production of oils, gases and solid carbon Waste water is the only by- product Process is not yet proven on a large scale.	Approximate cost $US90/tonne[1].	Small plants possible although larger scale plants expected to be most economic.	Changing World Technologies	Carthage, Missouri USA. New plants planned for both USA and Italy.
Chemical Processes					
Biodiesel production from tallow	Biodiesel production technology is well proven, including production from animal fats Rendering of meat wastes to produce tallow is first required Economics of biodiesel production depend upon market price of diesel, which can fluctuate	Approximate production cost of 25c/L-40c/L of biodiesel produced plus cost of rendering to produce tallow (about $80/t). .	Most economic for large scale developments, although AJ Bush in Qld is planning an on site plant to produce 60 million litres per year.	Australian Renewable Fuels Pty Ltd	Small plant already built in Maitland NSW. Larger plants to be developed in WA and Qld with 40 million L/annum and 60 million L/annum capacities respectively (using

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[1] Cost based on current cost of $25 - $35 to produce one barrel of oil. Producers expect this cost to reduce to approximately $20/barrel in the near future.

Technology	Advantages / Disadvantages	Cost	Application	Technology Suppliers	Operational Sites
	according to crude oil prices Potential for on-site utilisation of biodiesel produced for powering transport vehicles. As yet no Australian standards in place for biodiesel				approximately 60,000 – 85,000 tonnes of fat/year). Renderer AJ Bush is planning to build an on site plant in Qld to utilise tallow produced by rendering activities.

Table 2 Biofuel utilisation technologies

Biofuel	Technology
Biogas	Boiler fuel
	Electricity production in microturbines or fuel cells
	Heat and power co-generation in internal combustion engines
	Off site use as natural gas surrogate
Syngas	Boiler fuel
	Electricity production in microturbines
	Heat and power co-generation in internal combustion engines
	Off site production of alcohols
Pyrolytic oil	Boiler fuel
	Electricity production in microturbines
	Heat and power co-generation in internal combustion engines
	Off site production of alcohols
	Off site use as fuel surrogate in incinerators, power plants etc.
Non rendered meat waste	Off site use as fuel surrogate in incinerators, power plants etc.
Paunch manure	Off site use as fuel surrogate in incinerators, power plants etc.
MBM	Boiler fuel
	Off site use as fuel surrogate in incinerators, power plants etc.
Tallow	Boiler fuel
	Off site use as fuel surrogate in incinerators, power plants etc.
Biodiesel	Boiler fuel
	Transportation fuel for vehicles
	Heat and power co-generation in internal combustion engines
	Off site use in commercial fuel production
Solution of basic organic compounds	Processing to biogas in anaerobic digester
	Use as C-substrate in wastewater treatment plants
	Off site use as raw product for the chemical industry

1. Introduction

Meat processing generates large quantities of solid wastes, including straw bedding, manure, paunch contents, inedible offal and bone, condemned stock, and wastes from wastewater treatment. All these wastes have a high organic content. Solid waste from meat processing is therefore highly putrescible and cannot be disposed of or reused without further treatment. Traditional solid waste management practices in Australia typically include:

- Rendering of offal, bones and blood into saleable products such as meat and bone meal (MBM), blood meal and tallow;
- Composting of straw, manure and paunch contents; and
- Off site disposal, e.g. at a landfill, or wastewater treatment plant for wastes that cannot be processed by rendering and composting.

In the past, this system has worked very well in Australia and worldwide. Rendering is particularly profitable as it produces saleable products from solids that would otherwise have to be discarded as waste at a cost. According to industry sources, net financial returns from sale of MBM and tallow (after the costs of processing are taken into account) from rendering can be up to $50-$60 per head for beef cattle.

However, the recent BSE[2] outbreaks in Europe have demonstrated that this system is more fragile than it appears. For example the demand for meat and bone meal in Europe has declined because of BSE related restrictions of its sale. This has led to a situation where there is now a need to dispose of stockpiles of rendered products as well as non-rendered meat wastes in ways that ensure that the BSE cycle is broken and / or the destruction of the BSE prion. Thermal destruction of meat industry wastes as well as other waste to energy technologies are therefore increasingly applied in Europe as a surrogate for the traditional rendering process.

The same pressure does not currently exist in Australia, which is currently BSE free. However, this situation cannot be safely assumed to remain as it is and many factors outside the direct control of the meat industry can have serious negative impacts on its markets, for example:

- A reported case of BSE in Australia, confirmed or not; or
- Introduction of a requirement, statutory or voluntary, for livestock to be raised on rendering product free feed only in one of the export markets.

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[2] Bovine Spongiform Encephalpathy. BSE is a fatal neurological disorder of adult cattle commonly referred to as “mad cow disease”. It has been found that consumption of products containing constituents made from contaminated cattle can lead to development of Creutzfeldt-Jakob Disease (CJD) in humans.

In those areas where BSE is a concern, the use of dead carcases as an input for rendering and production of animal feed is prohibited, as is the use of the brain and spinal cord for human consumption. As preventative measure, the European Union has taken action to ban the sale of some affected meat products, and to prevent use of rendered products such as Meat-and-Bone Meal (MBM) in animal feed.

Any such event could leave local meat processors exposed, if no other disposal / reuse routes are available for solid wastes. This could trigger a similar sudden demand for waste to energy technologies in Australia.

At the same time, environmental regulations in Australia are becoming increasingly tighter, for example in regards to odour emissions (with associated significant impacts on costs, site selection and public acceptance of composting facilities) or on landfills. The latter may go as far as banning organic wastes from landfill disposal and raising costs for disposing of non-organic wastes to landfill to values more similar to Europe ($100-250/tonne). These developments have the potential to make the established disposal routes for non-rendered solid waste uneconomical and unviable.

Both aspects make it desirable for the meat industry to develop a better understanding of the status quo of alternative technologies for the treatment of its solid wastes.

Waste to energy processes are likely to have a very good potential as a future solid waste management strategy as they provide a barrier to the proliferation of diseases and are in line with global movements to reduce greenhouse gas emissions which are gaining momentum.

In Australia, mandatory renewable energy targets have been set by the government. At the same time businesses have an increasing desire to reduce operational costs, by minimising energy and waste disposal costs. Both factors have already led to a greater push to capture and utilise the energy from various wastes.

Other effects of the greenhouse gas protocol is that the “production” of carbon credits, which are a globally saleable commodity, could become a positive factor in the cost balance of a solid waste treatment scheme. A related trend is the encouragement to generate “green power” from renewable sources. The Government permits this power to be sold to customers at a premium. Such power earns the supplier Renewable Energy Certificates (RECs) worth approximately $40/MWh.

By their nature, some of the waste to energy processes can provide integrated treatment of several different waste streams (e.g. renderable waste + wastewater treatment waste) in the same treatment process which would increase their beneficial potential.

In summary, the benefits for individual abattoirs and meat processors of utilising waste to energy technologies can potentially include one or more of the following, depending on the current political and economical environment as well as the process:

- Reduced solid waste quantities and disposal costs;
- Energy cost reductions and / or earnings from production of biofuel or green power;
- Carbon credits;
- Improved odour control; and
- Greater social, economical and environmental sustainability.

It is noted that despite these potential benefits, waste to energy processes are not likely to provide a cheaper means of solid waste management to the Australian meat industry compared to today’s practices and under current conditions. However, future development may mean that current practices cannot be continued and more expensive technologies (e.g. waste to energy) therefore just have to be accepted and applied.

In general the financial feasibility of establishing a technology at a particular plant will depend upon the scale of its operations, its location, land availability, and the potential for use of other alternatives to economically dispose of solid wet wastes.

2. Scope of report

In preparation for a potential future demand to use waste to energy processes to manage solid wet wastes from red meat processing, Meat and Livestock Australia (MLA) commissioned GHD to:

- Identify and describe suitable technologies and the associated bearers of knowledge, designers, suppliers, contractors, operators and demonstration sites (as applicable);
- Identify, where applicable, local requirements and other factors in the decision making process that may have led to a certain design or decision in favour of particular process elsewhere but which are not applicable to the Australian meat industry;
- Determine indicative capital and operating costs, including identification and quantification of products and potential markets, required infrastructure and feasible plant sizes;
- Identify knowledge gaps that need to be filled in order to gain a better understanding for a certain technology; and
- Collate this information in a comprehensive report.

3. Red meat processing

Most red meat processing facilities or meat works are comprised of an abattoir including a kill floor and boning room. Many facilities also have their own rendering plant and / or a dedicated wastewater treatment system. Abattoirs receive livestock such as cattle, pigs, sheep, goats and deer for slaughter and further processing of carcases into meat products. Processing includes:

- Slaughtering;
- Carcass dressing;
- Hide removal;
- Evisceration;
- Trimming and carcass washing.

Many abattoirs also have a boning process and offal processing lines. Figure 1 describes the main processing steps undertaken at an abattoir.

Inedible by-products such as bone, fat, heads, hair and condemned offal are sent to the rendering plant (either on or off site) where processing of these solid meat wastes into useful products such as meat meal and tallow occurs. The rendering process can be either a “dry” or “wet” process. In Australia, the majority of rendering systems are dry systems (MRC, 1997). Generally, the processes undertaken at a rendering plant include:

- Grinding of raw materials such as bones, heads and offal into small pieces;
- Heating and agitation of the ground material in continuous or batch cookers;
- Separation of tallow and solids by decanter centrifuges or presses; and
- Milling of solids to a fine powder and transferring to a container; and
- Separation of water from tallow.

In Australia, on site rendering is a common practice at larger meat processing plants. Smaller abattoirs often do not have a rendering plant as it is not economically viable for them to render the by-products of the abattoir operation. Where meat-processing facilities do not have a rendering plant, the by-products are often collected and sent to an independent contract rendering company. As meat processing plants generate large quantities of high strength wastewater, they usually also have a dedicated wastewater treatment system, which typically comprises:

- A screen, through which wastewater is passed to remove coarse solids;
- A “save all” or Dissolved Air Flotation (DAF) unit to remove fats and grease;
- A biological treatment system with anaerobic and aerobic processes (such as ponds and sequencing batch reactors (SBRs) respectively) to reduce the organic load in the wastewater.

Once the wastewater has been treated it is typically disposed of by either irrigation to land, or disposed of to sewer.

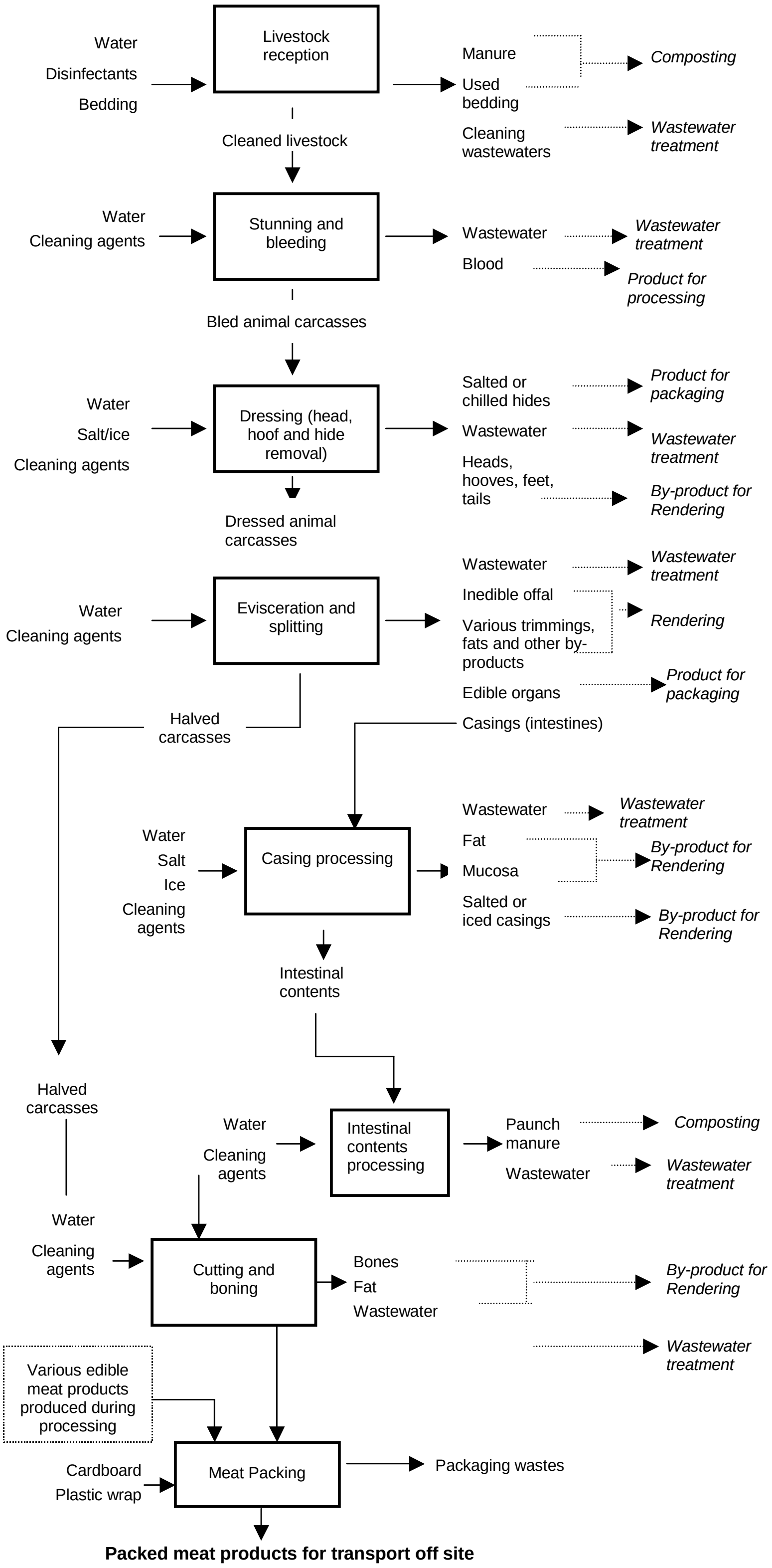

Figure 1 Meat processing by-products and (solid and liquid) waste generating processes

(adapted from COWI, 2000)

4. Characteristics of meat processing wastes

Processing of meat and meat products generates large quantities of wastewater and solid wastes, however, the scope of work for this project is to focus on solid wastes only. Solid wastes are generated in three main process areas:

- Processing of animals at the abattoir;
- Rendering of by-products at the rendering plant; and
- Treating wastewater in the treatment plant.

4.1 Solid wastes generated at abattoirs

Solid wastes generated at abattoirs include the following:

- Yard manure;
- Paunch contents (paunch manure);
- Wastewater treatment sludges;
- Boiler ash where coal is used to fire boilers; and
- Packaging wastes (paper, cardboard and plastics).

The products, by-products and wastes generated at each stage of the meat processing process as well as their end use and traditional management options are summarised in Table 3. For some types of wastes, a variety of management options are available.

Table 3 Summary of products, by-products, and wastes as per traditional solid waste management practice

Products for sale	By-products for rendering	By-products for composting	Wastes for treatment and / or disposal
Boned meat Edible Offal Hides	Fats, bones, trimmings etc Heads, tails, feet, hooves etc Inedible offal Condemned offal Blood Coarse screenings from effluent treatment DAF float / fat collected in save alls	Manure Paunch manure Used bedding Coarse and fine screenings from effluent treatment Sludge from biological wastewater treatment (e.g. ponds, activated sludge, HRAT)	Wastewater treatment wastes (screenings, fat, sludges) Packaging wastes

4.1.1 Quantities

Quantities of solid wastes generated by meat processing are dependent on the type of livestock processed and whether rendering is used for waste management. Table 4 shows the proportion of the total live carcass weight (LCW) of the major products and abattoir by-products for beef and pork processing and their traditional means of management ie composting.

Table 4 Products and by-products from meat processing

		Percentage of live carcase weight (LCW)	
		Beef	**Pork**
Products	Boned meat	40	64
	Edible Offal	5	10
	Hides	7	-
	Blood	3	3
	Total	55	77
By-products for rendering	Heads, hooves, tail etc.	39	20
	Various trimmings, fats and bones		
	Condemned offal		
	Inedible offal		
By-products for composting	Paunch manure	Approx. 3-5	Approx. 3
Total		100	100

(Adapted from COWI, 2000 and per comms MLA 2003)

Almost 40% of the weight of a beef cow is currently disposed of by rendering, and could be utilised for suitable waste to energy processes. An additional 3-5% of paunch manure that is currently composted could also be utilised in such processes.

4.2 Solid wastes generated at rendering plants

At rendering plants, abattoir by-products such as trimmings, inedible offal and condemned offal and beasts are dehydrated to produce tallow, meat meal and bone meal. Little solid waste is generated in this process. . However a very strong (high organic loading) wastewater is generated during rendering which in turn produces solid wastes when treated. Figure 2 shows the solid and liquid material inputs and outputs of a typical rendering plant.

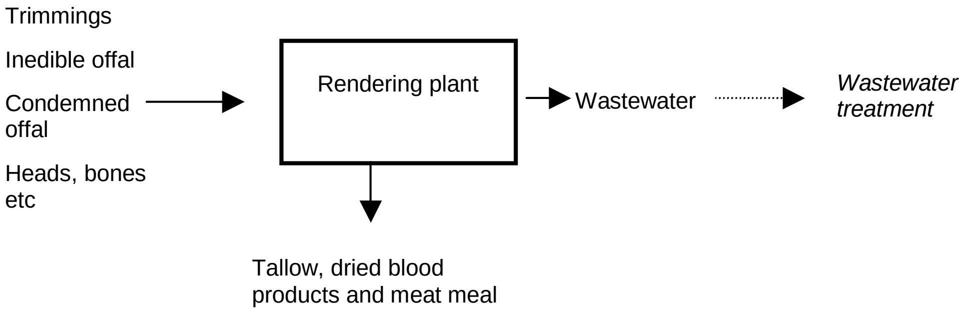

Figure 2 Wastes generated at rendering plants

(adapted from COWI, 2000)

There are two rendering streams – the so-called “edible” and the “inedible” streams. Most meat wastes are usually sent to the edible rendering line to produce meat meal, for feeding to animals. However, if animals are found not to be in good condition, or if they are found dead in holding pens, they are normally sent to the inedible rendering line, for production of bone meal.

Table 5 summarises the estimated production of rendered product from red meat in Australia for the period July 2000 to June 2001. This information was provided by Food Science Australia, a division of CSIRO, and has been published by the Australian Rendering Association (ARA).

Table 5 Annual production of rendered products from red meat

Commodity	Annual production (tonnes)	
Mixed species meat meal	234,000	516,000
Single species meat meal	282,000	
Blood meal	31,000	
Tallow	567,000	

These figures do not include rendered products from the non red meats, such as fish and poultry, which are additional to the above.

A total of approximately 2.5 million tonnes of raw material is rendered annually, according to estimates made by the ARA. This results in approximately 615,000 tonnes of meat meal, and 589,000 tonnes of tallow or oil being produced annually. Red meat processing is the most significant contributor to this with 516,000 t/a meat meal and 567,000 t/a tallow.

Rendering plants are located throughout Australia, and the majority of rendering takes place on site at abattoirs. Figure 3 shows the locations of rendering facilities and abattoirs in NSW. However there are some large mixed rendering plants that service a number of different customers such as red meat processing and poultry processing plants. An example of this is the rendering facility operated by AJ Bush at Bromelton in Queensland.

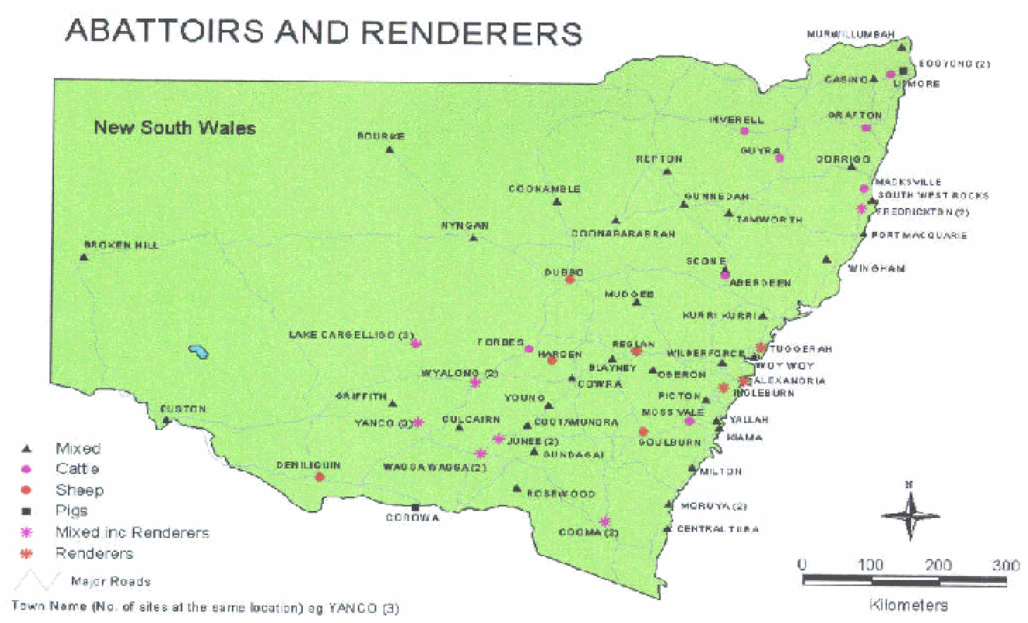

Figure 3 Locations of rendering plants and abattoirs in NSW

According to information provided by the Bureau of Rural Sciences Australia, the breakdown of rendering plants in terms of daily throughput is as shown in Table 6:

Table 6 Summary of rendering plants in Australia

Size	Daily throughput tonnes/day	Annual throughput tonnes/yr	Number of plants
Small	Less than 50	Less than 12,000	27
Medium	50 to 100	12-25,000	35
Large	100 to 500	25-62,000	29
Extra large	More than 500	More than 62,000	3
Total			94

The information presented in Table 6 provides a guide in regard to the waste to energy processes that might actually be financially and/or technologically feasible to replace the rendering process or to process its products, since they are largely dependent upon the throughput of the facility. For some technologies, the minimum economic size of facility may be larger than the throughput of the small abattoirs or rendering facilities.

Table 7 (compiled from various sources) shows the composition of rendered meat wastes.

Table 7 Composition of rendered solid meat wastes

	MBM, sample Bavaria	MBM, sample Ireland	MBM, sample Portugual	Tallow	Partially rendered (wet) offal
Net calorific value, MJ/kg	18.0	15.7	17.8	39	6-12
Water %	18.0	18.9	2.2	0.1-0.4	45-65
Ash %	4.6	29.4	23.6	Not avail	7-14
Volatile solids %	77.4	51.7	74.2	>99	21-48
Nitrogen %	22.03	5.8	10.6	Not avail	Not avail
Total Sulphur %	7.65	0.5	0.4	Not avail	Not avail
Hydrogen %	0.62-5.86	7.7	6.9	Not avail	Not avail
Carbon %	40.83	37.2	47.3	Not avail	Not avail

The chemical composition of rendered products is dependent on the type of livestock processed and the relative quantities of the individual wastes included in the rendering plant feed stock (e.g. high N-content of blood, etc.).

4.3 Solid wastes generated by the wastewater treatment process

Wastewaters mainly arise from the different steps of the slaughtering process such as washing of the animals, bleeding out, skinning, cleaning of animal bodies and cleaning of rooms and equipment. This wastewater typically contains blood, particles of skin and meat, manure, hair, bone and other pollutants.

The volume of effluent generated is a reflection of the volumes of water used, since 80-95% of the water used in abattoirs is discharged as effluent (MRC, 1995). The remainder is contained in by-products and wastes or lost through evaporation (COWI, 2000). In Australia, the average water consumption is 12 kL/ tHSCW[3].

Meat processing effluent generally exhibits the following properties:

- High organic loads due to the presence of blood, manure and undigested stomach contents (high BOD typically around 2,000 mg/L);
- High levels of fat (typically around 1,700 mg/L);
- Fluctuations in pH due to the presence of caustic and acidic cleaning agents in the operations;
- High concentrations of nitrogen, sulphur, phosphorus and salt (from faecal/body matter and additives);
- High concentration of total solids (typically around 3,500 mg/L);
- Moderate to high temperature if rendering is employed.

As described in Section 3, most meat processing facilities contain a wastewater treatment system that comprises treatment units such as a screen, a DAF (or an Induced Air Flotation IAF) unit, and a biological treatment system, e.g. anaerobic lagoons and / or aerobic lagoons. All of these wastewater treatment units generate solid wastes such as:

- Coarse solids separated from the wastewater at the wastewater screens;
- Saveall or DAF top scrapes (fats and grease); and
- Primary and secondary wastewater treatment sludges.

The coarse solids trapped by screening and the fats and grease produced by the DAF unit are either disposed of as wastes or sent to the rendering plant as an input to the rendering process (depending on quality).

The sludges that are deposited at the base of lagoons, regardless of whether they are anaerobic, facultative or aerobic, must be extracted approximately every 5 to 10 years to ensure that the capacity of the system is not compromised. The usual practice is to naturally drain the sludges and spread them onto land.

If the biological treatment system comprises an activated sludge plant, fixed bed reactor or anaerobic high rate reactor, sludges are produced and withdrawn continuously and hence require ongoing processing and disposal. As requirements for better quality of treated wastewater occur, the quantity of sludge from biological treatment of wastewater will increase.

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[3] The unit of hot standard carcase weight (HSCW) is a base unit that takes into consideration the type of species killed. This allows the wastewater loads to be determined on the basis of production, irrespective of the different animals processed.

Due to the nature of the wastewater the coarse screening materials, the fats and grease extracted from the DAF unit are high in organic matter and therefore have a high energy potential. Compared to those wastes, the secondary wastewater treatment sludges are lower in organic matter and energy. A summary of the approximate quantities and qualities of solid wastes typically produced in wastewater treatment plants of the red meat processing industry is shown in Table 8.

Table 8 Quantity and quality of solid wastes from wastewater treatment

Parameter	**Large Abattoirs**		**Small Abattoirs**	
	Hg/tHSCW	Hg/tHSCW	Hg/tHSCW	Hg/tHSCW
Solids in wastewater	33	18-55	33	3-124
COD in wastewater	53	15-117	38	10-43
Solids in sludge	86	33-142	71	13-167

Based on GHD report 1998.
Assume yield of 1kg ss/hg COD

4.4 Packaging waste

Waste materials are also produced at the packaging lines. These wastes typically comprise materials such as cardboard and plastic. For the purpose of this study it is assumed that these wastes can be recycled off site rather than requiring on site processing.

5. Overview of waste to energy technologies

Various technologies exist that enable the conversion of wastes to energy, with some technologies inherently more suitable for the conversion of meat wastes to energy than others. Application of of waste to energy technologies in the meat industry in Australia to date is almost non existent.

Possible reasons for this are provided by SEDA (1999):

- The high water content of meat wastes, which limits the options available for harnessing the energy value of non rendered materials;
- Comparatively low energy costs in Australia – however these are expected to increase in future;
- Lack of equipment and technology suppliers in Australia; and
- Lack of knowledge and consequently lack of interest in energy recovery by the industries generating wet wastes – this is combined with a reluctance to invest significant capital outside their core business. ..

This chapter provides an introduction to the various waste to energy technologies that could be applied to solid wastes fromthe red meat industry. Technologies to convert organic wastes to energy can be classified as follows:

- Thermal processes that directly convert organic waste or biofuel into heat and / or power;
- Biological processes that use biological means to convert organic waste into a biofuel which is then used in a separate process to generate heat and / or power;
- Thermochemical processes that apply high temperatures and / or pressures to convert organic waste into:
  - a biofuel which is then used in a separate process to generate heat and / or power; or
  - a raw product that can be used in the chemical industry; or
  - a C-substrate that can be beneficially used in wastewater treatment;
- Chemical processes that convert organic waste at relatively moderate temperatures and pressures into biofuels that can then be used in a separate processes to generate heat and / or electricity.

It is noted that some of these technologies may not provide a complete waste to energy system unless combined with another process step, e.g. anaerobic digestion plus biogas utilisation in a gas engine. Where this is the case, it has been outlined in the detailed description of the respective technology together with a list of options available for these processes required to complement the primary step.

The most appropriate technology to employ not only depends upon the composition of the waste stream to be processed but also on external factors such as the market for the products (fuel, heat, power, chemicals), availability of land, subsidies, environmental requirements, etc.

5.1 Thermal processes

Possible thermal processes applicable to meat wastes include direct incineration and the use of treated waste as ancilliary fuel in:

- Coal-fired power stations;
- Cement kilns; and
- On-site boilers.

One advantage of using thermal processes in a BSE situation is that they would provide one certain means of destroying the BSE prion, unlike other processes such as anaerobic digestion. They also permit the use of existing plant and equipment such as boilers and incinerators, power stations and cement kilns, provided that meat wastes can be prepared in accordance with normal fuel standards.

5.2 Biological processes

Highly organic solid materials, such as the wastes produced by the meat industry, can be treated very effectively by anaerobic digestion. The advantage of anaerobic digestion over aerobic digestion for these types of wastes is the large net energy gain and very low biomass production rate of anaerobic processes compared to the large net energy requirement for aeration and the fairly high biomass production rate of aerobic digestion processes.

In general, the following anaerobic digestion process arrangements are possible:

- Digestion of raw wastes;
- Digestion of rendered wastes;
- Co-digestion of raw or rendered wastes together with sewage sludge or green waste; and
- Digestion of hydrolysate from thermal hydrolysis.

It is noted that anaerobic digestion can be carried out at ambient temperature, at around 35 °C (mesophilic) and between 50 and 70 °C (thermophilic). The latter is often applied for cost effective capacity upgrades to existing sludge digestion plants with the added benefit of pathogen destruction. It is noted however, that destruction of the BSE prion at thermophilic temperatures cannot be expected as it has shown to survive the harsher rendering conditions.

No differentiation is therefore made in the following discussion between mesophilic and thermophilic digestion. Unless otherwise noted, digestion is always assumed to be carried out at mesophilic conditions, because digestion at ambient temperatures is too slow and thermophilic digestion is normally less robust to operate than mesophilic digestion.

5.3 Thermochemical technologies

Thermochemical technologies utilise thermal energy and / or high pressure to allow chemical reactions to take place that lead to the conversion of organic solids into gas, longer chain alkanes (e.g. oil), char or their “disassembly” into their basic constituents such as amino acids, fatty acids etc. Within the thermochemical class of technologies, a number of processes have been identified that have potential for the waste to energy treatment of meat processing waste. These are:

- Thermal hydrolysis;
- Gasification;
- Pyrolysis and low temperature conversion; and
- Thermo-depolymerisation and chemical reformer process;

Thermochemical technologies are generally used around the world to process solid wastes with relatively low moisture contents such as municipal solid waste (household garbage) and dewatered or dried sewage sludge. Commercially operating thermochemical waste to energy plants are typically large, highly engineered, complex and centralised facilities, which often receive feedstock from a number of sources.

Depending on the underlying basic chemical processes, the type of product produced, process conditions and proprietary reactor design, some of these technologies are best suited to dry wastes as feed stock and would hence require drying of the waste as a pre-treatment step, whilst others can operate with wet wastes as feed stock.

5.4 Chemical processes

Chemical reactions that occur between wastes and other chemicals at low temperature and pressure, can be used to produce fuels from waste products. One such process that is commercially proven is production of biodiesel from meat fat and rendered products.

There are three basic process options for production of biodiesel from oils and fats (US National Biodiesel Board):

- Base catalysed transesterification;
- Direct acid catalysed transesterification; and
- Conversion of the oil to its fatty acids and then to biodiesel.

Each of these general process areas is described in more detail in the appendices of this report.

6. Thermal processes

Thermal processes are attractive in that they can potentially be applied to both rendered and non rendered meat wastes, to dispose of increased volumes arising from concerns about BSE in products of rendering, such as MBM and tallow.

Direct combustion of non rendered meat wastes in solid fuel boilers would not normally be contemplated, due to the wet nature of the wastes, and the amount of energy required to drive off the moisture, before combustion can take place. Combustion usually requires a waste stream to have a maximum moisture content of 60% to obtain a zero energy balance, where the energy put into the system equals the usable excess energy out of the system (SEDA, 1999).

If specific sources of wet waste are already being dewatered to more than 40% solids, then direct combustion may be feasible. Likewise, combining wet wastes with dry streams may make direct combustion of wet wastes possible, although it would be unlikely to generate high net energy outputs. The variability of non-rendered wastes would also cause difficulties in combustion equipment, which require relatively homogeneous in feeds to maintain high efficiencies. Generally, only pre-dried and treated wastes such as MBM would be suitable for boiler feed.

Purpose design incinerators are more robust than boilers in terms of the feedstock they can receive, and they offer possibilities of co-firing meat wastes with dry wastes of higher calorific value, to overcome the energy consumption associated with combustion of wet wastes. They are widely used for combustion of medical wastes, and municipal solid wastes, which are highly variable in nature. Even with these systems it is preferable to pre-dry material at <100°C to improve overall thermal efficiency.

The calorific value of rendered products such as tallow can be as high as that for natural gas, while MBM has a calorific value of approximately 50% of natural gas, and slightly lower than coal. Table 9 compares the calorific value of meat wastes with other common fuels.

Table 9 Estimated calorific values for wastes and common fuels

Fuel / Waste	Calorific value, LHV MJ/kg
Partially rendered (wet) offal, 35-55 % DS	6-12
Lean MBM (92 – 95% DS)	18-19
Fat MBM (90 – 95% DS)	20-22
Tallow (99.8% DS)	39.7
Coal	25 – 30
Fuel Oil	42 – 43.5
Natural Gas	39.8
Domestic Waste	7.5 – 15
Sewage Sludge (wet)	8.0 – 11.5

Exact calorific values for whole carcasses are unknown as there is limited experience in incinerating/combusting whole animal parts. It has been estimated that carcases containing up to 70% moisture and up to 5% incombustible solids would have a heating value of approximately 6 MJ/kg, other reported values are 10 –12 MJ/kg for carcasses and 11 –13 MJ/kg for quartered meat (European IPPC Bureau, 2002).

6.1 Incineration

6.1.1 Technology description

Incineration is the term normally used to describe the mass burning of wastes.

Different types of incineration processes may be used, including mass burn combustors, rotary kilns, multiple hearth incinerators, controlled air incinerators, retort incinerators, and fluidised bed incinerators. The heat generated by combustion of wastes can be used to produce stream to drive turbines that produce electricity, or the heat can be utilised for other industrial purposes, such as heating, or producing hot water.

Waste is normally introduced to the incinerator using a hydraulic ram and moves through the combustor on an active grate. Grates can be rotary, reciprocating, ram-driven, or of other designs.

In the first stage, the waste is normally dried with radiant heat. During subsequent stages the waste undergoes a form of pyrolysis and rising gases from the waste are combusted above the bed. The waste itself is then combusted, and combustion ash then falls into a quench pit at the end of the grate.Incinerators are generally large, heavily engineered and centralised facilities. Some incinerators are not compatible with solid fuels or solid waste, as these materials will start to burn too high in the furnace. (Changing World Technologies, 2003) There are many types of incinerators but typically modern incinerators comprise the following components:

- Bunker;
- Feeder;
- Kiln;
- Afterburner;
- Steam generator;
- Slag dischargers;
- Exhaust gas cleaning system (or air pollution control devices); and
- Chimney stack.

6.1.2 Process flow diagram

The set up for a typical incineration process is shown in Figure 3.

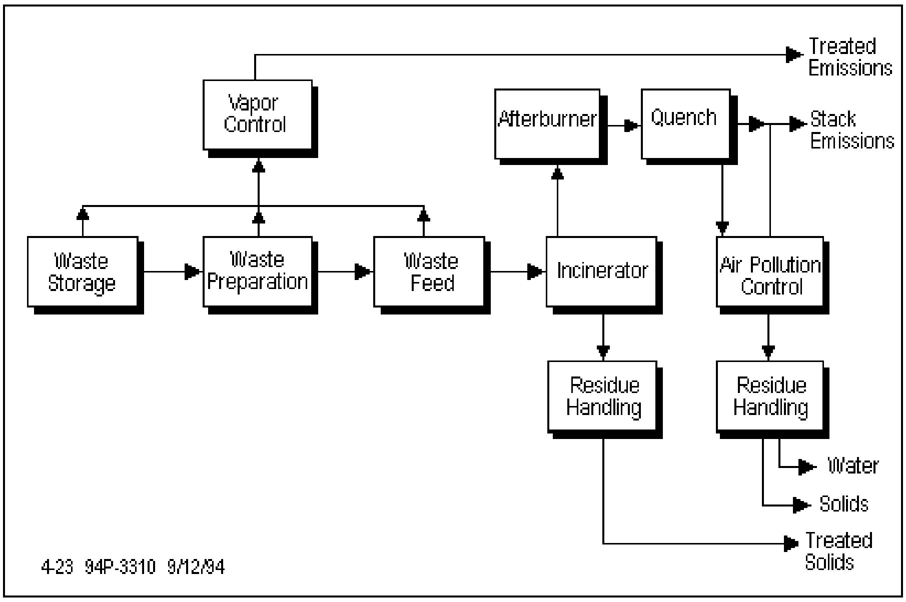

Figure 3 Typical incineration process

(US Department of Energy)

6.1.3 Feasibility for processing of meat wastes in Australia

On site incineration could be used to process meat wastes, if the waste is relatively dry and is ground to a homogenous particle size for efficient combustion. MBM would be well suited for incineration as it is highly calorific, easily flammable, and can be easily ground and mixed homogenously with other waste. MBM also has a lower level of air pollutant emissions compared to other wastes that are commonly incinerated (such as domestic waste).

Even tallow could be combusted in burners used for heavy oils. (Nottrodt, 2001).

Whilst incineration of non rendered meat wastes is technically possible, the following factors affecting the effectiveness of their incineration need to be considered (adapted from SEGHERSenergy, 2002):

- Variable composition (can be lumpy, different sizes, different fat content) can lead to varying calorific value of the waste stream fed to the incinerator;
- Disruptions to process control can result from fast and violent combustion of volatile compounds such as fat which are not homogenised throughout the feed;
- Difficulty feeding waste to the furnace if it becomes lumpy; and
- Composition of fly ash may cause slagging and fouling (and hence decreased efficiency and increased corrosion of boiler) depending on concentrations of sodium, potassium, phosphorus, calcium, sulphur, and chlorine.

Studies in Germany have shown that the cost of incinerating MBM is about the same as the standard cost of incinerating normal domestic waste (Nottrodt, 2001).

The literature review did not uncover any cost data for incineration of animal wastes that was specific for Australian operations. Incineration costs for the burning of domestic and industrial waste however has been estimated to be between $180 - $260 per tonne (NSW State Government, 2000).

6.1.4 Energy generation from incineration

The high temperature of the exit gas stream from an incineration unit can be used to create steam and generate electricity for use at the meat plant. Figure 4 shows typical consumption and emission data for a rendering plant processing 1 tonne of MBM that is subsequently incinerated in a fluidised bed combustion unit.

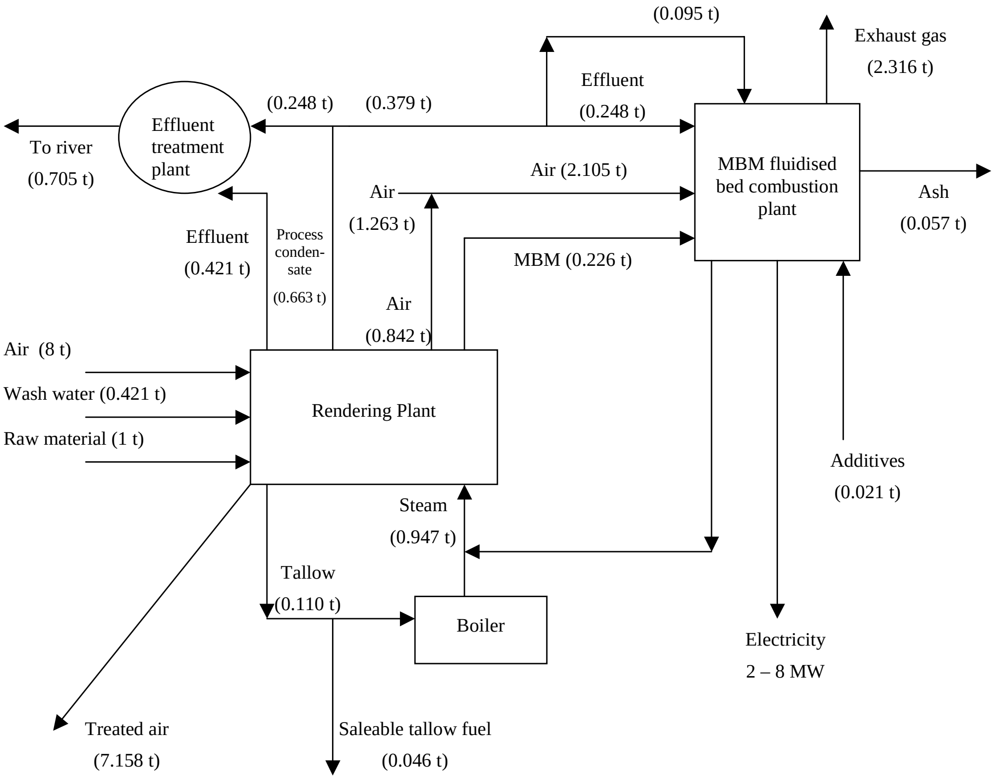

Figure 4 Consumption and emission data for rendering with on-site combustion of MBM

(European IPPC Bureau, 2002)

Stockpiling of MBM in Europe has led to much research being undertaken to investigate the potential to recover energy from incineration of this material. (SEGHERSenergy, 2002):

- Case 1: Lean MBM with a calorific value of 18.5 MJ/kg and 5% moisture content;
- Case 2: Partially rendered offal with a calorific value of 9.5 MJ/kg and 45 % moisture content; and
- Case 3: A mixture of 50% lean MBM, 10% tallow, 30% partially rendered offal and 10% of biosolids resulting from treating rendering waste water.

The resulting energy production and fuel savings for these three scenarios are summarised in Table 10.

Table 10 Potential energy derived from incineration of 50,000 t/a MBM

Case	Max. thermal energy recovery MWth	Max. net electricity production[4] MWe	Number of homes lit	Non CO_2 – neutral fuel savings tonne/a
1	27.3	5.2	9,200	17,600
2	14.0	2.6	4,600	8,800
3	20.5	3.7	6,600	13,500

6.1.5 Operational sites

- Facilities in Widnes and Wyminton, UK – joint capacity for MBM of 60,000 t/a.
- Fawley, UK – MBM of 60,000 t/a.

6.1.6 Technology suppliers

Incineration is well established throughout the world particularly in Europe, the US and Japan where it is used to process municipal and hazardous wastes. At the end of 2000, MBM was being incinerated at 10 different waste incineration plants in Germany alone (Nottrodt, 2001).

The British Government awarded contracts to only three companies to perform the incineration of MBM under their Over Thirty Months Scheme, a scheme that requires slaughtered cattle over the age of 30 months to be disposed of in such a way that they could not enter the human food chain.

In Australia, public perception of the environmental and health impacts of incineration as well as sufficient availability of landfill space have prevented its widespread use, although it is still used for disposing of medical wastes.

Table 10 Proprietors of incineration systems for animal waste

Company	Contact details	System	Operational sites
Howden 3Ts International Limited	Picton House, Lower Church Street Chepstow, Monmouthshire United Kingdom, NP16 5HJ Tel: +44 1291 630370 Fax: +44 1291 625746 http://www.howden-3ts.com	Howden have a range of incinerators especially designed to dispose of animal carcases.	Animal Carcase Incinerator PD288 used at Central Laboratory Research Lab, United Arab Emirates
Segers Keppel Technology Group	Hoofd 1 2830 Willebroek Belgium Tel : +32 (0) 3 880 77 00 Fax : +32 (0) 3 880 77 99	Seeger have a range of combustion equipment to deal with different waste types.	Various sites throughout the world including Korea, China, USA,

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[4] Net electricity excludes electricity consumed by rendering plant itself

	http://www.seghersgroup.com/sk/home.nsf		Italy, and Belgium.
Shanks Waste Solutions	Tel: 44 (0)1628 524523 http://www.shanks.co.uk Email: info@shanks.co.uk	Various incineration systems for different waste types, including MBM	Various including Shetland and Fawley, UK

6.2 Coal-fired power stations

6.2.1 Technology description

Similar to dried sewage sludge, dried meat industry wastes could be used as surrogate or supplementary fuel for coal-fired power stations. Due to the plant design of coal-fired power stations, the use of a dried, finely milled product is mandatory and the use of wet waste would therefore not be possible. Also, combustion of liquid fuels such as tallow is not possible and it would therefore require a different means of disposal.

The required pre-treatment/drying of the waste could be carried out by rendering and use of the MBM as feed stock. Other alternatives could be to solely dry the waste in a dedicated dryer, either directly or after anaerobic digestion, and use the dried and milled raw waste as a feed stock. However, this literature review could only identify direct use of MBM.

6.2.2 Feasibility for processing of meat wastes in Australia

Large-scale trials of using MBM as a support fuel for coal-fired power stations have been underway in Germany since 2000. An industrial power station at Lunen is using MBM to provide 50-60% of furnace heat in generating 45 MW of power. It is planned to continually increase the ratio of MBM to coal and secondary fuels to 100% (Nottrodt, 2001).

Important to the successful use of MBM as an alternative fuel in power stations is the inlet feed particle size of MBM, which should be at most 1-2 mm (SEGHERSenergy, 2002).

European experiences of using MBM as a fuel supplement in coal-fired power stations has shown that there are advantages over 100% coal combustion including (Nottrodt, 2001);

- Improved combustion;
- More stable incineration;
- Decreased levels of emissions of carbon and carbon monoxide; and
- Lower ash production.

However, prior to this technology being adopted as common practice, more research is required to evaluate the potential effects such as;

- Potentially higher NO_x emissions;
- Effects of higher phosphorus levels on scaling and corrosion rates;
- Changes in slag residues due to higher calcium and phosphorus content.

Disposal of MBM in power station boilers is considered feasible, given that the material is dry and relatively homogeneous, and that MBM has been successfully used as boiler fuel overseas. Mandatory renewable energy targets have been set in Australia, and power generators are actively seeking alternative fuels than coal, to meet their obligations.

The main issue for meat processors would be the cost of transporting MBM to the nearest power station that would/could accept such material as feedstock.

6.2.3 Operational sites

- Industrial power station operated by Rethmann Lippewerke GmbH in Lunen, Germany.
- Glanford power station in Flixborough, UK – annual input of MBM 85,000 t/a, also uses poultry litter as feedstock.

6.3 Cement kilns

6.3.1 Technology description

Production of cement clinker is an energy intensive process, which can be used to dispose of wastes including domestic and hazardous wastes. Burning of wastes with a high energy content as a substitute for fossil fuels has both environmental and economic advantages.

Cement manufacturing consists of producing “clinker” which is a combination of silica, alumina and iron oxides which have been combined at a high temperature, cooled and then ground in with other additives to make the final product. Wastes can be safely burned in a cement kiln as the high temperature and alkaline conditions lead to the decomposition of chlorine and sulphur into neutral forms.

There are also no chemical residues or solids requiring disposal after the process as these are incorporated into the clinker. The integrity of the clinker however may be affected if large quantities of solid waste are introduced (Environment Australia, 1997, p.38).

6.3.2 Feasibility for processing of meat wastes in Australia

The high calorific value of meat wastes means that it would be suitable to be fed into the cement clinker process. However process difficulties may be encountered in feeding the waste to the furnace where the waste contains a high fat content. In this situation mechanical conveyance such as using a plate and chain conveyor, may need to be implemented to prevent clogging of feed pipes. An additional consideration is the potential for undesirable formation and build up of alkali chlorides, where the waste contains high levels of chlorine (Nottrodt, 2001).

The effects on emission levels due to using meat wastes in cement clinker production are minimal, and if inlet waste concentrations are controlled, the cement product quality is not compromised (Nottrodt, 2001).

Processing of general meat wastes in cement kilns is not currently undertaken in Australia. However, the use of MBM in cement clinker manufacture in Europe has been demonstrated to be economically viable.

Processing of MBM in cement kilns is not an on-site solution for meat processors, and individual meat processing facilities and rendering plants would need to transport MBM from their facilities to the nearest cement production facility that agrees to accept this material.

While the use of cement kilns to dispose of waste has been evaluated to be relatively safe if properly designed and operated (Environment Australia, 1997), their use might not be accepted by the wider community

6.3.3 Operational sites

MBM has been used to produce cement clinker in the German cement industry. This has also taken place in France and Switzerland where MBM can make up as much as 10% of the input feed to the process (UKRA, 2003). In Germany in 2001, 245,000 tonnes of meat and bone meal and animal fat with an average calorific value of 19 MJ/kg, were used as fuel in cement production (German Cement Works Association, 2001).

There are currently no cement manufacturing operations in Australia that use meat waste products as a fuel source for clinker production. The use of waste oil and other types of waste such as tyres is however endorsed by the Australian Cement Industry Foundation[5] where the quality control of the waste material and cement product is tightly maintained.

6.3.4 Technology suppliers

Suppliers of technology for using waste in cement kilns can be found internationally. More research is required to identify companies that are able to use meat waste as opposed to industrial or domestic wastes.

6.4 Boiler fuel

6.4.1 Technology description

Meat wastes with a high calorific value such as tallow could be burnt in most boilers. Tallow has the advantage of having much lower sulphur than either gas or fuel oil. MBM may also be able to be burnt in on site boilers, although no examples of this have been found in the literature review.

6.4.2 Feasibility for processing of meat wastes in Australia

It would be theoretically feasible for rendering facilities to use tallow that they produce as fuel for their own on site boilers. However, the economics of doing this versus selling tallow on the open market have so far prevented the operation of such a scheme. There may also be issues to resolve if long term contracts have already been negotiated by rendering plants to supply tallow to other industries.

The use of MBM or raw waste as boiler fuel appears more difficult and hence less feasible, particularly for on site use.

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[5] The use of alternative fuels in Australian cement kilns reduced the use of fossil fuels equivalent to 57,000 tonnes of coal in 1999 (Cement Industry Federation). At the Blue Circle Southern Cement plant in Waurn Victoria, waste oil consumption has been as high as 15 million litres annually, replacing 30% of natural gas requirements (Cement Industry Federation).

6.4.3 Operational sites

There are currently no systems operating on meat wastes such as animal carcases, offal, MBM or tallow. However, combustion of solid wastes such as municipal waste, biomass fuels such as green waste is being undertaken (Figure 4). Effluent sludge is already currently being used to fuel boiler systems in Australia.

Energy Equipment Australia Pty Limited operates a number of waste to energy plants in Australia including:

- Nowra, New South Wales, - 18MW Green Waste to Energy;
- Bell Bay, Tasmania **–** 65MW Green Waste to Energy;
- Kemerton, Bunbury, Western Australia **–** 65MW Green Waste to Energy;
- Gold Coast, Queensland – 65MW Green Waste to Energy for EnviroStar Energy Limited; and
- Morwell, Victoria **–** 65MW Green Waste to Electrical Energy and Steam for industries.

Figure 4 Fluidised bed combustion unit installed on green waste to energy site in Staplyton, Queensland

(Energy Equipment Australia Pty Limited)

6.4.4 Technology suppliers

It is noted that no site operating on processed or un-processed meat waste could be identified in this literature review. It is however possible that suppliers of biomass boilers may be able to design and build a boiler for the use of meat industry waste. Table 11 provides information on biomass boiler suppliers that were identified during this investigation.

Table 11 Proprietors of boiler systems for biomass wastes

Company	Contact details	System	Operational sites
Energy Equipment Australia Pty Limited	EE Technology Building 8, 190 George Street, Paramatta NSW 2150 Tel: 61 2 9891 3738 Fax: 61 2 9891 2778 http://www.energyequipment.com.au	Energy Equipment Australia Pty Limited designs, constructs, and operate waste to electricity/steam energy plants using fludisied bed combustion technology.	Listed above

7. Biological processes

7.1 Process principles

Anaerobic digestion involves the biological degradation of organic matter by a mixture of different species of anaerobic micro-organisms in the absence of oxygen. The process occurs naturally in the stomach of ruminants, in landfills and water soaked soils. In engineered anaerobic digestion systems, solid waste or wastewater is processed under controlled ambient conditions in digestion reactors.

In both cases, the organic content of the waste is reduced significantly, typically by around 50% of the original volatile solids (VS) content for solid waste and up to 90% of the total (mainly dissolved) COD content for liquid waste. The destroyed organic material is converted into biogas, which is principally a mixture of methane CH_4 (50-70%) and carbon dioxide CO_2 (30-50%) (SEDA, 1999) and other minor constituents as shown in Table 12.

Table 12 Biogas composition from anaerobic digestion of unspecified animal by-products

Component	Percentage volume
CH_4	40-70
CO_2	30-60
Other gases, including	1-5
H_2	0-1
H_2S	0-3

(European IPPC Bureau, 2001)

The maximum potential methane yield from an anaerobic digestion process is 0.352 m^3 CH_4 / kg COD destroyed (SEDA, 1999). Gas production rates are dependent on the type of waste and of the effectiveness of the reactor design and operation.

For maximum production of biogas it is important to maintain optimal conditions for methane production. These include controlling the pH and alkalinity, carbon/nitrogen ratio, temperature, moisture content (relatively dry wastes only) and maintaining an appropriate retention time (which in turn is dependant on temperature).

The anaerobic process has three distinct decomposition phases (SEDA, 1999):

- A hydrolysis phase, which is responsible for the breakdown of complex organic compounds into smaller organic molecules;
- An acid phase where one set of microbes degrades long chain carbon compounds to short chain (simple) acids;
- Methane phase, where another set of microbes degrades the acids to methane, carbon dioxide and water.

Anaerobic digestion of liquids, slurries and pulps is typically carried out in continuously stirred tank reactors (CSTR). These are typically cylindrical tanks made of concrete or steel, usually with conical bottom and top. The feed is heated to approximately 30-35 ^{o}C and is well mixed to optimise contact between substrate and biomass, provide constant conditions (temperature, substrate concentration, etc.) in the whole reactor, avoid settling and facilitate release of the biogas.

Anaerobic digestion of wastes with lower water content requires different reactor designs to overcome problems with air (oxygen) in the feed, seeding of the waste, optimising contact between biomass and substrate etc. These designs are typically proprietary.

A typical digestion plant with biogas utilisation comprises:

- Digester,
- Biogas collection and balancing system;
- Biogas scrubber to remove H_2S; and
- Biogas use in boiler or for combined heat and power in a gas engine.

An example for an anaerobic digestion process for meat industry waste is shown in Figure 5.

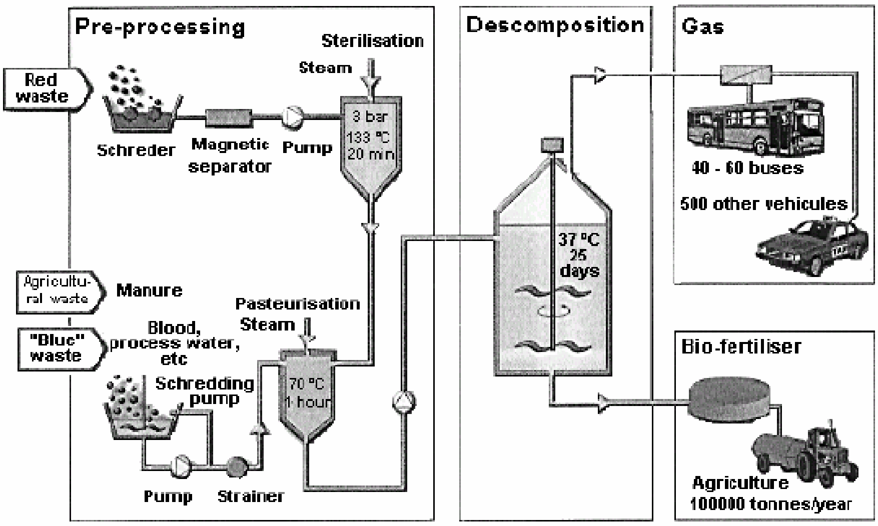

Figure 5 Overview of typical biogas production process

(European IPPC Bureau, 2002)

A general advantage of anaerobic digestion with biogas utilisation compared with direct thermal utilisation is that biogas is a relatively clean product. Thus its combustion is less critical in terms of air emission limits for heavy metals etc.

The main disadvantage is that it doesn't provide complete destruction of the waste. The quantity of the residue depends very much on the total process concept and can be minimised by pre-treatment steps such as thermal hydrolysis. However the residue is often suitable for composting to produce fertiliser, although this would not be applicable in the case of a BSE scare.

7.2 Digestion process options

7.2.1 Digestion of raw wastes

Meat industry wastes are very suitable for anaerobic digestion. Some pre-treatment would be required in order to homogenise the feed stock are shown in Table 13. Detailed description of disintegration methods is shown in Appendix A.

Table 13 Pre-treatment required for Anaerobic Digestion

Waste	Pre-treatment	Moisture	Equipment	Comments
Raw meat waste	Particle size reduction to 10-25 mm	Add water or ‘wet’ waste	Pulper	Difficult to homogenise
Paunch/straw/screenings	Particle size reduction to few mm	Add water or ‘wet’ waste	Pulper	Potential to block reactor
Fat and Grease	Particle size reduction to few mm	No water needed	Pugmill mix with other wastes	Care to avoid blockages
Pond sludges	Blend with dry wastes	May need to dewater and degrit	Degrit and dewater. Maybe bypass AD	
Activated Waste – Sludge	Thicken and disintegrate	Need to thicken/dewater	See Appendix A	See Appendix A
High rate anaerobic sludge	Thicken	Need to thicken	-	

It is noted that if renewable energy / greenhouse gas emission or landfill disposal related considerations are the driver towards waste to energy technology, anaerobic digestion by itself can provide a satisfactory (and as shown later: well proven) solution. If however BSE or a similar problem is the driver it must be considered that the biological processes of anaerobic digestion may only impair the reactivity of BSE prions but cannot irreversibly destroy them (Nottrodt, 2001).

This problem can be solved by drying the digested waste and then incinerating it This may sound unnecessarily complicated, compared to direct incineration of the raw waste. However, one must consider that anaerobic digestion reduces the total quantity of solids and produces relatively clean biogas - the utilisation of which is comparatively straight forward and easy. Anaerobic digestion can thereby reduce the required throughput of an incineration plant including all process- and off-air treatment.

Odours may also be reduced. Mechanical dewatering of the waste to a degree where there is a net water reduction (i.e. more water is removed than was added in the pulper etc.) prior to drying may also be possible once it has undergone digestion, thereby reducing the required evaporation capacity of the system. Due to all these factors it is often found for sewage sludge that digestion prior to dewatering and drying is viable. A similar outcome is therefore considered possible for raw meat waste.

7.2.2 Digestion of rendered wastes

Direct digestion of rendered wastes is not considered technically viable due to the low water content of the MBM and the tallow. In the case of MBM the product would require addition of water or another wet waste. In the case of tallow, an additional problem arises in the form of providing sufficient contact between the organisms and the substrate. Effectively this would require to produce an emulsion from the tallow. A secondary problem would be the formation of tallow crusts on equipment and the surface of the water in the digester which can cause mechanical problems and reduces the efficiency of the process.

The digestion of rendered wastes would also not overcome the problem of safe destruction of the BSE prion. In order to achieve this outcome it would therefore be required to introduce additional processes, similar to the digestion of raw wastes. If BSE prion destruction is a goal in future waste to energy considerations, the digestion of rendered wastes would not offer any advantages over the digestion of raw wastes.

7.2.3 Co-digestion

Co-digestion of wastes has recently been tested in a number of pilot and full scale installations. Typically, green waste or organic municipal wastes are digested together with sewage sludge. In regard to meat industry waste, the findings of Sections 7.2.1 and 7.2.2 apply.

7.2.4 Digestion of hydrolysate from thermal hydrolysis

An alternative role that anaerobic digestion can play is that of a second step after a thermal hydrolysis of the waste. In this case, BSE prion destruction is taken over by the thermal process and overall solids destruction is maximised. This option is described further in Sections 8.1 and 8.2, covering thermal hydrolysis processes.

7.3 Feasibility for processing of meat wastes in Australia

Anaerobic digestion of municipal solid wastes and solid wastes from the meat industry is already being undertaken in a number of locations around the world. It is a well-understood and robust technology for organic wastes generally, and can also be undertaken at a relatively small scale, which makes it feasible for some individual meat processing facilities to have on-site facilities, rather than have to transport wastes to centralised facilities.

The most prominent example for the use of such technology in Australia is the Earthpower - Biomass Facility at Camellia, NSW, which is described in more detail below. Unfortunately there is no long term operational experience from this plant yet. However, thorough due diligence studies were carried out on behalf of EarthPower and its debt and equity partners and commissioning so far appears to be successful. The technology can therefore be considered feasible for Australia.

Another interesting technology currently being developed as a prototype in WA is the DiCOM® process. It has been trialled on a number of substrates including the putrescible component of municipal solid waste (MSW) and poultry manure.

The DiCOM® process has been developed over the last 5 years by Organic Resource Technologies Ltd (ORT) in Western Australia. It involves an innovative hybrid biological process that integrates both aerobic and anaerobic digestion in a single vessel to produce biogas and compost products from putrescible wastes.

In MSW applications, DiCOM® can be applied to a sequencing batch system of operation to provide for continuous bioconversion of the organic fraction of the waste stream. This is achieved using 3 processing vessels that each require 5 days for loading to match the Monday to Friday typical Council waste collection cycle, followed by 14 days of biological treatment. The nominal overall process cycle time is therefore only 19 days.

The waste material remains in the vessel throughout the treatment process and the resulting pasteurised compost does not require further maturation or biological processing.

The biogas (carbon dioxide and methane) produced in the anaerobic digestion phase of the process can be combusted in gas engines or turbines to produce electricity, or to provide heat to meet plant needs and/or used to dry the compost into pelletised form for sale.

Claimed advantages of the DiCOM® process include:

- Full bioconversion with reduced conversion time and cost;
- Significant cost effectiveness over existing in-vessel processes;
- Improved productivity and environmental performance;
- Flexibility in treating a variety of organic wastes such as food and animal wastes, industrial and waste water sludges; and
- Small footprint requirements making it suitable for location in populated areas (the source of the waste).

The cost for processing wastes using anaerobic digestion has been estimated to be between $70 - $150 per tonne of waste input (NSW State Government, 2000). However, the cost of processing wastes using new ORT technology has been estimated to be considerably less than for conventional digestion due to lower capital and operating costs, of the order of $55 per tonne.

7.4 Energy generation

Biogas can be used to fuel co-generation units (combined heat and power units, CHP) and produce energy in the form of electricity and heat that can be used at the meat facility. Energy generation rates of 300kWh/t of animal by-products processed have been reported. This represents a methane production of 400m^3/h (European IPPC Bureau, 2002).

Along with the generation of energy or heat which can be used at the meat facility, anaerobic digestion of solid wastes has environmental benefits including:

- Production of fertiliser (digested waste or composted digested waste);
- Production of CO_2-neutral energy; and
- Reduction of odour emissions compared to many other traditional waste management practices, e.g. direct composting.

Biogas plants using animal manure and other small amounts of other solid meat wastes are in operation in Europe as are plants processing household wastes and sewage sludges (ref. Sections 7.5 and 7.6 for further details and some examples). Table 14 shows actual and estimated figures for energy, heat, and economic data from biogas plants used to power CHP units in Denmark.

Table 14 Biogas Use at Danish Farms

Manure m^3/yr	Fat containing waste m^3/yr	Biogas produced (or anticipated) m^3/yr	Electricity produced MWh/yr	Heat produced MWh//yr	Electricity saved on site MWh/yr	Heating oil saved on site MWh/yr	Straw saved t/yr
14,600	750	750,000	1,400	1,960	543	178	
10,950	550	520,000	1,430	1,716	300	80	
4,380	550	350,000	1,000	1,200	150		125
23,000	800	1,000,000	2,600	3,120	430	120	
9,125	850	750,000	1,650	2,310	278		
6,570	550	536,100	1,533	1,840	157		
12,000	900	831,420	2,377	28,533	324	72	40

(European IPPC Bureau, 2002)

7.5 Technology suppliers

7.5.1 Overview

Suppliers of this technology are listed below.

Table 15 Suppliers of anaerobic digestion systems

Company	Contact Details	Product
BTA Biotechnische Abfallverwertung GmbH & Co. KG	Rottmannstr.18 D-80333 München Germany T: +49 (0)89 52 04 60-6 Fax: +49 (0)89 523 23 29 email: post@bta-technologie.de www.bta-technologie.de	Anaerobic digestion systems for the treatment of solid domestic, municipal, industrial and agricultural waste
Valorga International SAS	Parc du Millénaire – 1300 avenue Albert Einstein - BP 51 F-34935 Montpellier Cedex 09 France T: +33 (0)4 67 99 41 00 Fax : +33 (0)4 67 99 41 01 www.steinmuller-valorga.fr	Anaerobic digestion systems for the treatment of solid domestic and municipal waste
HAASE Energietechnik AG	Gadelander Strasse 172 D-24531 Neumuenster Germany T: +49 (0)4321 878-0 Fax: +49 (0)4321 878-29 www.haase-energietechnik.de	Anaerobic digestion systems for the treatment of biomass and organic residues

7.5.2 BTA process

(Source: BTA website)

BTA GmbH & Co. KG has developed and continuously improved the BTA process since 1984, is holding various patents and is worldwide realising BTA plants or parts thereof together with its licensees and co-operation partners. BTA undertakes engineering work and plant construction.

7.5.2.1 General description

The BTA-Process was developed to transform biowaste (OFMSW organic fraction of municipal solid waste) from households, commercial and agricultural waste into high-grade biogas and valuable compost. For example the following feedstock can be used:

- Organic components of municipal solid waste (mixed waste);
- Source separated organic waste from households (e.g. kitchen leftovers);
- Food waste from restaurants, canteens and markets;
- Waste from food processing industries;
- Waste from slaughterhouses (e.g. rumen content);
- Waste from agriculture (e.g. manure);
- Sewage sludge and screenings from sewage plants; and

- Residual waste[6].

The general results of the BTA process are:

- Substantial waste volume reduction;
- Environmentally benign treatment of waste;
- Maximum energy recovery;
- Reduction of CO_2-emissions; and
- Production of high grade compost

The process consists of two major steps: Mechanical wet pre-treatment and biological conversion. Detailed description is shown in Appendix A.

7.5.3 Valorga process

(Source: Valorga International website)

Valorga International SAS is the successor of Steinmüller Valorga SARL. On March 2003, Valorga International has treated more than 2 million tonnes of household waste. The system has been successfully developed from pilot to full scale as follows:

1982: 5 m³ pilot plant in Montpellier (France) for attempts of anaerobic digestion on the organic fraction of the household refuse and the mixture of substrata (liquid manures + household waste).

1986-1987: 50 m³ pilot plant in Vannes (France) for attempts of anaerobic digestion of mixture of substrata (organic fraction of the household waste, liquids manure, purification sludge).

1984-1990: 500 m³ pilot plant in La Buisse (near Grenoble - France) for the treatment of 8,000 tons by year of household waste.

1988: 250 m³ pilot plant in the University of Liège in Belgium treating a mixture of straw compost and liquid manures.

1987: Construction of the first full scale plant, starting up in August, 1988. First plant worldwide for the treatment of household waste by continuous anaerobic digestion with a high content of dry material, in Amiens (France), handling the totality of the household waste of this municipality, is 55,000 tons a year. Since the end of 1994, the treatment is widened to the household waste of the city of Abbeville, what carries the annual tonnage treated to 70,000 tons a year. This plant constitutes the first industrial reference of the process Valorga.

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[6] Environmentally responsible deposition of residual waste requires reducing the organic portion of the waste so that no further chemical or biological reaction is likely to occur in the landfill. This can be achieved by using the BTA-Process.

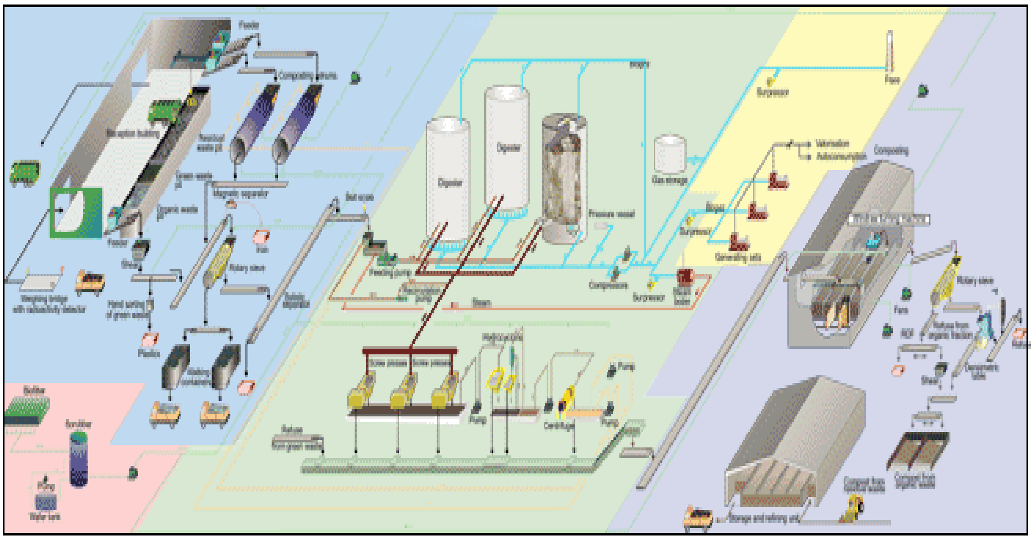


Figure 6 Valorga Process

The Valorga process was designed to treat organic solid waste. It is thus adapted to the treatment of mixed municipal solid waste, source sorted household waste (biowaste), organic residual fraction after biowaste collection (grey waste).

In the case of a mixed collection, anaerobic digestion is performed after a sorting unit that separates the organic material (fermentable matter, paper and cardboard) from the non-digestible material. The remaining fraction can undergo a specific treatment, i.e. plastics incineration.

An installation for treatment of organic waste according to the Valorga process is made up of a unit for the reception and the preparation of waste, an anaerobic digestion unit, a compost production unit, a biogas utilisation unit, an air treatment unit and optional, an excess-water treatment unit. A detailed description is shown in Appendix C.

A list of Valorga International's plants in operation and under construction is shown in Table 16.

7.6 Operational Sites

7.6.1 Earthpower - Biomass Facility, Camellia, NSW

(Source: EarthPower Technologies Sydney Pty Ltd website).

This $30 million plant utilises an anaerobic digestion process from BTA (Germany) to produce biogas. The biogas is combusted in a CHP plant (gas engines/generators) to produce around 3.5 MW of green electricity that is sold into the grid and around 6 MW of heat. Residual solids are converted into high-grade liquid and solid organic fertiliser.

The facility will have a capacity of 100,000 tonnes per annum of segregated solid and liquid organic wastes of all types derived from food and food processing activities. This definition includes all source segregated foods and putrescible organic materials produced across the range of domestic, commercial and industrial food preparation, processing and consumer activities, such as raw, cooked or processed animal (meat, fish, animal wastes) and vegetable (fruits, vegetables, cereals, edible oils, fats and greases) derived wastes.

A general process flow diagram of the process is shown in Figure 7.

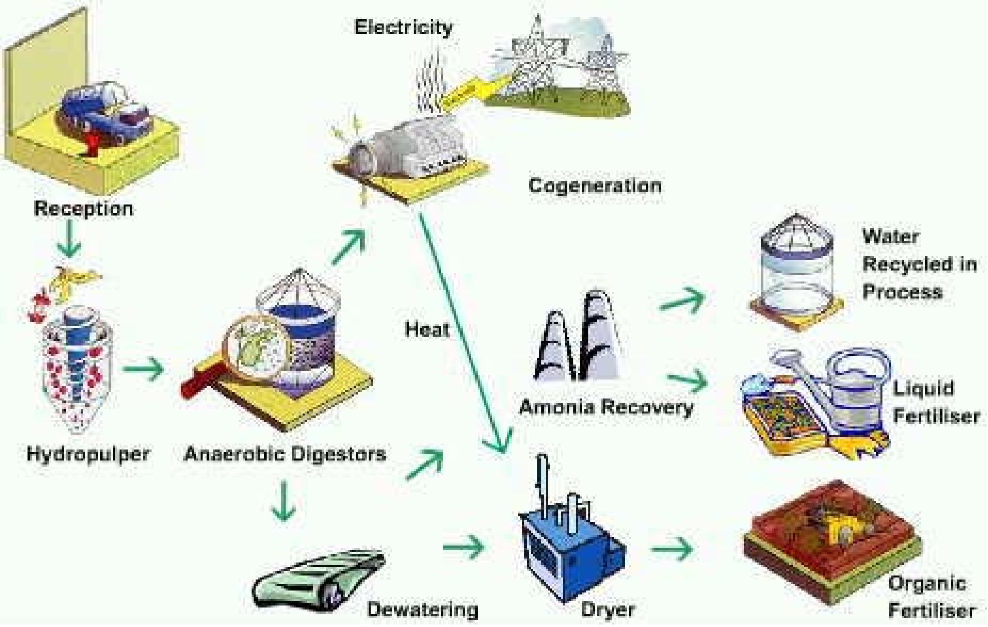


Figure 7 Process flow diagram of the Earthpower plant, Camellia

(Source: Earthpower, www.earthpower.com.au)

Using the green power produced in the plant avoids the use of power produced from other non-renewable resources such as brown and black coal and natural gas. The production of the organic fertiliser allows the displacement of nitrogen and phosphorous conventionally produced from chemical or petrochemical sources in industrial processes that utilise non-renewable sources of energy supply.

In addition, transporting the food and wastes to Camellia will typically require less transport fuels when treated there, because of the shorter distances from source to disposal, when compared to tips. According to the EarthPower website (www.earthpower.com.au) all these factors lead to significant greenhouse gas savings, which can be summarised as follows:

Landfill avoidance	75,150 t/a CO_2 equivalent
Replacement of conventional electric power by green energy	30,150 t/a CO_2 equivalent
Transport savings	310 t/a CO_2 equivalent
Inorganic fertiliser replacement	420 t/a CO_2 equivalent
Total	106,030 t/a CO_2 equivalent

Commissioning of this facility has begun with first deliveries of food wastes during December 2002. Regular waste deliveries are currently being received from a variety of liquid and solid food waste producers and solid wastes will be ramped up to full production by August 2003.

7.6.2 HAASE Energietechnik installations

(Source: HAASE Energietechnik website)

Schwanebeck Co-Fermentation Plant, Germany
The Schwanebeck Co-Fermentation Plant currently processes a total of 40,000 cubic metres of pig manure and 10,000 tons of biowaste per year. The energy potential of the biogas is used to generate heat and electricity in a cogeneration plant.

There is sufficient heat and electricity to power all the installations on site. Excess energy is sold to local utility companies.

Groeden Biogas Plant (Brandenburg/Germany)
The biogas plant at Groeden was commissioned in 1995, and since that date it has been producing 10,000m3/day of biogas, this comes from a feedstock of 110,000 tonnes of raw material annually.

Raw material is made up of 75% pig and cattle manure, the remaining 25% is biowaste, sewage, sludge, earth and food waste.

Biogas is converted to electrical and thermal energy in a CHP plant. 17% of the electricity energy produced is enough to power the plant, the remaining power is sold to external users. Heat is used throughout the plant for warming buildings and the biomass. The solid residues from the process are sold as compost or deposited in a landfill.

Table 16 Valorga Reference Installations

Location	Country	Capacity t/yr	Volume ML	Date	Waste	% TS	% VS	HRT (d)	Gas Nm^3/tVS	CH_4 $Nm^{3/}/tVS$	Biogas Use (MW)
Amiens	France	85,000	2 x 2.4 1 x 3.5	1988 1996	MSW	60	63	18-22	140-160	220-250	5.5 Elec
Bacelone	Spain	120,000	3 x 4.5	Expected 2003	MSW	42	58	25	114	260	Elec
Bassano	Italy	44,200 8,200 3,000	3 x 2.4	Expected 2003	MSW BW SL	62	31	31	129	270	Elec
Cadiz	Spain	210,000	4 x 4	2001	MSW	-	-	23	145	220-250	Elec Heat
Engle	Germany	35,000	2 x 3	1998	KW GW	36	70	25	100-110	240-260	940 HWE
Frieberg	Germany	36,000	1 x 4	1999	KW GW	-	-	25	110-120	280	Elec HWE
Geneva	Switzerland	10,000	1 x 1.3	2000	KW GW	-	-	24	110-120	280	Elec HWE
La Coruna	Spain	182,500	4 x 4.5	2001	MSW	-	-	10-20	130-150	250-270	5 x 1.25 heat
Mons	Belgium	23,000 35,700	2 x 3.8	2002	MSW BW	-	-	25	110-120	280	
Tilberg	The Netherlands	52,000	2 x 3.3	1994	MSW	46	45	20	80-85	220-230	biogas
Varennes	France	100,000	2x 4.2 1 x 4.5	2002	MSW BW	-	-	25	154	245	

BW – biowaste; GW – green waste; KW – kitchen waste; MSW – municipal solid waste; SL – sludge

7.6.3 Industrial Slaughterhouse in Israel

(Source: Migal Galilee Technology Centre)

Anaerobic digestion of meat wastes containing intestinal content, blood, urine and animal manure was carried out in thermophilic conditions (temperature range of 50 – 60°C) to examine the ability of the process to deal with high COD loading and with pathogenic microorganisms such as Salmonella and coliform.

Generated biogas was used on-site to generate hot water and the solid residue from the process was used as fertilizer.

Figure 8 Anaerobic Methaogenic Thermophilic Digestion Unit

(Migal Galilee Technology Centre)

8. Thermochemical processes

A variety of thermochemical processes have been developed for the treatment of organic wastes such as municipal bio wastes and sewage sludge.. In comparison with biogas production from anaerobic digestion, which utilises biological processes at close to normal ambient conditions, thermochemical processes utilise physical-chemical effects at elevated temperatures (and sometimes elevated pressures) to carry out the conversion. .

The following thermochemical processes have been assessed herein:

- Thermal hydrolysis;
- Thermal pressure hydrolysis;
- Gasification and pyrolysis; and
- Thermal depolymerisation.

8.1 Thermal hydrolysis

This process is based on the scientific principle that the chemical reactions that lead to the formation of organic macromolecules, such as fats, proteins and carbohydrates, are reversible reactions and can therefore go either way. Depending on the ambient conditions under which these reactions takes place, these macromolecules are either preferably produced or destroyed. Water is the by-production of the production of those molecules; if the reaction is reversed, water is therefore consumed (hydrolysis).

For all organic matter, the chemical equilibrium at normal ambient conditions is on the side of the products (otherwise living organisms could not exist). At high temperatures and pressures however, the equilibrium is reversed and is on the side of the basic components.

For example fats consists of glycerin, a C3 molecule with 3 alcohol groups (-OH), one at each C-atom, and fatty acids. When fats are formed, each alcohol group reacts with a fatty acid molecule such that the acid connects to the respective C-atom of the glycerin via an O-bridge, thereby releasing one water molecule (ester-formation). When this reaction is reversed, the ester is hydrolysed and the fat molecule is disassembled into glycerin and fatty acids. In a similar way, carbohydrates such as starch are hydrolysed into mono-, di- and oligo-saccharides (depending on reaction conditions and retention times) and proteins are hydrolysed into aminoacids via poly- and oligo-peptides.

Due to the underlying principle of this process, thermal hydrolysis is best carried out with wet waste.Hydrolysis of organic matter can be carried out at high temperature and pressure or at lower temperature and ambient pressure under addition of a base or an acid (in the case of fat hydrolysis, cooking under addition of a base leads to formation of soap). In order to provide water for the hydrolysis, higher temperatures, which lead to increased reaction rates, require higher pressure to maintain a liquid phase; the pressure is thus coupled to the temperature.

Typical operating temperatures are in the range of 150 to 250 °C. Not maintaining the liquid phase basically leads to steam cracking, which is a different process and leads to different products.

8.1.1 Process description

Very few thermal hydrolysis plants are operating commercially. One of the technology providers, which has a good description of its process, and a number of plants operating worldwide, is the Norwegian company Cambi AS.

In Cambi 's patented hydrolysis plant, waste or sludge is cooked under high pressure and temperature (133 – 200 °C). The organic components in the sludge dissolve in water as the cell structures in the substrate break open under the temperature and pressure used. Energy rich compounds from the cells are then dissolved. Cambi's solution is based on a heat treatment of the waste, without the addition of air (anaerobic process), so that the most easily degradable substances dissolve in water and are not oxidised.

The liquid phase is used for the production of biogas or as a carbon source for a biological wastewater treatment plant. Alternatively, the entire waste mass can go through a digestion process after hydrolysis in order to produce a maximum amount of biogas prior to dewatering and post-treatment of the compost (if the latter is desired).

The hydrolysis process creates large amounts of dissolved organic compounds including organic acids, which are effectively broken down into biogas in a digester. Compared to conventional processes for activated sludge, there is up to a 100% increase in the amount of biogas produced. As much as 55-60% of the organic material is converted to biogas. This increase in energy production is significantly larger than the energy consumption needed in the hydrolysis process, so the process provides a considerable energy surplus. The biogas can be burned in a combined heat and power installation in order to produce as much electricity as possible. The excess heat from this installation is almost sufficient to supply the hydrolysis with required heat energy.

Due to pre dewatering and viscosity change in the hydrolysis the digester can be loaded with a sludge concentration of 8-12% dry solids (DS). The speed of digestion is also considerably increased. Together these factors improve the digester capacity 2-3 times.

For sewage sludge, the dewatering properties after the hydrolysis process are up to 100% improved. A dry solids content of sludge over 30% for biosludge can be achieved without problems. This gives a considerable reduction in the mass and there is often no need for drying the sludge before it is transported, dispersed or burned. If drying is still necessary, both investment requirement and energy cost will be significantly reduced.

Low volume of reject water in the reject from final dewatering after digestion combined with high concentrations allow a separate treatment and recycling of nutrients.

Pathogens, such as intestinal bacteria and spores are effectively eliminated through the sterilization process.

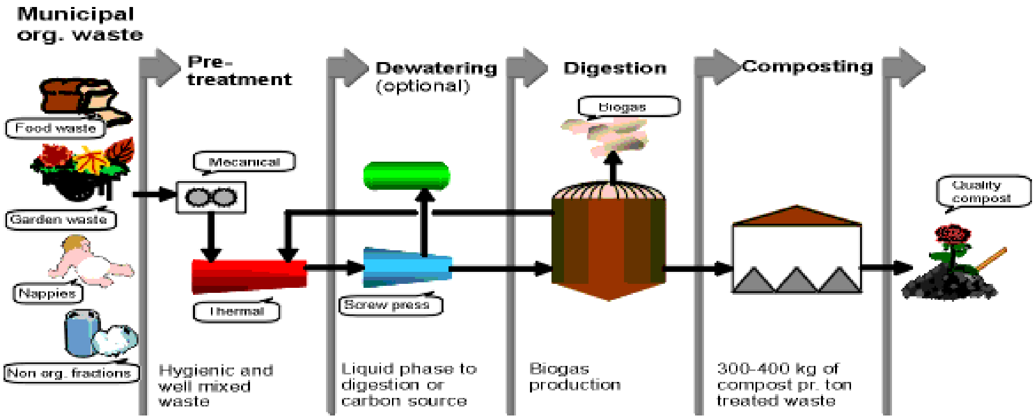


Figure 9 Example for a biowaste treatment process

(Source: Cambi website)

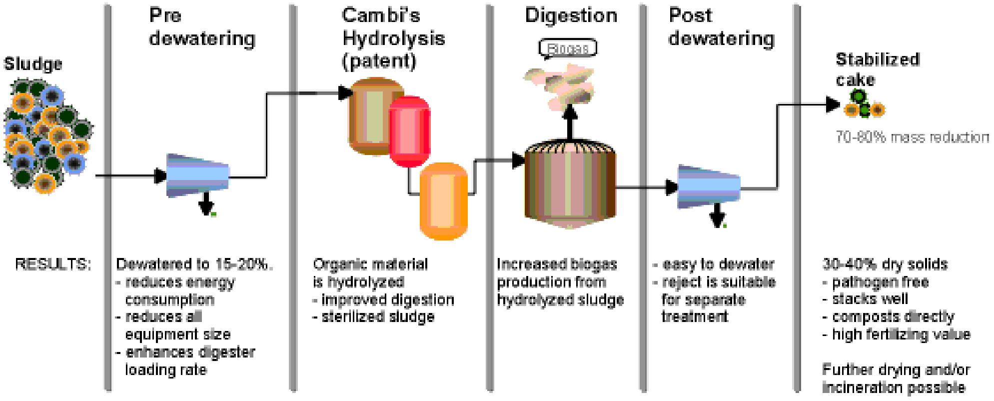


Figure 10 Example for a sewage sludge treatment process

(Source: Cambi website)

8.1.2 Feasibility for processing of meat wastes in Australia

In a review of two Cambi plants installed on municipal WWTPs in Denmark, Evans comes to the following conclusions (from Cambi website):

> *Denmark has taken a very positive view of recovering energy from organic wastes by anaerobic digestion (AD) and then using the digestate (digested material) on land. Substituting CHP (combined heat and power) from AD for fossil energy is part of the national energy plan. Co-digestion of manure, putrescible waste and biosolids is becoming increasingly common. Part of the reason for digesting manure is so that it can be transferred from areas of intensive animal production to arable farming areas.*
>
> *Two wastewater treatment works in Denmark, at which thermal hydrolysis has been retrofitted before mesophilic anaerobic digestion, were studied. The older of*

> *these was commission in May 2000. Biogas production (and solids destruction) at both has doubled, the dewaterability has increased enormously and the odor from the Class-A EQ biosolids was negligible. Even though one of the thermal hydrolysis plants was close to houses there was no odor problem. The H2S content of the biogas decreased after thermal hydrolysis was commissioned (because the pH of the digester contents increased); this has reduced maintenance on CHP engines. Electricity generation increased such that income from "green" electricity became a significant contribution to the budgets.*
>
> *Both works reported that the thermal hydrolysis plants have been very reliable and have experienced no breakdowns. The smaller of the works operates 24/7 but is only staffed 8/5. Outside these hours (and days) alarms and condition monitoring are dialed out to the mobile phone-linked laptop computer of the standby person who can assess whether the condition can be controlled remotely or whether attendance on site is required.*
>
> *In both cases sludges that were difficult and expensive to dispose have been transformed into biosolids whose values are appreciated by those who receive them for recycling. Costs have been reduced dramatically and payback has been rapid.*

From a general engineering perspective it appears that the process is suited for the treatment of meat industry waste. Although the technology has not yet been applied to this type of waste in particular, the supplier appears to have a good understanding for the application of this technology not only for sewage sludge but also for organic waste. Installation of an anaerobic digester to produce biogas is recommended, typically including on site gas utilisation.

A draw back is that there still remains enough organic matter to warrant the production of compost. Although the quantity of this residue will be significantly reduced compared to the raw waste quantity, this could be an issue if relatively cheap disposal options, such as composting, cannot be realised (e.g. due to legislation or public perception after a BSE incident). The cost of processing municipal biowaste in Lillehammer Norway using this process is expected to be of the order of 50 Eros per tonne ($A90/tonne), according to a paper by Weisz..

8.1.3 Technology supplier

Cambi AS

Solbraaveien 10
N-1383 Asker
Norway
Tel: +47 66 77 98 00
Fax: +47 66 77 98 20
http:// www.cambi.com

8.1.4 Operational sites

(Source: Cambi website)

8.1.4.1 Treatment of municipal biowaste

The Mjøsanlegget plant in Norway is used to process 14,000 t/year of municipal biowaste. The plant treats (source separated) wastes such as food waste, nappies, wet paper, and some garden wastes, which are prohibited from being disposed of to landfill, and that are difficult to process using large scale composting plants.

The plant produces a liquid carbon source that is used at a nearby wastewater treatment plant, as well as high quality compost, and biogas that is used for electricity production. Pictures of the plant are shown in Figure 11 and Figure 12.

Figure 11 Storage for liquid carbon source and digester

Figure 12 Exterior of the finished plant

8.1.4.2 Sludge treatment

Cambi sludge treatment plants in place throughout the world are listed in Table 17.

Table 17 Cambi sludge treatment plants

Location:	Niigata, Japan (test plant)
Delivered:	2002, commissioning and evaluation in 2003
Capacity:	1,200 tons DS/year
Sludge type:	Municipal, mixed primary, secondary
Biogas utilisation:	Existing (test plant)
Biosolids utilisation:	Existing (test plant)
Location:	Fredericia, Denmark
Delivered:	2002
Capacity:	8,000 tons DS/year
Sludge type:	Municipal and industrial waste activated sludge
Biogas utilisation:	CHP, (Electricity, and process/plant heating)
Biosolids utilisation:	Dewatered cake for agriculture purposes
Location:	Black & Veatch/Patterson Candy Ltd., Dublin, Ireland
Delivered:	2002 (Simon Hartley Cambi Ltd.)
Capacity:	36,000 tons DS/year
Sludge type:	Municipal, mixed primary, secondary
Biogas utilisation:	CHP, (Electricity, and process/plant heating)
Biosolids utilisation:	Dried granules for agriculture

Location:	NOSES, Aberdeen, Scotland
Delivered:	2001 (Simon Hartley Cambi Ltd.)
Capacity:	16,500 tons DS/year
Sludge type:	Municipal, mixed primary, secondary
Biogas utilisation:	CHP, (Electricity, and process/plant heating)
Biosolids utilisation:	Dewatered cake to agriculture
Location:	Næstved, Denmark
Delivered:	2000
Capacity:	1,600 tons DS/year
Sludge type:	Municipal, waste activated sludge
Biogas utilisation:	CHP, (Electricity, and process/plant heating)
Biosolids utilisation:	Dewatered cake to composting
Location:	Thames Water, Chertsey, England
Delivered:	1999 (Simon Hartley Cambi Ltd.)
Capacity:	8,000 tons DS/year
Sludge type:	Municipal, mixed primary, secondary
Biogas utilisation:	Process heating, CHP planned
Biosolids utilisation:	Wet product to agriculture, dewatering planned

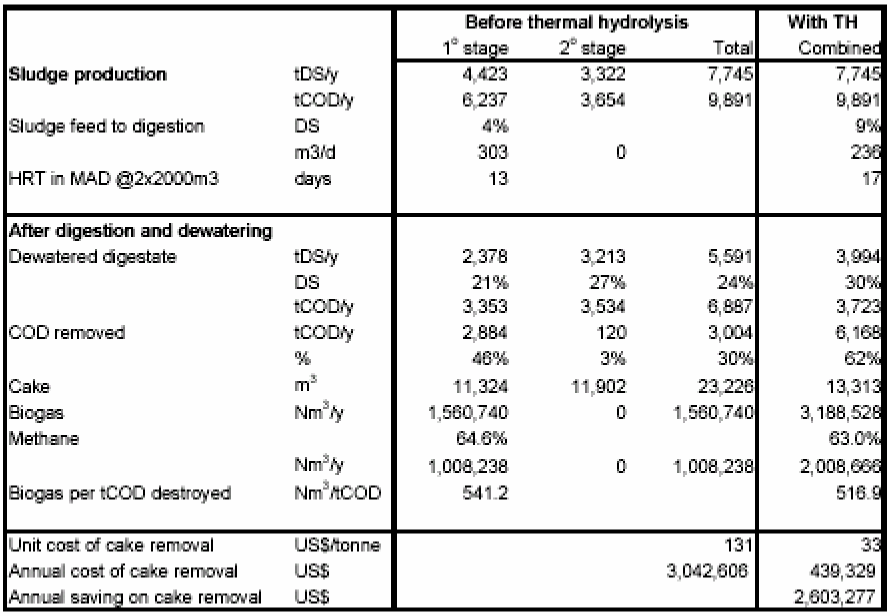
Figure 13 Cambi Thermal Hydrolysis Plant, Dublin

(source: Cambi)

An independent review of the Cambi thermal hydrolysis process has been carried out to determine the effect of the process of digestibility, biosolids quality, energy recovery, pathogen reduction, dewaterability, and the market for beneficial use of end products. The review, carried out by Tim Evans Environment, examined the sludge production process at the Fredericia wastewater treatment plant in Denmark. This treatment plant processes wastewater from dairies, breweries, other food industries, refineries, and a fertiliser factory. The population serviced by the facility is approximately 50,000, however the total load is 350,000 population equivalent (Evans, 2002).

The review found that processing sludge through the thermal hydrolysis unit prior to digestion resulted in greater solids destruction in the digesters allowing for better dewatering of the remaining biosolids, and a smaller volume of dewatered cake. An additional benefit of the process was a doubling in biogas production. The results presented by Evans are shown in Table 18. They show the use of hydrolysis as a pre-treatment process prior to digestion resulted in significant cost savings due to decreased waste disposal costs and increased biogas production.

Table 18 Comparison of performance indicators before and after implementing thermal hydrolysis at Frederica waste water treatment plant



		Before thermal hydrolysis			With TH
		1° stage	2° stage	Total	Combined
Sludge production	tDS/y	4,423	3,322	7,745	7,745
	tCOD/y	6,237	3,654	9,891	9,891
Sludge feed to digestion	DS	4%			9%
	m3/d	303	0		236
HRT in MAD @2x2000m3	days	13			17
After digestion and dewatering					
Dewatered digestate	tDS/y	2,378	3,213	5,591	3,994
	DS	21%	27%	24%	30%
	tCOD/y	3,353	3,534	6,887	3,723
COD removed	tCOD/y	2,884	120	3,004	6,168
	%	46%	3%	30%	62%
Cake	m^3	11,324	11,902	23,226	13,313
Biogas	Nm^3/y	1,560,740	0	1,560,740	3,188,528
Methane		64.6%			63.0%
	Nm^3/y	1,008,238	0	1,008,238	2,008,666
Biogas per tCOD destroyed	Nm^3/tCOD	541.2			516.9
Unit cost of cake removal	US$/tonne			131	33
Annual cost of cake removal	US$			3,042,606	439,329
Annual saving on cake removal	US$				2,603,277

8.2 Thermal-Pressure-Hydrolysis – TPH process

(Source: Prechtl)

8.2.1 Process description

This process utilises the same principles as the Cambi process, however it differs from it in some points, mainly in that it is a continuous process and that it applies higher temperatures (200 - 230 °C, 20 – 30 bar pressure). According to the technology supplier, the higher temperatures offer the advantage of better fat and protein destruction which reduces potential foaming problems in the digester.

The process can basically accept all waste as feed stock and the required pre-treatment is limited to grinding to particle size <50 mm. Existing logistics, buildings and processes of rendering plants can be used for delivery and crushing of the animal by-products.

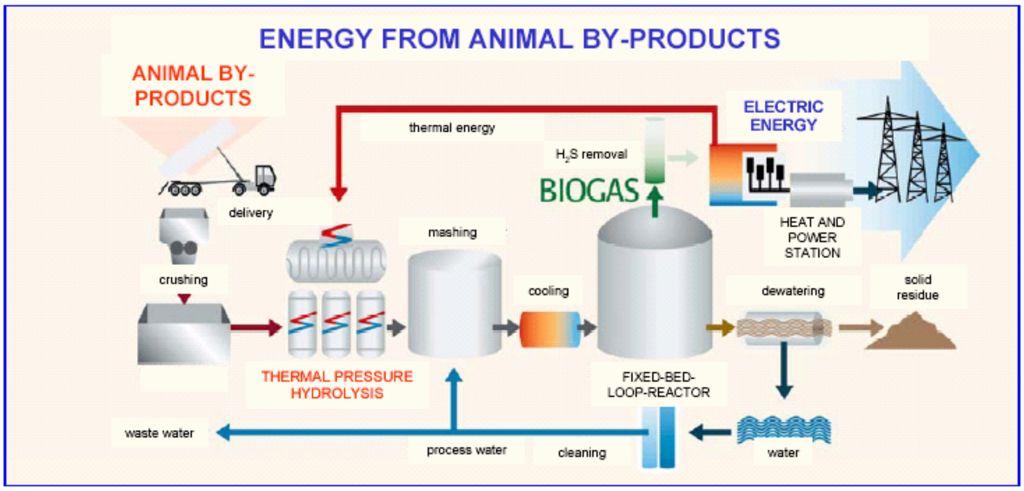


Figure 14 Process combination TPH and digestion of animal byproducts

The TPH product is a virtually solids free (depending on content of inorganic solids) hydrolysate with a COD of 100,000 to >200,000 mg/L.

After mixing with process water, the hydrolysate is converted into biogas in a fixed-bed loop-reactor, operating at an organic loading rate of 8 to 12 kg COD/(m^3·d). A microbiological H_2S removal step is integrated to clean the biogas prior to its use in a combined heat and power station, producing an excess of thermal and electric energy for the whole process. The electrical energy can be sold and the thermal energy is partly used for the TPH process and for NH_3-stripping.

Due to the good degradation performance in the anaerobic step the solid residue left after dewatering can be easily dewatered. For meat industry waste, the quantity of the solid residues after digestion are about 20% of the feed stock only. After dewatering, the remaining solid residue and the elemental sulphur from the removal of H_2S from the biogas are also utilised in a thermal process. In a second process step the NH_3 stripped from the process water is catalytically oxidised to nitrogen.

With the exception of the wastewater all products are thermally used. In comparison with the present production of animal meal through rendering which uses fossil fuels, the process combination of TPH and anaerobic digestion appears to be able to produce renewable energy entirely from animal by-products.

Operating results from a pilot plant at a rendering plant (operating as an alternative to the traditional rendering process) are shown in Table 19.

Table 19 Results of the anaerobic treatment of animal byproducts after TPH

COD loading rate	CODtotal reduction	CODdissolved reduction	Methane content	Biogas yield
[kg/m^3*d]	[%]	[%]	[%]	[m^3/t Input]
approx. 10	80 – 90	85 – 93	70 – 77	200 - 300

It has been observed that, the mono-fermentation process is more stable and faster than in conventional fermentation processes after a pre-treatment with the TPH-Process. Biogas yield is in the range of 230 to 270 m^3/t raw material, with a methane content between 70 to 77%.

Using a combined heat and power station with an electric efficiency of 38% it is possible to produce up to 780 kWh from 1,000 kg of raw material. At a unit rate of 0.04 Euro/kWh the corresponding proceeds are about 30 Euro/t.

In contrast to the traditional rendering process producing animal meal, the TPH based process combination needs no energy intensive drying of the raw material. Using energy from the combined heat and power station for sterilisation reduces the thermal power requirements from 500 – 700 kWh/t (traditional rendering plant) to about 200 kWh/t. Therefore it is possible to reduce the operating costs of the plant, based on the current price for natural gas, in the order of 15 Euro/t.

Compared to existing rendering plants the amount of water which needs to be separated decreases because of the process water cycle and the loss of water through the step of NH_3-stripping and biogas production. The excess waste water has a typical composition like a normal waste water from anaerobic waste fermentation plants, with COD concentrations between 4 to 7 kg/m^3 after conditioning.

8.2.2 Feasibility for processing of meat wastes in Australia

The TPH process is not yet as far developed as the thermal hydrolysis process, but it seems to offer some advantages over thermal hydrolysis and other processes such as conventional anaerobic digestion for meat wastes. This is because The main focus for the development of the TPH process was the treatment of meat waste to overcome BSE concerns in Europe.. Also a higher operating temperature is used which is likely to lead to a better BSE destruction and is also likely to minimise the quantity of residual solids that require further treatment.

Whether or not the continuous operation of the TPH process is an advantage will depend on the overall process layout. Overall, the process is therefore considered feasible for meat wastes, but the amount of capital investment required is difficult to define because of the early stage of development of the process and lack of operational plants. Similarly, no unit costs for operation were able to be found.

8.2.3 Technology supplier

ATZ EVUS
Entwicklungszentrum für Verfahrenstechnik
Kropfersrichter Straße 6 – 8
D-92237 Sulzbach-Rosenberg
Germany
Tel: +49 (0) 09661 908-400
Fax: +49 (0) 09661 908-469
http://www.atz-evus.de

8.2.4 Operational sites

ATZ-EVUS has run a pilot plant for the past 2 years, which is installed at a rendering plant in Bavaria for the pre-treatment of animal by-products with a capacity of 1,500 kg/h (maximum) followed by a 70 m^3 biogas reactor.

An order for the design of a 50,000 t/a full scale plant for the treatment of meat waste has already been obtained. This project, as well as the pilot trials, have been subsidised by the Bavarian Government in order to establish a safe alternative to the traditional rendering process whereby the use of MBM etc in animal feed stock is safely avoided. The expected capital cost for this plant (greenfield site) is 10 to 12 million Euro.

8.3 Gasification and pyrolysis

8.3.1 Process principles

Gasification and pyrolysis are quite similar thermochemical technologies. Gasification of coal is a mature technology, and was used throughout the 19th century for producing town gas. However, application of gasification and pyrolysis to wastes is a relatively new development.

Pyrolysis is a thermal process for the degradation of organics with little or no oxygen present. The end product is a gas mixture containing hydrogen, methane and carbon monoxide. An oily liquid by-product may also be produced. Gasification converts hydrocarbon material into lighter gaseous compounds in a thermal reaction with steam and oxygen. The end product is a fuel gas composed of hydrogen, carbon monoxide and carbon dioxide.

These processes operate at higher temperatures than thermal hydrolysis processes (between 350 and 2,000°C), not necessarily under pressure as maintaining a liquid water phase is not necessary for these processes.

Due to the much harsher conditions under which these processes are carried out, destruction of organic matter goes much further than that achieved with thermal hydrolysis. Depending on the operating conditions, a great quantity of the solid organic matter is thus converted into gaseous matter, forming basic molecules such as CO, NH_3, H_2S, H_2O, etc.

Historically, gasification and pyrolysis processes have been widely used in a large variety of industrial and municipal applications for the production of syngas as a raw product for the chemical industry or as a fuel. The selection of processes / technologies discussed herein can therefore by no means be considered complete but only a selection of processes that appeared to be most relevant for the treatment of solid waste from the meat industry.

8.3.1.1 Gasification

Biomass gasification is a process in which heat and a gasifying agent, such as air, steam or oxygen, are applied to solid biomass to transform the solid into a gaseous fuel, referred to as ‘syngas’ (SEDA, 1999). The gas can then be burned as a fuel in boilers, internal combustion engines or gas turbines (Nolan-ITU, 1999).

There is limited information on the composition of syngas produced from gasification of various types of animal waste, however data for gasification of meat bone meal (MBM) from rendering plants has been reported. The typical chemical composition of a syngas produced from the gasification of MBM with a moisture content of approximately 3-5% is shown in Table 20.

Table 20 Typical chemical composition of syngas produced from MBM

Chemical Composition	%
CO	18 – 24
H_2	15 – 22
CO_2	10 – 14
CH_4	1 – 4
N_2	45

(European IPPC Bureau, 2002)

Gasification with air produces a low-energy syngas, with a heating value about one-fifth that of natural gas. Indirectly heated gasification and oxygen-blown gasification produces a medium-energy syngas, with heating values as high as half that of natural gas. Gasification is possible with a number of substrates with varying properties, but feedstocks with a higher moisture and ash content will give a syngas with lower heating value. This is due to the fact that part of the heat released during partial combustion in the gasifier is needed to evaporate the water (SEDA, 1999).

As well as the useful heating value of the syngas, the gas can potentially be used as an input feedstock methanol and ethanol. Syngas from the gasification of animal waste (manure) has been studied to assess its suitability as a feedstock for ethanol production. Koger et al (2002) report that depending on the type of catalyst used, ethanol production from one tonne of pig waste can range between 350 to 800 litres. This technology however is yet to be proven on a commercial scale.

8.3.1.2 Pyrolysis

Pyrolysis is the destructive distillation of biomass in the absence of air. The process involves heating the waste (between 400 °C to 900 °C) in the absence of oxygen and under pressure, to produce a liquid hydrocarbon (term ‘pyrolysis oil’), a gas, and a solid char. The process can be varied to favour the production of either of the products. A “fast” pyrolysis process favours production of oil (up to 80% of the weight of the dry feed), this oil has an energy content of approximately 17 MJ/kg, which is about half the energy value of conventional fuels (SEDA, 1999).

Figure 15 Pyrolysis system for municipal and industrial wastes at Honmoku Factory in Yokohama, Japan

(Japanese Advanced Environmental Equipment)

8.3.2 Overview of gasification/pyrolysis waste treatment technologies

Pyrolysis/gasification systems operating around the world are typically centralised facilities that collect wastes from different sources. Gasification/pyrolysis may be suitable technologies for conversion to energy of abattoir solid and liquid wastes, but it is likely that such facilities would be centralised and would receive both wet and dry feedstocks from a number of sources. The sources of waste would need to be mixed and dried to achieve the required moisture content.

Gasification/pyrolysis process descriptions vary for different specific technologies and are generally patented.

Numerous gasification/pyrolysis systems are in operation throughout the world particularly in Europe, the US and Japan for the treatment of municipal solid wastes. There are many proprietors of gasification/pyrolysis systems and some of the major companies are listed below. These companies typically provide design-build-own-operate or design-built-operate options.

8.3.2.1 Brightstar Environmental (SWERF^{TM})

(Source: Brightstar Environmental)

The SWERF process consists of three integrated components, shown in Figure 16:

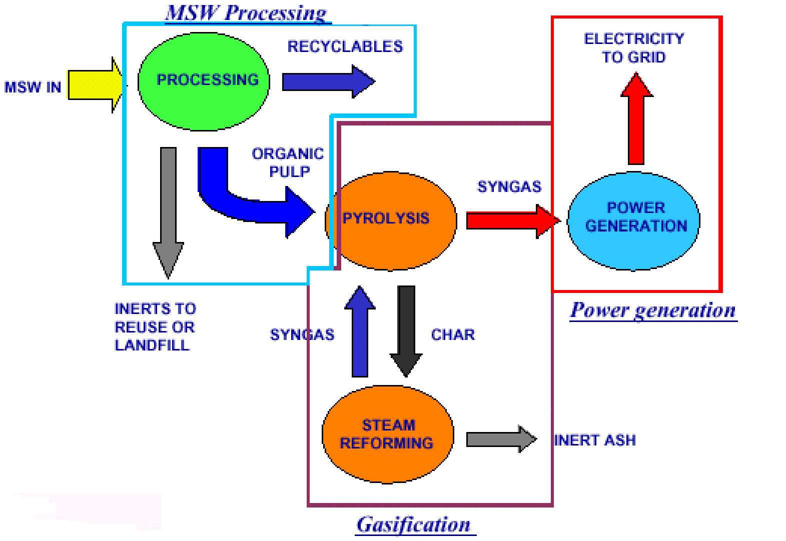


Figure 16   Brightstar Environmental waste to energy process

1. Pre-processing of waste: Pre-processing involves receival of the waste, sterilisation with steam in an autoclave (with heat and pressure) and then mechanical separation. Steel, aluminium and some rigid plastics are recovered for recycling and a pulp is produced from the organic material. The pulp is then washed to remove sand and glass, and dried in preparation for gasification. Sand and glass are further processed for use in a number of beneficial applications.
2. Gasification: The organic pulp is fed into a high temperature gasifier that converts the elements to a gaseous compound consisting mainly of carbon, hydrogen and oxygen. These elements are reformed into a synthesis gas, which is processed to make a clean, dry fuel gas, which is suitable for use with a variety of power generation equipment or as a chemical feedstock.

Figure 17 Conversion to syngas via pyrolysis

3. Electricity generation: The syngas is used to drive highly efficient internal combustion engines to produce renewable electricity that is supplied to the local electricity distribution grid for use in homes and businesses in the same area in which the SWERF plant is located. This plant has recently been closed down temporarily due to complexities of operation.

8.3.2.2 Environmental Solutions International (ESI) (Enersludge^{TM})

(Source: ESI promotional material)

The Enersludge^{TM} process uses a relatively low temperature of 450°C to convert the organics in dried sewage sludge to clean fuels for reuse. The process produces a ‘Bio-oil’ that can be used to produce electricity. Waste gases and char are also produced and are combusted to generate heat to dry the incoming sewage sludge. The plant has been proven at full scale.

8.3.2.3 Compact Power (UK)

Compact Power’s technology uses pyrolysis, gasification and high temperature oxidation to “convert waste to fuel and other usable products e.g. carbon”.

8.3.2.4 Organic Power (Norway)

The process of this Norwegian company uses a combination of gasification and pyrolysis on a small scale.

8.3.3 Technology suppliers

Proprietor	Contact details	System	Operational sites (see description below)
Brightstar Environmental / Energy Developments Limited	848 Boundary Road PO Box 535 Richlands Queensland 4077 Tel: 07 3275 5600	SWERF^{TM} System	Wollongong, NSW
Environmental Solutions Inyternational	21 Teddington Road PO Box 116 Burswood WA 6100 Tel: 08 9470 4004	Enersludge ^{TM}	(Subiaco sewage treatment plant)
Enerkem Technologies Inc Germany	375, de Courcelette, suite 900 Sherbrooke, Québec Canada – J1H 3X4 Tel: (819) 347-1111 http://www.enerkem.com	BIOSYN ^{TM} system	Prototype gasification facility is located in Sherbrooke
Energy Products of Idaho USA (EPI)	4006 Industrial Ave Coeur d'Alene, Idaho USA 83815-8928 Tel: (208) 765-1611 http://www.energyproducts.com	Fluidised bed gasifiers	Not known
Pyrovac International Inc	Groupe Pyrovac 333, rue Franquet Sainte Foy, Québec G1P 4C7 Tel : (418) 652-2298 Fax : (418) 652-2275 http:// www.pyrovac.com	Pyrocycling	Pilot plant in Quebec, Canada

8.3.4 Feasibility for processing of meat wastes in Australia

In Australia, there are very few examples of operational gasification and pyrolysis systems for both solid and liquid wastes. Two established systems in Australia are Brightstar Environmental/ Energy Development's Solid Waste and Energy Recycling Facility or SWERF^{TM} system (gasification) located near Wollongong (NSW) and the Environmental Solutions International (ESI) Enersludge^{TM} system (pyrolysis) at Subiaco (WA). Both have recently been shut down indefinitely due to high operating and maintenance costs and difficulties reaching stable operation.

The Enersludge plant at Subiaco cost $22 million to build, and was designed to process 25 dry t/day of sewage sludge (initially at 2-4% solids content). After taking into consideration the benefit of oil produced from the process, the cost per tonne of dry solids is estimated to have been approximately $90 / dry tonne.

Further investigation is required to determine the feasibility of gasification and pyrolysis for meat waste. No specific examples of meat waste or rendered products such as MBM being used as feedstock for pyrolysis or gasification plants are apparent. However it is likely that MBM, being already relatively homogeneous and dry, would be more suited to these processes than unprocessed meat wastes, particularly those which would normally be sent for rendering.

Gasification and pyrolysis processes are capable of generating 500-600 kWh and 200-400 kWh per tonne of electricity respectively from general waste streams. Net costs per tonne of input for domestic and industrial wastes have been estimated to be between $80 - $170, while the net benefit per tonne of input is estimated to be between $15 - $25 based on direct electricity generation (NSW State Government, 2000).

Like most thermochemical technologies, the capital costs of such facilities are very high requiring a fairly large minimum throughput (~25t/day) for economical operation. This may require the construction of a central facility accepting wastes from a larger number of surrounding meat processors.

8.3.5 Operational sites

The following is a short description of commercially operating gasification/pyrolysis systems.

8.3.5.1 Brightstar Environmental (SWERF^{TM})

(Source: Brightstar Environmental http://www.cleanenergy.org/states/fl/Brightstar.pdf)

Brightstar Environmental has an operating SWERF in Wollongong NSW as shown in Figure 18. The system feedstock is typically municipal solid waste.

The plant has been shut down indefinitely however, as it has been found to be uneconomical under current conditions due to its high operating and maintenance costs.

Figure 18   SWERF plant, Wollongong

8.3.5.2 Environmental Solutions International (ESI) (Enersludge^{TM})

(Source: ESI promotional material)

Environmental Solutions International has built an Enersludge^{TM} facility for the treatment of sewage sludges at Subiaco in Western Australia. The capacity of the plant is 16 t/d DS.

The plant has been shut down indefinitely however, as it has been found to be uneconomical under current conditions due to its high operating and maintenance costs.

8.3.5.3 Enerkem (BIOSYN^{TM}) (Canada)

(source: http://www.enerkem.com/)

Enerkem explains that this technology can be applied to readily available organic residues from diversified sources, such as sorted municipal solid waste (RDF), urban wood, agricultural residues, forest thinnings, sludges, as well as wastes from various industries, such as sawdust and pulp mill residues, spent oils, plastic-rich residues and rubber-containing wastes.

The technology is modular and can be functional at low (1 tonne/h) or large (10 tonnes/h) capacities with high conversion efficiency. Enerkemprovides performance guarantees: a minimum energy efficiency of 70% as well as the gas composition of its Syngas for each specific feedstock.

The Biosyn system involves:

- Pretreatment of the feedstock to produce a dry homogeneous fuel;
- Rapid gasification with air or oxygen enriched air at temperatures varying between 700°C and 900°C to produce a syngas generally comprising nitrogen, carbon dioxide, carbon monoxide and hydrogen; and
- Scrubbing (cleaning) of the syngas to remove light hydrocarbons and tar.

8.3.5.4 Compact Power (UK)

Compact Power runs a commercial plant at Avonmouth near Bristol. The plant consists of two pyrolysis tubes which can process 8,000 tonnes of waste a year. The facility primarily treats clinical wastes and municipal solid wastes. Compact Power also has planning permission to construct other plants in the UK.

8.3.5.5 Organic Power (Norway)

Organic Power currently has eight projects in Scandinavia and South Korea.

8.4 Thermo-depolymerisation and chemical reformer process

The Thermo-Depolymerisation and Chemical Reformer Process, or TDP, is a new technology that is being developed and commercialised in the US by Changing World Technologies (CWT).

The TDP process converts low-value, organic materials into oils, gases and carbon using water, pressure and temperature, followed by rapid decompression and further extreme heating (reforming). The process is said to mimic the natural geological processes that occur deep under the earths crust but in a fraction of the time – hours and days rather than years. CWT was awarded $12 million in grants from the US Government to develop this technology.

To test and refine the technology, CWT established a research & development plant at the Philadelphia (Pennsylvania) Naval Yard in partnership with the Gas Research Institute, which opened in December 1999. There the company successfully applied its thermal conversion process to a range of feedstocks, including animal waste, tyres, mixed plastics and paper.

Where earlier attempts at thermal conversion failed, CWT’s thermal process apparently succeeds in breaking down long chains of organic polymers into their smallest units and reforming them into new combinations to produce clean solid, liquid and gaseous alternative fuels and specialty chemicals.

ConAgra Foods was one of the first enterprises to express early interest in the commercial application of CWT's thermal process. CWT has had a joint venture with ConAgra Foods, Inc. since December 2000 for the first commercial application of the technology for the conversion of poultry offal at one of ConAgra's large Butterball Turkey plants. This plant commenced operation in April 2003.

8.4.1 Technology description

Thermo-depolymerisation (TDP) involves controlling temperature and pressure to break down wastes into different grades of light and heavy oils. The process involves mixing the organic wastes with water and heating the mixture under pressure to a specified reaction temperature. After reaction, the slurry mixture is flashed to release the gaseous products. Further volatiles are separated from solids via a reforming reaction, the residual oil is then heated to separate off moisture and any further gases.

A process schematic provided on the Changing World Technologies website is shown below.

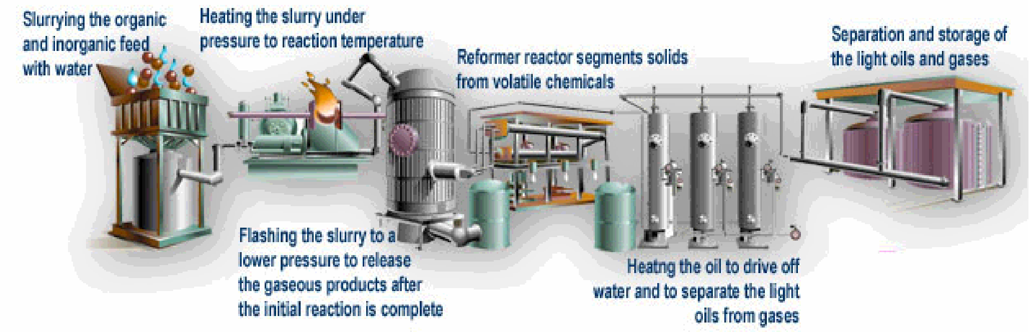


Figure 19 TDP process

According to the CWT website, the process involves five main steps:

- Pulping and slurrying the organic feed with water;
- Heating the slurry under pressure to the desired temperature;
- Flashing the slurry to a lower pressure to separate the mixture;
- Heating the slurry again (coking) to drive off water and produce light hydrocarbons; and.
- Separating the end products.

A number of claims are made by CWT about the energy efficiency and environmental benefits of this technology. For example, it is claimed that TDP is 85% energy efficient. The low energy requirements are said to be due to the short residence times of materials at each stage and to the holding of water under pressure.

In addition, it is said to generate its own energy, utilise recycled water throughout, and use the steam naturally created by the process to heat incoming feedstock, thereby recapturing (some of the) expended energy. In addition, it is claimed that TDP produces no uncontrollable emissions and no secondary hazardous waste streams. Without detailed information these claims are difficult to prove or disprove.

The key differences between TDP and other processes are the:

- Ability of TDP to work with a wet feedstock;
- Ease of separating the products;
- Narrow range of the chemical constituents in the products due to chemical reforming; and
- Low temperatures of the gaseous product.

Widespread application of this process to a range of organic and non organic wastes is envisaged, with reduced US dependence on foreign supplies of fossil fuels seen as one of the major advantages.

8.4.2 Technology suppliers

The TDP technology is owned by Changing World Technologies (CWT) and is being commercialised by their partnering company Renewable Environmental Solutions. Both companies are located in the US.

Contact details for these companies are as follows:

Changing World Technologies	**Renewable Environmental Solutions**
460 Hempstead Avenue	2001 Butterfield Road
West Hempstead, NY 11552	Downers Grove, IL 60515
Tel: 516 486-0100	Tel: 630 512-1000
http://www.changingworldtech.com/	

8.4.3 Feasibility for processing of meat wastes in Australia

Due to the limited amount of technical information available about this process and the experimental nature of the technology, it is difficult to say whether this technology would be feasible for the meat industry in Australia. Currently the technology providers are focusing on developing only large scale production processes.

The cost of producing one barrel of oil via thermal depolymerisation has been estimated to be US$12-15, or approximately $25-30 (The Engineer, 2003). Based on the ConAgra plant (see below), where 200t/day of animal wastes are required to produce 600 barrels/day of oil – the cost of processing the meat waste is therefore estimated to be $90/tonne.

8.4.4 Operational sites

CWT has partnered with ConAgra Foods, Inc., North America's largest foodservice manufacturer and second largest retail food supplier, to build and operate a full scale facility at ConAgra's Butterball turkey processing plant at Carthage, Missouri..

Similar plants are planned for sites throughout the USA and Italy to process wastes including sewage, chicken offal, manure, pork, and cheese wastes.

Figure 20 Inside the first commercial TDP plant in Carthage

(Source: Changing World Technologies)

9. Chemical processes

9.1 Biodiesel production

The use of biodiesel as an alternative to fossil fuels is currently practised throughout the globe. Countries that are currently using biodiesel include; USA, Germany, Italy, France, Austria, Brazil, Canada, Hungary, and The Czech Republic (Australian Renewable Fuels).

Figure 121 Biodiesel Plant in Austria

(Australian Renewable Fuels)

Production of biodiesel from oils is not a new technology - it has been commonly produced using oils from crops such as rapeseed, canola, and soybeans, and from cotton and mustard seeds (Biodiesel Association of Australia). More recently, the production of biodiesel from tallow has been shown to be a commercially viable method of producing valuable energy from what would otherwise be a low value product or waste stream.

Biodiesel made from animal fat has been tested as a fuel in many countries. Results have so far indicate that it can be successfully substituted for other diesel fuels and biodiesel fuels made from vegetable oils, with no affect on performance (Gerpen, 1996 and Marc-IV Consulting, 1998). Biodiesel has the same energy content as diesel, and can be used in a diesel engine without modification (CSIRO, 2002).

Figure 22 Biodiesel storage tanks at facility in Europe

(Australian Renewable Fuels)

Standards for biodiesel have been set in Europe and the USA, however Australian standards for biodiesel are currently still in the process of being set. In Australia, biodiesel is listed as one of the fuels eligible for the fuel rebate (Biodiesel Association of Australia).

The use of tallow as the feedstock for biodiesel processes offers several advantages over the use of vegetable oils:

- Utilisation of a waste stream to generate energy;
- Tallow is non-toxic;
- Lower hydrocarbon emissions compared to biodiesel fuels made from soy, canola and rapeseed (CSIRO, 2002);
- Safer to store and handle compared to petroleum diesel as it has a higher flashpoint (149°C compared to 61°C for diesel); and
- For every one unit of energy needed to produce biodiesel, 3.24 units of energy are gained (Marc-IV Consulting, 1998).

9.1.1 Technology description

There are three basic process options for production of biodiesel from oils and fats (US National Biodiesel Board);

- Base catalysed transesterification of the oil;
- Direct acid catalysed transesterification of the oil; and
- Conversion of the oil to its fatty acids and then to biodiesel.

According to the US National Biodiesel Board, most of the biodiesel produced today is done with the base catalysed reaction as:

- It is a low temperature (60-70^{o}C) and pressure process (20 psi);
- It yields high conversion (98%) with minimal side reactions and reaction time;
- It is a direct conversion to biodiesel with no intermediate compounds; and
- Simple process equipment and chemical reactants are all that is required.

Production of biodiesel occurs by reacting the fat or oil with a short-chained alcohol (usually methanol or ethanol) in the prescence of a catalyst. Products of this reaction are glycerine (which can be purified and sold), unreacted alcohol, and biodiesel. Catalysts are typically sodium hydroxide or potassium hydroxide (Biodiesel Association of Australia). There is little waste generated from the process as any unreacted alcohol can be recycled and glycerine is a marketable product. The ratio of biodiesel produced to input fat reacted is almost 1:1 on a mass basis (as shown below in Figure 23).

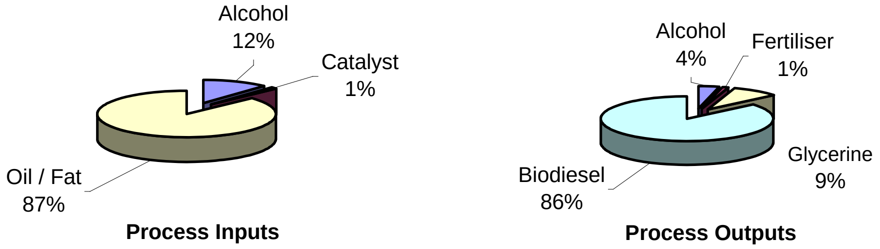


Figure 23 Input and output streams from biodiesel process (weight %)

9.1.2 Feasibility for meat industry

The cost of tallow as a feedstock for the biodiesel production process is lower than the cost of using alternatives such as waste cooking oil or crude soy oil (National Renewable Energy Laboratory 2003, and Rice et al, 1998). Therefore, the production biodiesel using tallow may be more economic than other fat alternatives.

It is estimated that production of biodiesel using waste grease and tallow costs approximately 40c/L compared to production of biodiesel from rapeseed, canola, or soyabeans which can range from 50-60 c/L (Oregon Department of Energy, and Rice et al 1998). This would equate to a cost of over $400/tonne of feedstock oil or fat material[7].

Figures obtained from feasibility studies conducted by GHD in Australia suggest that biodiesel production costs are of the order of 25c to 40c/L excluding the cost of the raw material (eg tallow). The market price for biodiesel is of the order of 90c/L..

The cost of producing biodiesel is still higher than production of mineral diesel, and thus biodiesel products may not be cost competitive with alternative petroleum diesel products unless they are used in fuel blends, or unless government subsidies are provided for renewable fuels. However, a study focusing on the use of biodiesel for buses has shown that biodiesel blends are competitive with natural gas and methanol fuels (Ahouissoussi and Wetzstein, 2002).

Production of biodiesel has been shown to be economically feasible where the production facility is of a large scale (> 800,000 L/year) (adapted from Bennet, 2002). The fact that the commercial biodiesel plants in Australia both have an output of 40 ML/yr or greater suggests that it would not be practicable to establish such facilities at most meat works, and that a number of centralised facilities, which receive raw materials from a number of industries would be more likely to be established.

Renderer AJ Bush is planning to establish a biodiesel production facility at its Bromelton rendering plant in Queensland, which suggests that medium sized facilities are also viable.

Further detailed information on biodiesel production is in Appendix D.

9.1.3 Operational Sites

9.1.3.1 Australian Renewable Fuels Pty Limited

Australian Renewable Fuels Pty Limited is currently constructing Australia’s first commercial scale biodiesel facility in Western Australia. Construction is due to be completed in 2003.

Once operational, the facility will process animal and waste fats using transesterification and esterification processes. The facility will use tallow to produce 40 million litres of biodiesel per annum. It will also produce 6,000 tonnes of raw glycerine and 1,800 tonnes of sulphate of potash fertiliser in paste form. There will reportedly be no effluent to dispose of from the process.

The Australian Renewable Fuels facility is an “off the shelf” plant from the Austrian company Energea that has an identical plant operating in Austria.

9.1.3.2 AJ Bush and Sons

AJ Bush and Sons operate Australia’s largest animal by-products rendering plant at Bromelton in south-east Queensland (Queensland Government). They are intending to develop a biodiesel facility with a planned annual capacity of 60 million litres per annum.

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[7] $400/tonne calculated based on 85% conversion of fats to biodiesel. Density of biodiesel of 0.88 kg/L.

The facility will be co-located with the rendering plant, and tallow from the rendering plant will be used as the primary feedstock to the biodiesel production process.

10. Utilisation of biofuels for energy production

Once a biofuel such as biogas, syngas, pyrolysis oil or biodiesel is produced there are a number of technologies that can be used to convert these fuels into energy. Existing technologies, which are generally restricted to larger installations include:

- Steam boilers;
- Gas turbines; and
- Internal combustion engines.

New and emerging technologies are making smaller scale facilities much more feasible. These technologies include:

- Micro turbines; and
- Fuel Cells.

These technologies are briefly described in Appendix E.

11. Summary of Findings

The scope of this study was to identify and provide information about waste to energy technologies and assess their likely suitability for solid wet wastes generated by the red meat processing industry, as an alternative to current waste management practices such as conversion of edible parts to meat and bone meal for animal feed, and composting of non-edible materials.

One of the aims of this study was to provide a basis for action for the meat industry if these practices become unsustainable at some time in the future, due to concerns about the possible spread of BSE.

A range of technologies used for meat processing wastes or similar wet organic materials have been examined from a technical perspective, and a practical viewpoint. Overseas examples of their use have been listed (where available) and major equipment suppliers have also been identified. Indicative unit costs have also be obtained where possible although such information is unreliable.

Costs from overseas plants are sometimes not applicable to the local situation, since such costs depend largely upon the scale of the plant and the local conditions such as labour costs, costs of other alternatives for waste disposal, costs of disposing of residuals to landfill and the market value of any energy generated.

It is noted that waste to energy technologies are unlikely to provide an economic advantage over current practices such as rendering at present, since meat and bone meal (MBM) and tallow are valuable commodities at present. Information provided by MLA indicated that market prices for MBM are of the order of $350-400/tonne and tallow can fetch up to $500/tonne at present. Typical costs of rendering are of the order of $80/tonne according to industry sources. On this basis most rendering operations are relatively profitable at present.

In contrast, the capital and operating costs of most waste to energy processes exceed the possible revenues obtained from the electricity generated and sold. They are at best marginally profitable, and in most cases, unprofitable in the conventional sense. Typical operating costs range from $180-260/tonne for incineration type plants and $80-170/tonne for gasification and pyrolysis type plants.

These normally only process relatively dry wastes, as a large amount of energy is needed to drive off water. Wastes with moisture contents of less than 60% are required to obtain a positive energy balance, where energy generated from combustion exceeds energy required to drive the process.

Financial viability of conventional waste to energy plants is normally accomplished through fees paid to plant operators by waste generators for disposal of wastes, due to other waste disposal options (such as landfilling) being equally or more expensive. Without such fees, most conventional waste to energy plants are not economically viable, as revenues from sale of electricity are not sufficient to cover the costs of producing and distributing electricity. Such revenue simply reduces the gate fees that need to be charged for wastes received at these plants.

Therefore there appears to be no economic incentive at present to cease current practices such as rendering and production of meat and bone meal, while such materials can still be used as animal feed. Production of biodiesel from tallow produced by rendering plants is the only waste to energy process that is likely to be economically viable in the current climate, as biodiesel has a market value of the order of 90c/L, and typical production costs of about 25-40c/L excluding raw material costs.

From this investigation it appears that the one of the most practical alternatives for individual meat processing plants in the event that there is a significant decline in the market for meat meal (due to BSE concerns) would be for them to continue operating their rendering plants, but for the MBM to be transported to coal fired power stations for blending with coal. Transport costs would depend upon the distance of meat processing plants from existing power stations, but could prove to be quite expensive for remote operators.

Also the acceptance of meat wastes as an alternative fuel source for the power industry would need to be determined by discussions with existing operators. However MBM is already being used as substitute fuel in German power plants and in cement kilns. Trials with local operators would be the best way of assessing the conditions under which MBM could be used to supplement existing fuels.

The current high demand for renewable energy by electricity retailers and current government schemes for encouraging its use mean that renewable energy certificates (RECs) are able to be issued to coal fired power stations that use MBM as a supplementary fuel. These RECs effectively provide a minimum subsidy of $40/MWh for such renewable energy sources. Whether this scheme continues is a subject of a current review of the MRET scheme being undertaken by the Commonwealth Government.

Meat and bone meal possesses many of the characteristics of current fuels such as coal, as it is reasonably homogeneous, has a calorific value approaching coal, and can be stockpiled and stored if necessary. The stable nature and the relative dryness of meat and bone meal suggests that it could also be used as feedstock for a number of other waste to energy processes, including pyrolysis, gasification, existing coal fired steam boilers and as fuel for existing cement kilns.

As mentioned already, conversion of tallow from rendering plants into biodiesel is also a feasible alternative to current food-related uses of tallow, in the event of a BSE scare. Major rendering plant operator AJ Bush is planning a biodiesel production facility at its Bromelton Rendering Plant in Queensland, to utilise the tallow from its rendering plants. The profitability of this type of operation would depend upon the market price of biodiesel at the time and the possibility of use of some or all of the biodiesel produced for powering transport vehicles owned by an abattoir or rendering plant operator.

Raw meat wastes are putrescible, wet (requiring considerable amounts of energy to dry them prior to energy recovery) and are not suitable for direct input to boilers and other existing processes due to their non-homogeneous nature. However, wet meat wastes appear to be suitable feed stocks for waste to energy processes such as anaerobic digestion with or without thermal hydrolysis, thermal pressure hydrolysis and thermal depolymerisation.

Anaerobic digestion is the most simple waste to energy option for raw meat wastes, as an alternative to rendering or composting. Typical costs quoted for anaerobic digestion are of the order of $70-$150/tonne Gas production can be enhanced by pre-processing of wastes by thermal hydrolysis however could this add approximately $90/tonne to the cost of the process, and the revenues from electricity generation are unlikely to cover such costs. Neither anaerobic digestion nor digestion combined with thermal hydrolysis would be suitable in the event of a BSE scare, as the temperatures associated with such processes do not appear to be high enough to destroy the BSE prion.

Thermal pressure hydrolysis offers great promise for wet meat wastes, with grinding of wastes to less than 50mm size the only preparation required. The process has been developed in Europe specifically to deal with meat wastes and minimise the likelihood of BSE transmission. The only drawback at present is that there is no full scale plant at this stage, therefore likely costs of operation are not able to be defined.

Another technology that is applicable to wet meat wastes is thermal depolymerisation and chemical reforming, the process being developed by Changing World Technologies. This, offers the possibility of being able to convert wet meat wastes directly into fuel. A full scale plant has been built in the US but no data on costs of operation are currently available.

As mentioned above, incineration is not a suitable waste to energy technology for wet meat wastes. Conventional gasification and pyrolysis processes also require feedstock fuels to be relatively dry, due to the large amount of energy required to drive off water from the fuel before chemical conversion processes take place. These processes are therefore only suitable for dried meat wastes such as MBM.

Whether rendered or non-rendered wastes are considered, the potentially high capital costs associated with waste to energy plants suggest that on site processing of either types of wastes is not financially viable for most small to medium scale meat processing facilities. There are large information gaps associated with the potential application of waste to energy technologies to meat wastes, particularly in relation to costs and specific application to meat wastes.

The most significant areas where primary factual data is absent or weak, is about the suitability of existing technologies such as pyrolysis and gasification for processing MBM and anaerobic digestion and emerging technologies such as thermal depolymerisation for processing non rendered meat wastes.

There are relatively few overseas examples of these practices being applied specifically to meat wastes, and little information on the costs of such processes that can be used to estimate costs in an Australian context. However more information on the suitability of thermal pressure hydrolysis and thermal depolymerisation, which offer the greatest promise in terms of processing wet meat wastes and eliminating the BSE prion, is likely to be available within the next 1-2 years, as a full scale plant is currently being either built or commissioned.

Future work undertaken to strengthen areas where information is absent or weak could include some practical trials involving disposal of MBM in existing facilities, such as existing power stations and cement kilns. With the technical difficulties currently being experienced at the SWERF gasification/pyrolysis plant at Wollongong, trials using MBM are unlikely to be possible, although MBM would be a less problematic fuel than the domestic garbage that it has been designed to process.

Additional work could be undertaken to investigate the likely costs of waste to energy technologies for typical individual meat processing facilities, as there are a number of local factors that affect the economic feasibility of waste to energy technologies.

These include the costs of operating rendering facilities (since it has been suggested by industry sources that many abattoirs may not understand their actual costs), proximity of other meat processors that could be involved in a joint waste to energy facility, distances to existing power stations and cement kilns, acceptance of MBM as fuel by existing operators, and their willingness to pay for such feedstock (as opposed to charging a gate fee for disposal).

Application of the newer technologies for wet wastes such as thermal depolymerisation and thermal pressure hydrolysis also warrants more detailed investigation, including formal liaison with the technology providers and site visits, although this should probably be delayed until their full scale plants are properly commissioned and operational.

An overview of waste to energy technologies assessed in the scope of this study is provided in Table 21. Technologies utilising biofuels are summarised in Table 22.

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Table 21 Overview of waste to energy technologies applicable to meat wastes

Technology	Advantages / Disadvantages	Cost	Application	Technology Suppliers	Operational Sites
Thermal Processes					
Incineration	Well suited for combustion of MBM, but not suitable for wet meat wastes due to energy required to drive off water High potential for energy recovery from dried meat wastes High level of environmental controls required	$180 - $260/t plus the cost of rendering to produce MBM (approx $80/t)	Medium to large scale offsite facilities would be expected, since most meat processing plants would not operate incinerators. Combustion of MBM in Europe is currently practised for up to 85,000 t/a (at one facility) - as a disposal method for MBM, rather than for energy production.	Howden 3Ts International Ltd (UK), Segers Keppel Technology Group (Belgium)	UK, Germany, France
Coal-fired power stations	Suited to dried meat wastes Not suitable for tallow or wet meat wastes Co-combustion of coal with MBM can improve combustion and lead to decreased levels of carbon and carbon monoxide as well as lower ash production	Cost of transporting MBM to power station (could be $20/t for 100km round trip), preparing fuel for boiler (ie crushing) and the cost of rendering to produce MBM (approx $80/t)	Transport to existing power stations required. On site applications unlikely. Power stations likely to accept small to large quantities of MBM and may pay operators for fuel or cover transport costs (due to high demand for renewable energy).	Power station, Lunen, Germany (MBM only)	Europe
Cement kilns	Possible supplementary fuel for cement plants,	Cost of transport to existing facility (could be $20/t for 100km round	Transport to existing medium to large scale offsite facilities		France, Switzerland,

Technology	Advantages / Disadvantages	Cost	Application	Technology Suppliers	Operational Sites
	which are very energy intensive Integrity of cement clinker can be affected if large quantities of solid waste are introduced Undesirable build up of alkali chlorides where waste contains high levels of chlorine	trip) plus the cost of rendering to produce MBM (approx $80/t).	expected. In 2001 in Germany 245,000 tonnes of MBM and fat were burnt in cement kilns.		Germany
Boiler fuel	Tallow has lower sulphur content than either gas or fuel oil Use of meat wastes as boiler fuel is still not commonly carried out	Cost of rendering to produce MBM (approx $80/t) plus cost of fuel preparation.	Most meat processing plants would not operate coal fired boilers, and installation of new boilers would be necessary.-	Energy Equipment Australia Pty Ltd (green waste only)	Green waste to energy plants in NSW, Tasmania, WA, Qld, and Vic.
Biological processes					
Anaerobic digestion	Well established process for most wet wastes Production of biogas and compost Unlikely to destroy BSE prion in meat wastes Pre-treatment of wastes required High capital costs	Estimates of $70-150/tonne typically reported. New technology such as ORT claiming costs as low as $55 / tonne.	Capacity depends on digestion/co-digestion process and mix of waste types. Small plants are feasible but best economies of scale are achieved for larger plants. Current digestion plants can be up to > 100,000 tonnes/year gross input.	Earthpower, ORT, BTA, Valorga International, Haase Energietechnik	Many plants in operation throughout Europe. Earthpower digestion plant in NSW currently being commissioned for food wastes
Thermochemical Processes					
Thermal hydrolysis	Production of biogas and compost Pathogens and spores are eliminated	Costs estimated to be $90/t in Norway for thermal hydrolysis plant. Additional costs of anaerobic	Wide range of plant sizes possible, with plants from 1200t/yr up to 36,000t/yr already	Cambi AS	Norway

Technology	Advantages / Disadvantages	Cost	Application	Technology Suppliers	Operational Sites
	Best suited to wet wastes. Provides greater speed of digestion, increased production of biogas and better dewatering properties than conventional anaerobic digestion alone. May not destroy the BSE prion, therefore not suitable if BSE is an issue	digestion ($70-150/t) need to be added to this	operating. On site operations, combined with existing or new anaerobic digestion plants is possible.–		
Thermal pressure hydrolysis	Can accept almost all waste as feed stock Pre treatment to grind particle size < 50 mm required Solid residues from processing meat wastes are only approximately 20% of feed stock of existing pilot plant. Biogas and solid products are used in further thermal processes. , High biogas yield and high methane content (70-77%) of biogas compared to normal digestion process Minimises quantity of solid residuals requiring disposal	Process not yet fully developed and operational – therefore costs not known	In process of planning full scale 50,000 t/a plant. Economics of small versus large plants not able to be assessed at present.	ATZ Evus	Pilot plant in Bavaria
Gasification & Pyrolysis	Processes have high energy requirements Higher overall efficiency than other thermochemical and biological processes when	$80 - $170 / tonne quoted in literature plus cost of rendering to produce MBM (approx $80/t).	Due to high capital costs and energy requirements, generally better suited for medium to large scale plants. On site plants likely	Brightstar Environmental (use or MSW), Environmental Solutions International (Enersludge),	Operational plants in Japan, South Korea, Norway, UK and other areas of Europe.

Technology	Advantages / Disadvantages	Cost	Application	Technology Suppliers	Operational Sites
	energy recovery is taken into account Suited to dry meat wastes High capital costs/uncertainty about possible application to meat wastes		to be uneconomic, with larger centralised facilities more feasible.	Compact Power (UK), Organic Power (Norway)	Brightstar Plant still in commissioning in Wollongong. Enersludge plant in Subiaco WA has closed due to being uneconomic to operate.
Thermal depolymerisation	Capable of processing variety of feed stocks Process has low energy requirements Well suited for wet wastes Production of oils, gases and solid carbon Waste water is the only by- product Process is not yet proven on a large scale.	Approximate cost $US90/tonne[8].	Small plants possible although larger scale plants expected to be most economic.	Changing World Technologies	Carthage, Missouri USA. New plants planned for both USA and Italy.
Chemical Processes					
Biodiesel production from tallow	Biodiesel production technology is well proven, including production from animal fats Rendering of meat wastes to produce tallow is first required Economics of biodiesel production depend upon market price of diesel, which can fluctuate	Approximate production cost of 25c/L-40c/L of biodiesel produced plus cost of rendering to produce tallow (about $80/t). .	Most economic for large scale developments, although AJ Bush in Qld is planning an on site plant to produce 60 million litres per year.	Australian Renewable Fuels Pty Ltd	Small plant already built in Maitland NSW. Larger plants to be developed in WA and Qld with 40 million L/annum and 60 million L/annum capacities respectively (using

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[8] Cost based on current cost of $25 - $35 to produce one barrel of oil. Producers expect this cost to reduce to approximately $20/barrel in the near future.

Technology	Advantages / Disadvantages	Cost	Application	Technology Suppliers	Operational Sites
	according to crude oil prices Potential for on-site utilisation of biodiesel produced for powering transport vehicles. As yet no Australian standards in place for biodiesel				approximately 60,000 – 85,000 tonnes of fat/year). Renderer AJ Bush is planning to build an on site plant in Qld to utilise tallow produced by rendering activities.

Table 22 Biofuel utilisation technologies

Biofuel	Technology
Biogas	Boiler fuel
	Electricity production in microturbines or fuel cells
	Heat and power co-generation in internal combustion engines
	Off site use as natural gas surrogate
Syngas	Boiler fuel
	Electricity production in microturbines
	Heat and power co-generation in internal combustion engines
	Off site production of alcohols
Pyrolytic oil	Boiler fuel
	Electricity production in microturbines
	Heat and power co-generation in internal combustion engines
	Off site production of alcohols
	Off site use as fuel surrogate in incinerators, power plants etc.
Non rendered meat waste	Off site use as fuel surrogate in incinerators, power plants etc.
Paunch manure	Off site use as fuel surrogate in incinerators, power plants etc.
MBM	Boiler fuel
	Off site use as fuel surrogate in incinerators, power plants etc.
Tallow	Boiler fuel
	Off site use as fuel surrogate in incinerators, power plants etc.
Biodiesel	Boiler fuel
	Transportation fuel for vehicles
	Heat and power co-generation in internal combustion engines
	Off site use in commercial fuel production
Solution of basic organic compounds	Processing to biogas in anaerobic digester
	Use as C-substrate in wastewater treatment plants
	Off site use as raw product for the chemical industry

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13. Glossary

AC	- Anaerobic contact
ARA	- Australian Rendering Association
BOD	- Biological Oxygen Demand
BSE	- Bovine Spongiform Encephalopathy
CAL	- Covered anaerobic lagoon
CAR	- Contact anaerobic reactor
CHP	- Combined heat and power
CJD	- Creutzfeldt-Jakob Disease
COD	- Chemical oxygen demand
CSTR	- Continuous stirred tank reactor
DAF	– Dissolved air flotation
DS	- Dry solids
FC	- Fuel cell
HSCW	- Hot Standard Carcase Weight
IAF	– Induced air flotation
LCW	– Live carcase weight
LHV	- Lower heating value
MBM	- Meat and bone meal
SS	- Suspended solids
TDS	- Total dissolved solids
TDP	- Thermo-depolymerisation process
TS	- Total solids
TVS	- Total volatile solids
UASB	- Upflow anaerobic sludge blankets
UASB	- Upflow anaerobic sludge blanket
UKRA	- United Kingdom Renderer's Association
UV	- Ultra violet

Appendix A

Detailed Technology Descriptions

A1 - Sludge Disintegration Methods

- Excess biomass from activated sludge plants or high rate anaerobic reactors: In particular excess activated sludge from activated sludge plants can contribute to the biogas production to a certain degree. Due to the typically low concentration at which this sludges are collected, gravity or better mechanical thickening prior to feeding into the digester is recommended. It is further recommended to investigate the economical benefits of using disintegration technologies. This process step cracks bacteria cells and thus makes the biomass and the enzymes of the cracked cells accessible / available for the digestion process. In this way, disintegration improves VS destruction, gas production and dewaterability of the digested sludge. There are a number of disintegration technologies available, mainly:
  - Ultrasonic disintegration (USD): Requires thickened sludge as feed stock for economical reasons. The operating principle of USD is the introduction of high energy ultrasound waves into the sludge with a typical frequency of 20 kHz. The sound waves produce a field of compression and de-compression waves in the water, oscillating at that frequency. In the de-compression areas cavitation takes place leading to the formation of gas bubbles. Collapse of these bubbles in the compression areas (basically when the next waves passes through) leads to very high pressure spikes and associated high shear forces as well as very high temperatures (very localised). The pressure spikes and associated shear forces cause rupture (partial and total) of the cell membranes of the bacteria in the sludge. As cavitation is the direct “product” of the USD, high wear on the emitters (“horns”, “sonotrodes”) due to pitting is inevitable. Therefore the sonotrodes are manufactured from titanium in order to achieve reasonable lifetimes. Through their lifetime, even these titanium sonotrodes experience material loss due to pitting. As they get lighter, their frequency shifts out of the optimum range. This ageing effect is compensated by continually increasing the power input until the maximum rated power of the sonotrode is reached; at this time, the sonotrode needs replacement. Reactor and process designs vary, depending on the supplier. Technology suppliers (all with full scale reference plants): IWE.tec (Germany), Sonico/Purac (UK), VTA (Austria).
  - Mechanical disintegration: Thickened sludge as feed stock will lead to better economics. The operating principle is to pump the sludge at high pressure and velocity through a narrow orifice. The pressure drop and velocity creates high shear forces which destroy the bacteria cells. Wear of the orifice is considerable. In the time available we could not clearly identify technology suppliers for this process, although it is relatively well documented, for example in an ATV (German wastewater association) task force report.
  - Milling: Requires thickened sludge a feed stock for economical reasons. Pressure and shear introduced by a ball mill are used to crack the bacteria cells. After the suspension has left the mill, the balls are separated from the suspension and returned to the process. Ball wear is considerable in order to achieve a satisfactory disintegration. In the time available only a key researcher for this process could be identified (Prof. Kunz, University Mannheim, Germany).

- Thermal disintegration: Thickened sludge as feed stock will lead to better economics. The operating principle is that of a pressure cooker and therefore basically similar to the thermal hydrolysis processes discussed later. It is not considered likely that this process can provide an economical benefit compared to other alternative disintegration technologies as it requires a more complex infrastructure than USD or mechanical disintegration or a lysate centrifuge. No further investigations with regard to potential suppliers have therefore been undertaken.
- Chemical disintegration: Thickened sludge as feed stock will lead to better economics. The operating principle is that of chemically destroying the bacterial cell membrane. This can be supported by elevated temperature and / or pressure, so that the boundaries between thermal and chemical disintegration can be somewhat blurred. Due to the ongoing demand of chemicals and associated increased salinity of the final effluent it is not considered likely that this process can provide an economical benefit compared to other alternative disintegration technologies. No further investigations with regard to potential suppliers have therefore been undertaken.
- Lysate centrifuge: Produces thickened sludge at the same time. The lysate centrifuge is basically a thickening centrifuge with “knifes” attached to the thickened sludge discharge. In combination with the high rotating speed, the knifes introduce high shear forces which lead to the destruction of the bacterial cells. The knifes can be retrofitted to suitable centrifuge designs, however the technology is protected by a patent and to our knowledge can therefore only be obtained from the following licensees: Decanter (Australia), Hiller (Germany). This technology is probably not as effective as USD, however it can be installed at very little additional capital cost (for knifes and associated license fee and possibly larger drive motors) and low additional operating cost (additional power requirement caused by the breaking moment of the knifes). As the process works more effectively at higher centrifuge speeds, thickening without polymer dosing may be considered which can offer capital and operating cost savings.

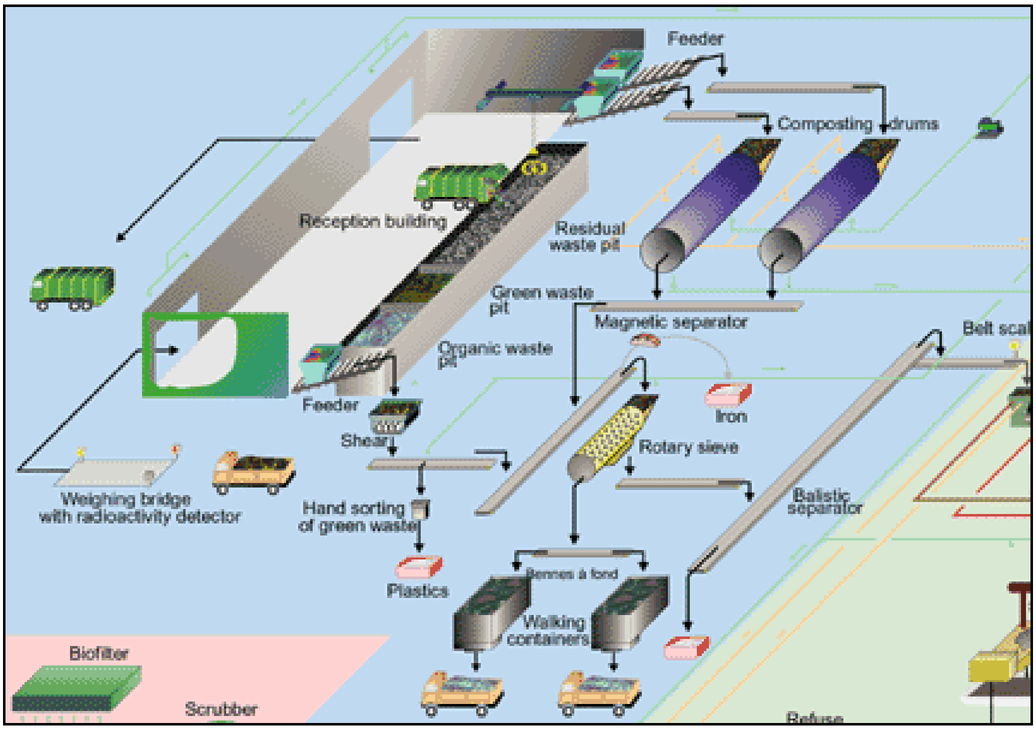
A2 - Anaerobic Digestion Processes

Valorga Process description

Waste reception and preparation unit

This unit is made up of:

- A weigh bridge to weight the collection lorries upon arrival in the factory;
- A waste reception bunker situated in the reception hall or a closed unloading hall with a foul air extraction system;
- A system including calibration, bag-opening and size reduction designed according to the waste to be treated; and
- Conveyors and hopper in order to bring the product to the anaerobic digestion unit.

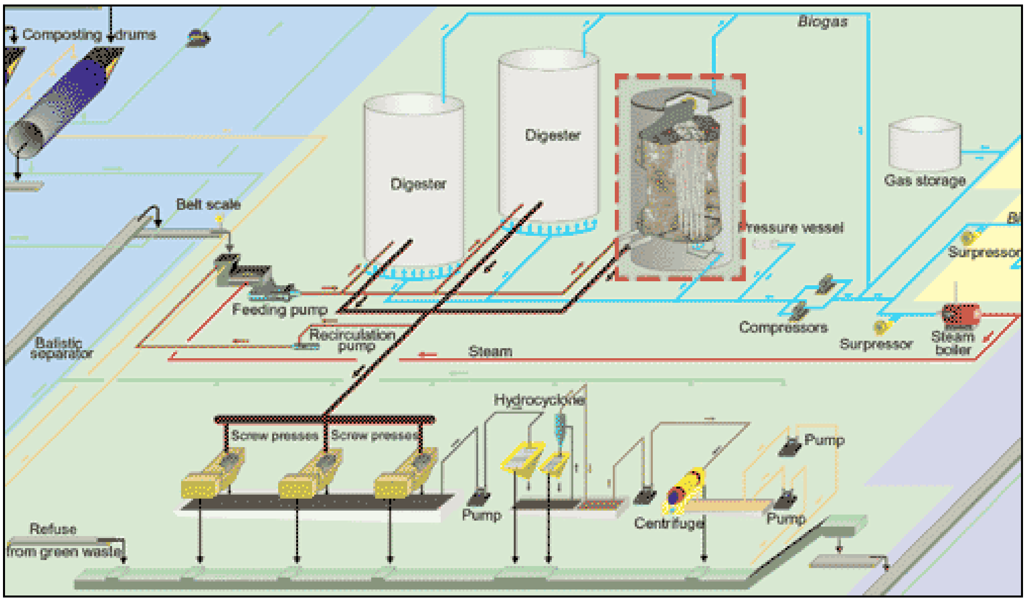


In the case of mixed waste or grey waste treatment the sorting unit is adapted to the composition of the waste to be treated.

Process description - Anaerobic digestion unit

The dilution and mixing of the waste in the form of a thick sludge, with a high dry matter content (20% to 35% depending on the type of waste), giving a reduction in the volumes of fermentation. Heating is provided by steam injection. The mixture is introduced at the bottom of the reactor with a piston pump

The digestion itself that takes place in fermenters under anaerobic conditions. The temperature can be in the mesophilic range (± 40°C) or thermophilic range (± 55°C). The Valorga fermenter is a vertical cylindrical digester with a plug-flow transfer of the matter. The digester has a vertical median inner wall on around 2/3 of its diameter. The introduction and extraction orifices are at the base of the fermenter on either side of this inner wall. The inner wall forces fermenting matter to follow a circular movement in order to go around it, so that waste may only be extracted after having covered the whole surface of the digester. This specialised geometry, along with a limited level of recycling for fermented matter, guarantees that waste will spend a minimum of around 3 weeks in the fermenter. This aspect is vital for a perfect hygienisation of compost.

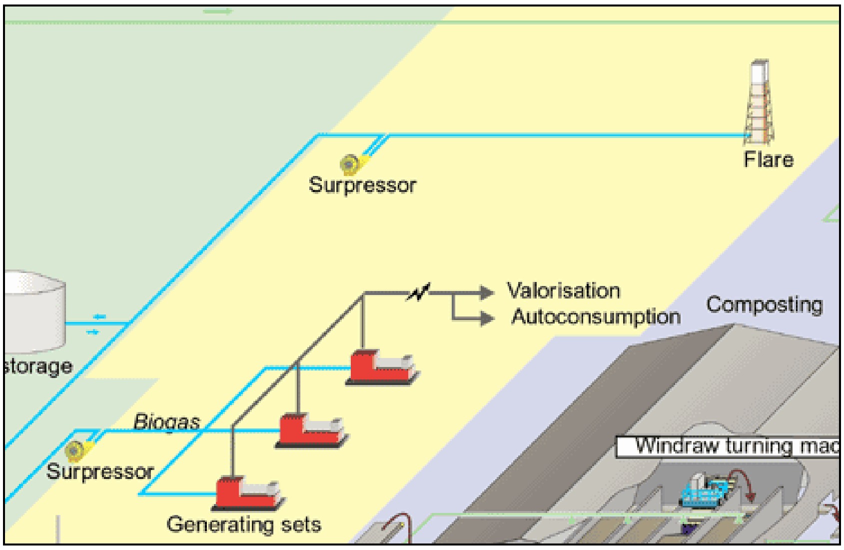


To ensure an optimal level of degradation in the digester, the feed should be homogenised. Valorga's patented mixing system is pneumatic: biogas is injected through injectors into the base of the reactor under pressure. A great advantage of this mixing system is that no mechanical mixing equipment is used in the fermenter, which would necessitate opening and maintenance of the digester, thus putting it out of action. The biogas used for the mixing turns in a closed circuit. The compression of biogas is made by a two level compressor (8 bar pressure).

The digested product taken out of the digester undergoes a mechanical pressing process, resulting in a solid fraction and a liquid fraction. The latter is further treated to remove suspended solids. A part of the clarified process water is used for dilution of the incoming waste. The remaining part is either discharged into the sewage network or transferred to the excess water treatment unit. The solid fractions are transferred to the aerobic post-treatment unit.

Process description - Biogas utilisation unit

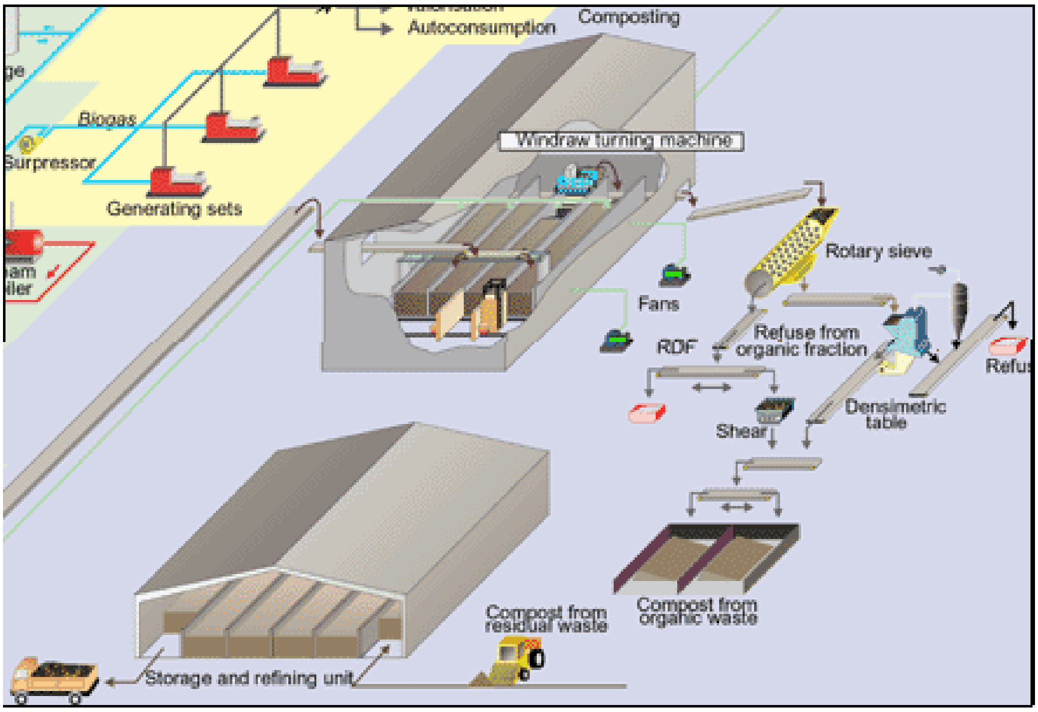
The biogas can be used for steam production, for electricity and heat production, or - after a purification step - in the same way as natural methane gas (city gas network, fuel for vehicles, etc.).



Process description - Aerobic post-treatment and compost refining unit

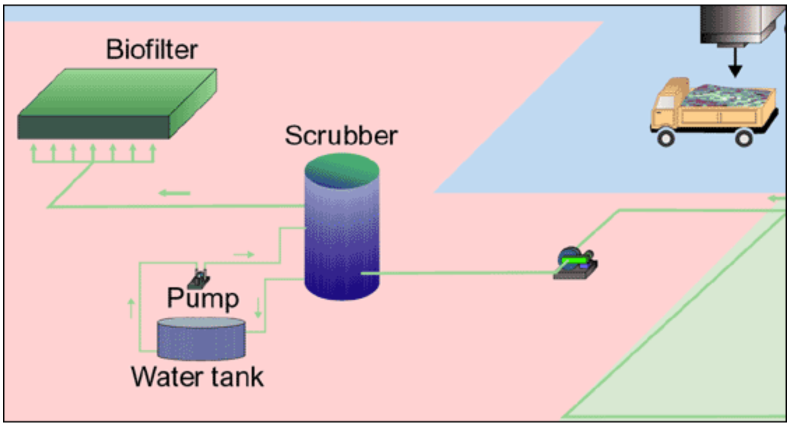
This unit is designed to produce a high quality organic soil amendment from the digested matter extracted from the digesters. It involves:

- The maturation and drying of the digested matter in a closed building under depression, where the product is stored during at least 2 weeks and eventually removed and aerated;
- The refining of the compost by separation of the inerts (scrap iron or/and rotary screen); and
- The storage and possible packaging of these organic amendments before they are sold.



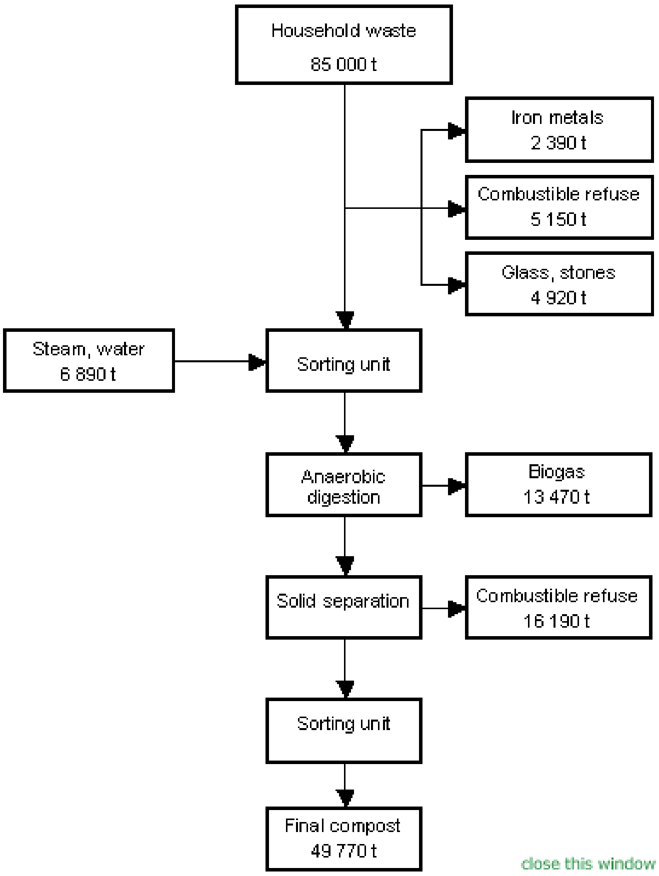
Process description - Air treatment unit

The foul air that could be emitted from confined sources (mixer, press,) is directly drawn off and sent to an air treatment unit, together with the air from reception and aerobic post-treatment halls.



Valorga Plants

Amiens, France
Treatment capacity: 85,000 t/a
Volume of digesters: 3 x 2,400 m^3 (start-up in 1988) + 1 x 3,500 m^3 (start-up in 1996)
Type of waste: Municipal solid waste with 60% DS and 63% VS
Retention time: 18 - 22 days
Biogas production: 140 - 160 Nm^3/t input to digestion
Specific methane yield: 220 - 250 Nm^3/t VS input to digestion
Biogas utilisation: High pressure steam for industrial purpose and 5,500 kW electrical power

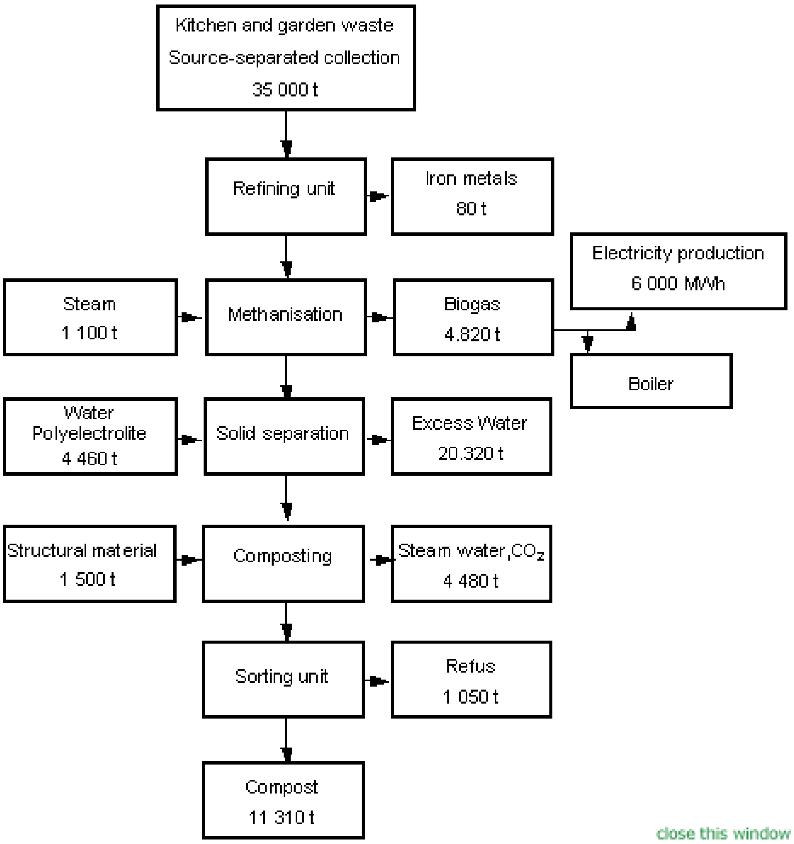


Barcelone - Ecoparque II, Spain
Treatment capacity: 120,000 t/a to anaerobic digestion unit
Volume of digesters: 3 x 4,500 m^3
Type of waste: Household waste with 42% TS and 58% VS
Retention time: 25 days
Biogas production: 114 Nm^3/t input to digestion
Specific methane yield: 260 Nm^3/tTVS input to digestion
Biogas utilisation: Electricity production

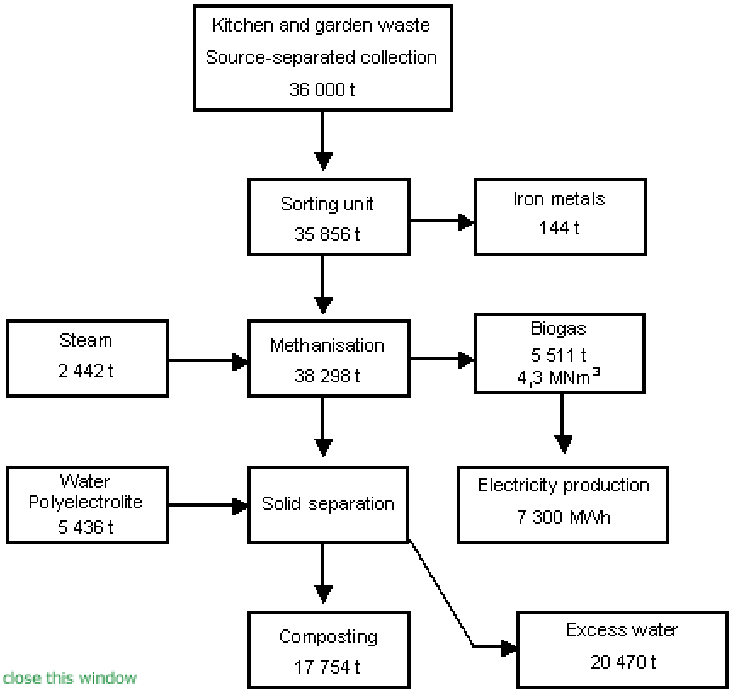
Bassano, Italy
Treatment capacity: 44,200 t/a MSW + 8,200 t/a biowaste + 3,000 t/a sludge
Volume of digesters: 3 x 2,400 m^3
Type of waste: 50,8% TS and 62,3% TVS
Retention time: 33 days
Biogas production: 129 Nm^3/t input digestion
Specific methane yield: 270 Nm^3/t TVS input digestion
Biogas utilisation: Electricity production

Cadiz, Spain
Treatment capacity: 115,000 t/a to anaerobic digestion unit
Volume of digesters: 4 x 4,000 m^3
Type of waste: Household waste
Retention time: 25 days at minimum
Biogas production: 145 Nm^3/t input to digestion
Specific methane yield: 220 - 250 Nm^3/t VS input to digestion
Biogas utilisation: Electricity and heat production

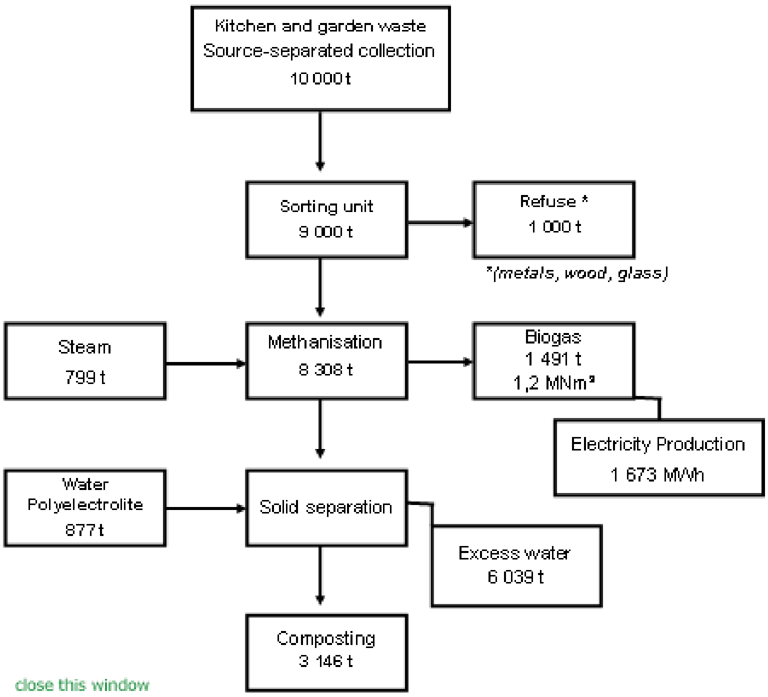
Engelskirchen, Germany
Treatment capacity: 35,000 t/a
Volume of digesters: 2 x 3,000 m^3
Type of waste: Biowaste (kitchen and garden waste) with 36% TS and 70% VS
Retention time: 25 days at minimum
Biogas production: 100 - 110 Nm^3/t input to digestion
Specific methane yield: 240 - 260 Nm^3/t VS input to digestion
Biogas utilisation: Electricity and heat production (Power 940 kWe)



Freiburg, Germany
Treatment capacity: 36,000 t/a
Volume of digesters: 1 x 4,000 m^3
Type of waste: Biowaste (kitchen and garden waste)
Retention time: 25 days at minimum
Biogas production: 110 - 120 Nm^3/t input to digestion
Specific methane yield: 280 Nm^3/t VS input to digestion
Biogas utilisation: Electricity and heat production



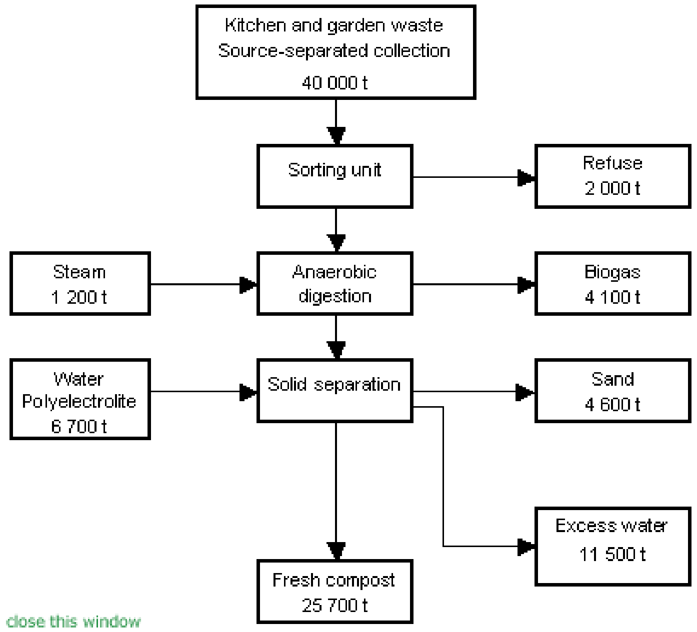
Geneva, Switzerland
Treatment capacity: 10,000 t/a
Volume of digesters: 1 x 1,300 m^3
Type of waste: Biowaste (kitchen and garden waste)
Retention time: 24 days at minimum
Biogas production: 110 - 120 Nm^3/t input to digestion
Specific methane yield: 280 Nm^3/t VS input to digestion
Biogas utilisation: Electricity and heat production



La Coruña, Spain
Treatment capacity: 182,500 t/a total, 142,000 t/a to anaerobic digestion
Volume of digesters: 4 x 4,500 m^3
Type of waste: Mixed Municipal Solid Waste
Retention time: 16-20 days
Biogas production: 130-150 Nm^3/t input to digestion
Specific methane yield: 250-270 Nm^3/t VS input to digestion
Biogas utilisation: Electricity (5 x 1,250 kW) + heat production

Mons, Belgium
Treatment capacity: 58,700 t/a (23 000 t/a household waste + 35,700 t/a biowaste)
Volume of digesters: 2 x 3,800 m^3
Type of waste: Sorted household waste + kitchen and garden waste
Retention time: 25 days at minimum
Biogas production: 110 - 120 Nm^3/t input to digestion
Specific methane yield: 280 Nm^3/t VS input to digestion
Biogas utilisation: Electricity and heat production

Tilburg, The Netherlands
Treatment capacity: 52,000 t/a
Volume of digesters: 2 x 3,300 m^3
Type of waste: Source-sorted organic fraction of municipal solid waste so called "Vegetable-Garden-Fruit" with 46% TS and 45% VS
Retention time: 20 days at minimum
Biogas production: 80 - 85 Nm^3/t input to digestion
Specific methane yield: 220 - 250 Nm^3/t VS input to digestion
Biogas utilisation: Injection into the gas network after purification



Varennes-Jarcy, France
Treatment capacity: 100,000 t/a household waste including 30,000 t/a biowaste
Volume of digesters: 2 x 4,200 m^3 + 1 x 4,500 m^3
Type of waste: Household waste + source sorted biowaste
Retention time: 25 days at minimum
Biogas production: 154 Nm^3/t input to digestion
Specific methane yield: 245 Nm^3/t VS input to digestion
Biogas utilisation: Electricity production

BTA Process description – Mechanical pre-treatment

In the waste-pulper the feedstock is mixed with recirculated process water. Contaminants like plastics, textiles, stones and metals are separated effectively and gently without any handsorting. A thick pumpable suspension (pulp) is produced which can be easily handled and digested. An optional but essential further component of the process is the grit removal system which separates the still remaining finest matter like sand, stones and glass splinters by passing the pulp through a hydrocyclone. Thus the plant is protected against increasing abrasion.

Process description – Biological conversion

Depending on the plant capacity and the desired type of energy- and compost utilisation various concepts can be offered for the biological conversion step:

4. One-stage digestion: Fermenting the produced pulp within one single step in one mixed fermentation reactor. This concept enables to use the BTA technology even for comparatively small decentralised waste management units. Existing digesters (i.e. on a sewage plant or agricultural biogas plants) can be used which results in an essential reduction of capital and operating costs. A process schematic for the one-stage digestion process is shown in Figure A1.

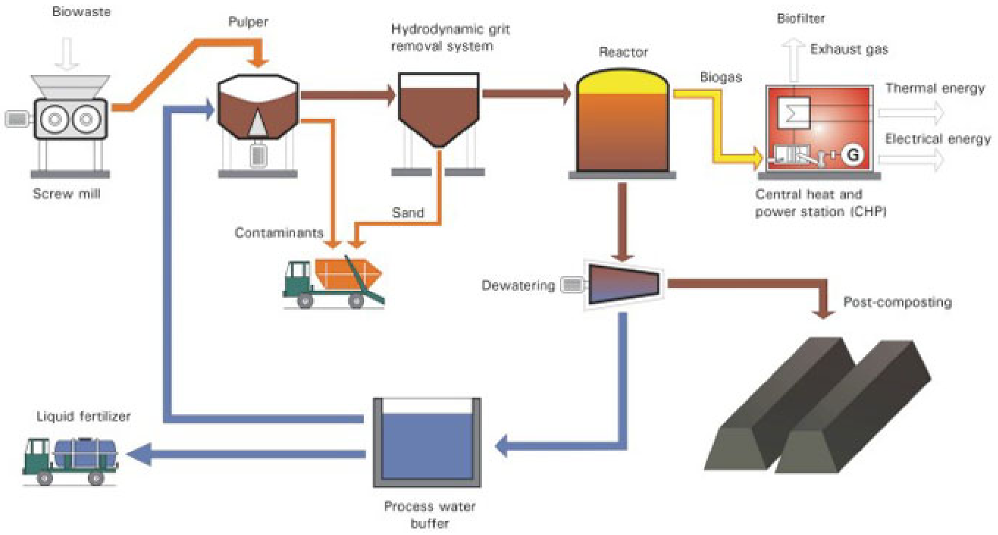


Figure A1 Schematic of the BTA one-stage digestion process

5. Multi-stage digestion: For plants with a capacity of more than 50,000 t/a the multi-stage digestion was developed, separating the pulp in a solid mass and a liquid phase by using a dewatering device. The liquid, already containing dissolved organic components, is directly pumped into a methane reactor remaining there for a period of 2 days. The dewatered solid material, still containing undissolved organic components, is once more mixed up with water and fed into a hydrolysis reactor. After 4 days the

hydrolysed solids are dewatered again and then the liquid is fed into the methane reactor whilst the solid residue is removed off site.

By distributing the degradation process on different reactors (acidification, hydrolysis and methanisation) optimal growth conditions for all groups of micro-organisms can be achieved. This allows a rapid and extended degradation of the organics resulting in a high yield of biogas. Within only a few days 60-80% of the organic substance are converted into biogas. A process schematic for the multi-stage digestion process is shown in Figure A2.

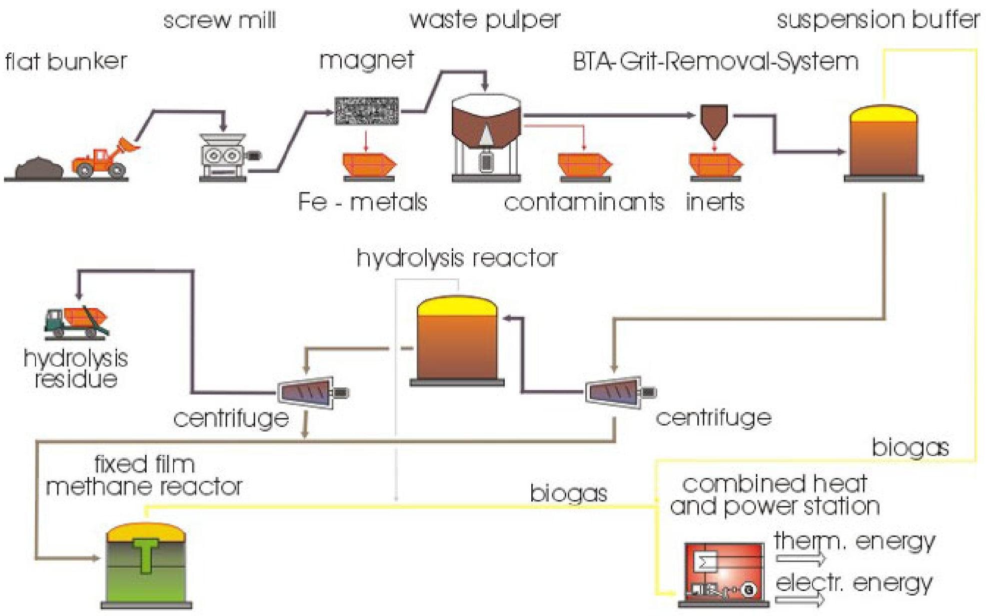


Figure A2 Schematic of the BTA multi-stage digestion process

6. Two-stage digestion: As a further variation for plants with medium capacity the two-stage digestion is available which is based on the multi-stage concept but without a solid/liquid separation. The pulp is fed into a mixed hydrolysis reactor and from there into an also completely mixed fermentation reactor. To enable optimal efficiency a part of the fermentation reactor content is fed back into the hydrolysis reactor.

For the treatment of food waste an additional sanitation step can be integrated.

The water demand of the process is met by recirculating the water which is contained in the waste. Excess water is fed into a sewage plant.

Products

Products of the process are biogas and compost. The biogas consists of 60-65% methane. Converted into electricity and heat the surplus can be fed into respective public grids.

After a short aerobic treatment (1-3 weeks) the anaerobic compost is sufficiently stabilised and matured. The stable crumbly structure improving root growth and aeration is superior to peat and yard waste compost. Due to its structure, the high percentage of organic substance, its low heavy metal and salt content as well as its good balance of nutrients BTA compost has a large range of agricultural and horticultural application.

BTA reference installations

(Source: BTA website).

Plants with BTA-Process

Plants with BTA-Process
1. Villacidro (Italy / Sardinia) 45,000 t/a mixed waste incl. sewage sludge The plant is designed according to the BTA-Process and went in operation in 2002. BTA has provided engineering works, delivered particular components and assists during the start-up.
2. Newmarket (Canada) 150,000 t/a biowaste, commercial waste, organic sludges. The plant went in operation in 2000. BTA has provided engineering works and has assisted during the start-up.
3. Toronto (Canada) Demonstration plant 15,000 t/a mixed waste alternatively 25,000 t/a source separated biowaste from household and commercial sources. The demonstration plant is designed according to the BTA-Process and went in operation in 2002. BTA has provided engineering works, delivered particular components and has assisted during the start-up.
4. Mertingen (District Donau-Ries) 11,000 t/a agricultural waste, 1,000 t/a biowaste. The plant started its operation in spring 2001. BTA has provided engineering works, delivered particular components and was advising in the construction.
5. Wadern-Lockweiler (Saarland) 20,000 t/a biowaste, commercial waste Start-up in 1998. "Quasi-2 step" digestion (i.e. thickening of the suspension with following hydrolysis). BTA has delivered particular components and has assisted in the start-up.
6. Erkheim (District Unterallgäu) 11,500 t/a biowaste, commercial waste Start-up in 1997. Combination of fully automated treatment with an agricultural-standard digestion. BTA has completely planned and erected the plant excluding the digestion reactors as well as the pre-treatment of food waste. Referring the gas utilisation the planning was done.
7. Kirchstockach (Munich District) 20,000 t/a biowaste Start-up in 1997. Plant is working with 2-step digestion. BTA has provided engineering works, delivered particular components, assisted in the start-up and has managed the trial run.
8. Karlsruhe 8,000 t/a biowaste Start-up in 1996. Erected at a landfill area; fully automated feeding system; biogas utilisation together with landfill gas. BTA has provided engineering works, delivered particular components and has assisted in the start-up.
9. Dietrichsdorf (Kelheim District) 17,000 t/a biowaste, commercial waste Start-up in 1995. Working with 1-step digestion. Extension with an additional treatment step including hygienisation for food waste in 1997. BTA has provided the design- and approval procedure, delivered particular components and has managed the start-up.
10. Elsinore (Denmark) 20,000 t/a biowaste Start-up in 1991. Plant with 2-step digestion. BTA has provided engineering works, has delivered particular components and realised the start-up of essential plant components. The plant is temporarily not in operation.
11. Garching 6 t waste per week The pilot plant was operated 1986 till 1998 and was used for a lot of tests in the area of research and development. Meanwhile essential parts of the test plant are integrated into the waste treatment plant in Mertingen.

Plants with BTA components

1. Parramatta / Sydney (Camellia) (Australien) 35,000 t/a commercial waste plus additional organic sludges.
BTA has provided engineering works, delivered the bunker technics, the Pre-treatment (BTA-Waste-Pulper, BTA-Grit-Removal-System), and the Control System. The start-up of the plant began in January 2003.

2. Verona (Italy) 70,000 t/a mixed waste
Reconstruction of a mixed waste treatment plant for 500 t/d waste. The wet pre-treatment is designed according to the BTA-Process. The plant went in operation in autumn 2002. BTA has provided engineering works, delivered particular components and assisted in the start-up.

3. Pulawy (Poland) 22,000 t/a mixed waste
The successful acceptance of the plant was in end of March 2001. The pre-treatment of the plant is designed as BTA-Pre-treatment. BTA has provided engineering works, delivered particular components and assisted in the start-up.

4. Nara City (Japan) 1,500 t/a food waste
The pre-treatment of the plant is designed as BTA-Pre-treatment. The plant will start its operation in April 2003. The BTA has provided engineering works, delivered particular components and assists during start-up.

5. Kushima City (Japan) 1,000 t/a commercial waste
The plant is operating since April 2001 and is working with BTA-Pre-treatment. BTA has provided engineering works, delivered particular components and assited in the start-up.

6. Toshigi (Japan)
The pilot plant was operated 1997 till 1998. BTA has provided engineering works, delivered particular components and has assisted in the start-up.

7. Münster 20,000 t/a biowaste
The plant is operating since 1997 and is working with a BTA-Lohse-Pulper.

8. Wels (Austria) 15,000 t/a biowaste
The plant is operating since 1997 and is working with a BTA-Lohse-Pulper.

9. Schwabach 12,000 t/a biowaste
The plant is operating since 1996 and is working with a BTA-Lohse-Pulper.

10. Baden-Baden 5,000 t/a biowaste
Start-up in 1993. Co mbination with an existing sewage plant. Treatment step designed for the demands of a composting plant. 1-step digestion together with sewage sludge. BTA has planned and erected the Pre-treatment and realised the start-up.

11. Kaufbeuren 2,500 t/a biowaste
Start-up in 1992. Integrated in a sewage plant, working with 1-step digestion. BTA has planned and erected the Pre-treatment and realised the start-up

Plants under construction

1. Ieper (Belgium) 50,000 t/a biowaste
The plant is designed according to the BTA-Process. BTA provides engineering works and delivers particular components.

2. Mülheim (a.d. Ruhr) 22,000 t/a biowaste, commercial waste
The plant is designed according to the BTA-Process. BTA provides engineering works and delivers particular components.

3. Alghoba (Libya) 11,000 t/a mixed waste
The plant is designed according to the BTA-Process. BTA provides the complete engineering works and delivers particular components.

4. Ko-Sung (Korea) 3,000 t/a biowaste
The plant is designed according to the BTA-Process. BTA provides engineering works. The plant will be integrated into a combustion plant.

A3 - Production of biodiesel

Biodiesel is produced via a transesterfication reaction between the primary ingredient (vegetable oil or animal fats), and an alcohol (methanol or ethanol), combined with a catalyst. Catalyst materials are typically potassium hydroxide or sodium hydroxide. Reaction products are glycerine (which can be purified and sold), unreacted alcohol, and biodiesel. The process is depicted in the flow diagram below.

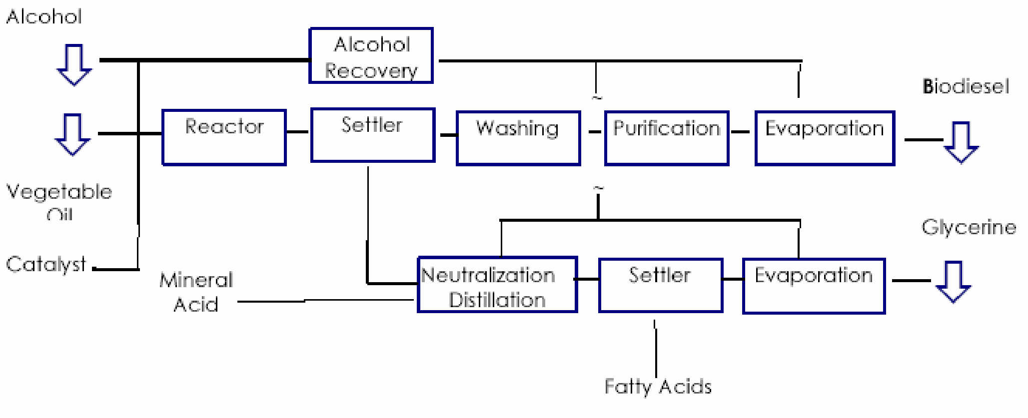


Figure A3 Production of biodiesel

(Source: National Biodiesel Board, www.biodiesel.org)

Uses of biodiesel

Biodiesel can be utilised as a replacement for petroleum diesel. It has the same energy content as diesel and can be used in diesel engines without their requiring modifications (CSIRO, 2002). Biodiesel can be used alone (B100) or mixed in any ratio with petroleum diesel fuel. The most common blend is a mix of 20% biodiesel with 80% petroleum diesel (B20).

The use of biodiesel made from vegetable oils generated from rapeseed, canola, soyabeans, cotton and mustard seed crops has been practiced for many years. The use of biodiesel generated from animal by-products has been tested in many countries and its use is becoming more accepted both internationally and within Australia.

Industries and organisations that are currently using biodiesel include (AJ Bush and Sons):

- Boating industry (Hawaii);
- City Council and School bus fleets (USA);
- Garbage trucks (USA);
- National Parks (USA);
- General Public (available from some local service stations in Europe); and
- All diesel engines (5% bio-diesel blend) (France).

Environmental Benefits

Combustion of biodiesel generates significantly less regulated emissions compared to petroleum diesel fuels. Additionally, biodiesel has a positive energy balance – for every unit of energy needed to produce a gallon of biodiesel, 3.24 units of energy are gained (National Biodiesel Board).

According to information provided by the Australian Biodiesel Association:

- The lifecycle production and use of biodiesel produces approximately 80% less carbon dioxide emission and almost 100% less sulphur dioxide;
- Combustion of biodiesel alone provides a 90% reduction in total unburned hydrocarbons, and 75-90% reduction in aromatic hydrocarbons;
- Exhaust emissions from particulate matter were 30 percent lower than overall particulate matter emissions from diesel; and
- Based on ames mutagenicity tests, biodiesel provides a 90% reduction in cancer risks.

Emissions data collected through evaluation of emission results and potential health effects submitted to the US EPA (Australian Biodiesel Association) is summarised below.

Biodiesel emissions compared to conventional diesel

Emission Type	**B100**	**B20**
Regulated		
Total Unburned Hydrocarbons	-93%	-30%
Carbon Monoxide	-50%	-20%
Particulate Matter	-30%	-22%
NOx	+13%	+2%
Non-Regulated		
Sulfates	-100%	-20%*****
PAH (Polycyclic Aromatic Hydrocarbons)******	-80%	-13%
nPAH (nitrated PAH's)******	-90%	-50%*******
Ozone potential of speciated HC	-50%	-10%
* Estimated from B100 result		
** Average reduction across all compounds measured		
*** 2-nitroflourine results were within test method variability		

(Source: Australian Biodiesel Association).

Quality

Biodiesel standards have been set in various European Countries and in the USA. A comparison of existing standards is shown on the following page. Australian biodiesel standards are currently in the process of being set by the Australian Biodiesel Association.

Sensitivities

Successful replacement of diesel fuels with biodiesel requires that the following issues are taken into consideration:

- Shelf-life: current industry recommendation is to use biodiesel or bio-diesel blends within 6 months to one year (AJ Bush and Sons);
- Performance in cold weather: Biodiesels can gel in very cold weather, which is also common for some types of other diesel fuels. Blends of biodiesel fuels therefore need to be managed with the same fuel management techniques of similar fuels (National Biodiesel Board);
- Biodiesel properties: Biodiesel is a good solvent and if left on surfaces it can dissolve certain types of paints, therefore any spills should be cleaned immediately (Australian Biodiesel Association).

Comparison of biodiesel standards

		Austria	**Czech Republic**	**France**	**Germany**	**Italy**	**Sweden**	**USA**
Standard/ specification		ON C1191	CSN 65 6507	Journal Officiel	DIN E 51606	UNI 10635	SS 155436	ASTM PS121-99
Date		1-Jul-97	Sep-98	Sep-97	Sep-97	Apr-97	Nov-96	Jul-99
Application		FAME	RME	VOME	FAME	VOME	VOME	FAMAE
Density 15°C	g/cm3	0.85-0.89	0.87-0.89	0.87-0.90	0.875-0.90	0.86-0.90	0.87-0.90	-
Viscosity 40°C	mm2/s	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	1.9-6.0
Distillation 95%	C	-	-	< 360	-	< 360	-	-
Flashpoint	C	> 100	> 110	> 100	> 110	> 100	> 100	> 100
CFPP	C	0/-15	-5	-	0/-10/-20	-	-5	-
Pourpoint	C	-	-	< -10	-	< 0/< -15	-	-
Sulfur	% mass	< 0.02	< 0.02	-	< 0.01	< 0.01	< 0.001	< 0.05
CCR 100%	% mass	< 0.05	< 0.05		< 0.05			< 0.05
10% dist.resid.	% mass			< 0.3		< 0.5	-	
Sulfated ash	% mass	< 0.02	< 0.02	-	< 0.03	-	-	< 0.02
(Oxid) Ash	% mass	-	-	-	-	< 0.01	< 0.01	-
Water	mg/kg	-	< 500	< 200	< 300	< 700	< 300	< 0.05%
Total contam.	mg/kg	-	< 24	-	< 20	-	< 20	-
Cu-Corros. 3h/50°C	-	1	-	1	-	-	< No.3	
Cetane No.	-	> 49	> 48	> 49	> 49	-	>48	>40
Neutral. No.	mgKOH/g	< 0.8	< 0.5	< 0.5	< 0.5	< 0.5	< 0.6	< 0.8
Methanol	% mass	< 0.20	-	< 0.1	< 0.3	< 0.2	< 0.2	-
Ester content	% mass	-	-	> 96.5	-	> 98	> 98	-
Monoglycides	% mass	-	-	< 0.8	< 0.8	< 0.8	< 0.8	-
Diglyceride	% mass	-	-	< 0.2	< 0.4	< 0.2	< 0.1	-
Triglyceride	% mass	-	-	< 0.2	< 0.4	< 0.1	< 0.1	-
Free glycerol	% mass	< 0.02	< 0.02	< 0.02	< 0.02	< 0.05	< 0.02	< 0.02
Total glycerol	% mass	< 0.24	< 0.24	< 0.25	< 0.25	-	-	< 0.24
Iodine No.		< 120	-	< 115	< 115	-	< 125	-
C18:3 and high. unsat. acids	% mass	< 15	-	-	-	-	-	-
Phosphor	mg/kg	< 20	< 20	< 10	< 10	< 10	< 10	-
Alcaline met. (Na, K)	mg/kg	-	< 10	< 5	< 5	-	< 10	-

RME.........Rapeseed oil Methyl Ester
FAME.......Fatty Acid Methyl Ester
VOME......Vegetable Oil Methyl Ester

(Source: Biodiesel Association of Australia, www.biodeisel.org.au)

Material Safety Data Information

Sample material data information for biodiesel is shown below (Source: Australian Biodiesel Association).

1. CHEMICAL PRODUCT

General Product Name: ***Biodiesel***
Synonyms: Methyl Soyate, Rapeseed Methyl Ester (RME), Methyl Tallowate
Product Description: Methyl esters from lipid sources
CAS Number: 67784-80-9

2. COMPOSITION/INFORMATION ON INGREDIENTS

This product contains no hazardous materials.

3. HAZARDS IDENTIFICATION

Potential Health Effects:

INHALATION:
Negligible unless heated to produce vapors. Vapors or finely misted materials may irritate the mucous membranes and cause irritation, dizziness, and nausea. Remove to fresh air.

EYE CONTACT:
May cause irritation. Irrigate eye with water for at least 15 to 20 minutes. Seek medical attention if symptoms persist.

SKIN CONTACT:
Prolonged or repeated contact is not likely to cause significant skin irritation. Material is sometimes encountered at elevated temperatures. Thermal burns are possible.

INGESTION:
No hazards anticipated from ingestion incidental to industrial exposure.

4. FIRST AID MEASURES

EYES:
Irrigate eyes with a heavy stream of water for at least 15 to 20 minutes.

SKIN:
Wash exposed areas of the body with soap and water.

INHALATION:
Remove from area of exposure, seek medical attention if symptoms persist.

INGESTION:
Give one or two glasses of water to drink. If gastro-intestinal symptoms develop, consult medical personnel. (Never give anything by mouth to an unconscious person.)

5. FIRE FIGHTING MEASURES

Flash Point (Method Used): 100.0° C min (ASTM 93)
Flammability Limits: None known

EXTINGUISHING MEDIA:
Dry chemical, foam, halon, CO2 , water spray (fog). Water stream may splash the burning liquid and spread fire.

SPECIAL FIRE FIGHTING PROCEDURES:
Use water spray to cool drums exposed to fire.

UNUSUAL FIRE AND EXPLOSION HAZARDS:
Oil soaked rags can cause spontaneous combustion if not handled properly. Before disposal, wash rags with soap and water and dry in well ventilated area. Firefighters should use self-contained breathing apparatus to avoid exposure to smoke and vapor.

6. ACCIDENTAL RELEASE MEASURES SPILL CLEAN-UP PROCEDURES

Remove sources of ignition, contain spill to smallest area possible. Stop leak if possible. Pick up small spills with absorbent materials such as paper towels, "Oil Dry", sand or dirt. Recover large spills for salvage or disposal. Wash hard surfaces with safety solvent or detergent to remove remaining oil film. Greasy nature will result in a slippery surface.

7. HANDLING AND STORAGE

Store in closed containers between 50° F and 120° F.
Keep away from oxidizing agents, excessive heat, and ignition sources.
Store and use in well ventilated areas.
Do not store or use near heat, spark, or flame, store out of sun.
Do not puncture, drag, or slide this container.
Drum is not a pressure vessel; never use pressure to empty.

8. EXPOSURE CONTROL /PERSONAL PROTECTION

RESPIRATORY PROTECTION:
If vapours or mists are generated, wear a NIOSH approved organic vapour/mist respirator.

PROTECTIVE CLOTHING:
Safety glasses, goggles, or face shield recommended to protect eyes from mists or splashing. PVC coated gloves recommended to prevent skin contact.

OTHER PROTECTIVE MEASURES:

Employees must practice good personal hygiene, washing exposed areas of skin several times daily and laundering contaminated clothing before re-use.

9. PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point, 760 mm Hg:>200°C
Specific Gravity (H_2O=1): 0.88
Vapour Pressure, mm Hg: <2
Vapour Density, Air=1:>1

Volatiles, % by Volume: <2
Solubility in H_2O, % by Volume: insoluble
Evaporation Rate, Butyl Acetate=1: <1

Appearance and Odour: pale yellow liquid, mild odour

10. STABILITY AND REACTIVITY

GENERAL:
This product is stable and hazardous polymerisation will not occur.

INCOMPATIBLE MATERIALS AND CONDITIONS TO AVOID:
Strong oxidizing agents

HAZARDOUS DECOMPOSITION PRODUCTS:
Combustion produces carbon monoxide, carbon dioxide along with thick smoke.

11. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL:
Waste may be disposed of by a licensed waste disposal company. Contaminated absorbent material may be disposed of in an approved landfill. Follow local, state and federal disposal regulations.

12. TRANSPORT INFORMATION

UN HAZARD CLASS: N/A

NMFC (National Motor Freight Classification):
PROPER SHIPPING NAME: Fatty acid ester
IDENTIFICATION NUMBER: 144920
SHIPPING CLASSIFICATION: 65

13. REGULATORY INFORMATION

OSHA STATUS:
This product is not hazardous under the criteria of the Federal OSHA Hazard Communication Standard 29 CFR 1910.1200. However, thermal processing and decomposition fumes from this product may be hazardous as noted in Sections 2 and 3.

TSCA STATUS:
This product is listed on TSCA.

CERCLA (Comprehensive Response Compensation and Liability Act):
NOT reportable.

SARA TITLE III (Superfund Amendments and Reauthorisation Act):
Section 312 Extremely Hazardous Substances:
None
Section 311/312 Hazard Categories:
Non-hazardous under Section 311/312
Section 313 Toxic Chemicals:
None

RCRA STATUS:
If discarded in its purchased form, this product would not be a hazardous waste either by listing or by characteristic. However, under RCRA, it is the responsibility of the product user to determine at the time of disposal, whether a material containing the product or derived from the product should be classified as a hazardous waste, (40 CFR 261.20-24)

CALIFORNIA PROPOSITION 65:
The following statement is made in order to comply with the California Safe Drinking Water and Toxic Enforcement Act of 1986. This product contains no chemicals known to the state of California to cause cancer.

14. OTHER INFORMATION

This information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any other process. Such information is to the best of the company's knowledge and believed accurate and reliable as of the date indicated. However, no representation, warranty or guarantee of any kind, express or implied, is made as to its accuracy, reliability or completeness and we assume no responsibility for any loss, damage or expense, direct or consequential, arising out of use. It is the user's responsibility to satisfy himself as to the suitableness and completeness of such information for his own particular use.

Appendix B

Technologies for utilisation of biofuels

Steam boilers

Biogas produced by anaerobic digester tanks or lagoons can be utilised to fire onsite boilers. This method of utilising the biogas is likely to be the most cost effective and energy efficient, since most abattoirs have a need for steam or hot water. Many existing boilers are fired by natural gas, LPG or coal, although diesel is sometimes used for standby units. This provides opportunities for substitution by biogas or biodiesel (full or blended with conventional diesel).

While existing boilers can be converted to take biofuels, it may be more cost effective in many cases to install new boilers, specifically designed for biofuel firing, with the existing boilers remaining as standby units, in case there is an interruption to supply of biofuel.

Gas turbines

Gas turbines are commonly used in large scale power plants, to convert natural gas directly into electricity. The main advantage of gas turbines over steam boilers is that they can be fired up relatively quickly, while steam boilers generally require a number of hours for start up and shut down procedures. However, conventional gas turbines would be too large for most meat works, and micro-turbines have begun to be used for smaller scale applications.

Internal combustion engines

Internal combustion engines are commonly used to drive electrical generators, particularly for smaller applications where gas turbines are not economic. They are one of the oldest and most reliable technologies and can be operated on conventional fuels as well as on biogas, biodiesel or pyrolysis oil.

Common applications for these engines are conversion of biogas from sewage treatment plant digestors, and from landfills into electricity. These engines are often set up in a cogeneration mode, where the waste heat from engine cooling systems is also utilised.

Microturbines

Microturbines are an emerging technology that converts gas into electricity. Currently commercially available microturbines range in size from around 30 to 300kW and they can be fuelled by biogas.

CSIRO Energy Technology has installed the fridge-sized, 30kW USA-manufactured Capstone microturbine at its North Ryde Laboratory, Sydney. Some current manufacturers of microturbines are listed in Table C1.

Table C1 Suppliers of microturbines

Manufacturer/ Supplier	Contact details	Equipment supplied/developed
Capstone	Aquatec Maxcon 119 Toongarra Road, Ipswich QLD 4305 Tel: 07 3813 7100	A 30 kW unit is available to the market with a 24-26% efficiency and a price of about $1,800 per kW. They have recently developed a 60 kW unit.

Manufacturer/ Supplier	Contact details	Equipment supplied/developed
Bowman Power Limited	Ocean Quay Belvidere Road Southampton SO14 5QY ENGLAND Tel: 44 23 8023 6700 http://www.bowmanpower.com	Bowman Power Systems, is developing the Turbogen™ family of small scale compact power generation systems ranging from 25 kW to 80 kW, for distributed power generation and for mobile power applications. These systems are based on compact gas turbines (Micro Turbine Engines) and high speed generator technologies (Turbo Alternators), together with associated power electronics (Power Conditioners).
DTE Energy	DTE Energy Technologies, Inc. 37849 Interchange Drive Farmington Hills, MI 48335 http://www.dtetech.com/	Dtech is developing a turbine that bridges the gap between existing microturbines (less than 100 kW) and larger power turbines (starting at about 800 kW). The ENT-400 will be rated for about 350 kW. The ‘Energy|now’ mini-turbine systems combines a Turbo Genset high-speed electric generator driven by a specially designed, high-efficiency aero-derivative, gas turbine engine from Pratt & Whitney Canada. DTE Energy Technologies has designed the controls that operate the turbine and generator and allow for the integration of the energy|now mini-turbine system into microgrids, and/or interface with utility grids.
Elliott Power Systems	Elliott Energy Systems, Inc 2901 S.E. Monroe Street Stuart, Florida 34997 Tel: 772-219-9449 http://www.tapower.com	Elliott Energy Systems Inc. is a fully owned subsidiary company of Ebara Corporation of Tokyo, Japan. Product lines now extended to 35 kW, 60 kW and 80 kW units. Elliott Energy Systems is in the final stages of commercialising an 80 kW natural gas powered microturbine generator set. It produces 80 kW of high-quality electrical power and significant thermal energy that can be used for cogeneration; (e.g hot water packages, absorption chillers and drying systems.) It is a viable alternative both functionally and economically to traditional reciprocating equipment and as a supplement to the utility grid.

Fuel cells

Fuel cells generate electricity via a catalysed chemical process that occurs when hydrogen is passed to the anode of a fuel cell and where oxygen is simultaneously being fed to the cathode of the cell.

The cathode and anode are separated by a membrane and are surrounded by electrolyte solution. Hydrogen is broken into a proton and electron in the presence of the catalyst, the electron flows between the anode and cathode thus producing an electric current. The protons pass through the membrane and combine with oxygen to form water.

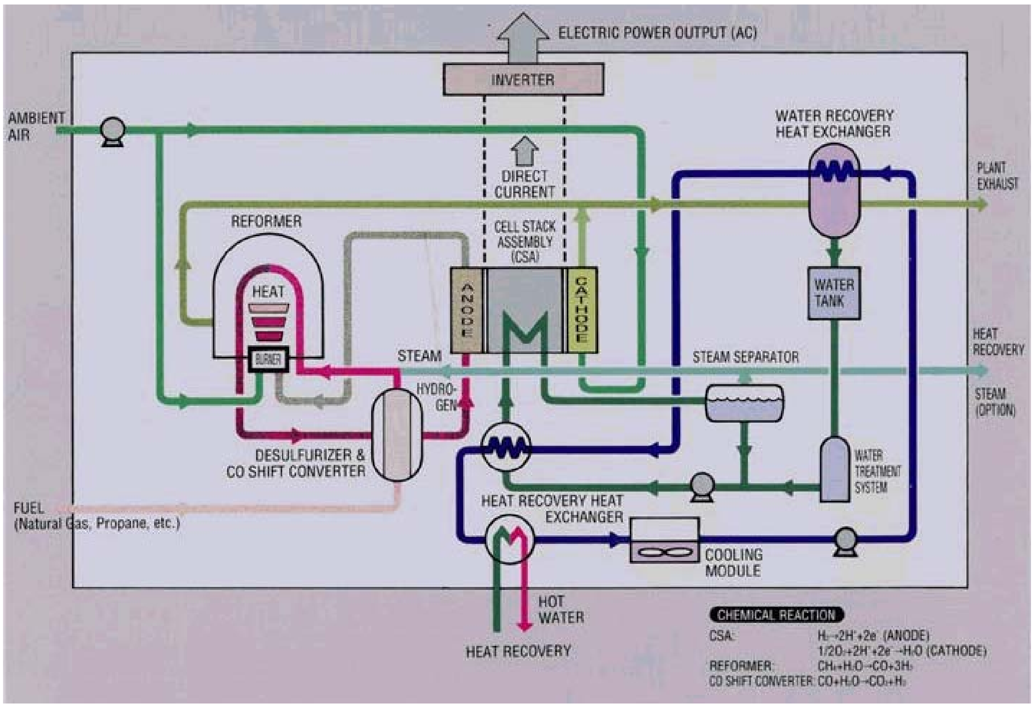


Figure C1 Fuel cell system schematic for Toshiba / UTC PC25 Fuel Cell System

(Toshiba Fuel Cells, http://www.toshiba.co.jp/product/fc/fce/system.htm)

The main advantages of using fuel cells to generate electricity over other technologies include:

- The only products of the process are heat and water;
- The process can operate at efficiencies two to three times that of the internal combustion engine (SAE International, 2003); and
- The process requires no moving parts.

"Cleaned" Biogas is suitable for use as the hydrogen source for electricity production using fuel cell technology. Biogas requires cleaning in order to remove impurities such as any hydrogen sulphide, halogens, moisture and bacteria. If uncleaned, these impurities (particularly hydrogen sulphide) can lead to catalyst poisoning and decreased efficiency due to blocking of reactive sites on the catalyst and the electrodes.

Fuel cells are characterised by the type of electrolyte they use and the operating temperature of the process. Different types of fuel cells and their operating efficiency are displayed in the table below.

Table C2 Characteristics of different fuel cells

Fuel Cell Type	Electrolyte	Charge Carrier	Operating Temperature	Fuel	Power range / Applications	Electrical Efficiency % today (target)
Alkaline FC (AFC)	KOH	OH^-	50-100°C	Pure H_2	Aerospace	40-60

Fuel Cell Type	Electrolyte	Charge Carrier	Operating Temperature	Fuel	Power range / Applications	Electrical Efficiency % today (target)
Proton exchange membrane FC (PEMFC)	Solid polymer (such as Nafion)	H^+	50-100°C	Pure H_2 (tolerates CO_2)	Automotive, CHP, (5-250 kW) portable	35 (45)
Phosphoric acid FC (PAFC)	Phosphoric acid	H^+	~ 220°C	Pure H_2 (tolerates CO_2, approx. 1% CO)	CHP (200 kW)	<42
Molten carbonate FC (MCFC)	Lithium and potassium carbonate	CO_3^{2-}	~ 650°C	H_2>, CO, CH_4, other hydrocarbons (tolerates CO_2)	200 kW – 2 MW range, CHP and stand-alone	47 (60)
Solid oxide FC (SOFC)	Solid oxide electrolyte (yttria, zirconia)	O^{2-}	~ 1000°C	H_2, CO, CH_4, other hydrocarbons (tolerates CO_2)	2-1,000 kW range, CHP and stand-alone	47 (65)

(Renewable Energy World, 2001)

Technology Suppliers

Table C3 Suppliers of fuel cells

Manufacturer/ Supplier	Contact details	Equipment supplied/developed
Ceramic Fuel Cells Limited	170 Browns Road Noble Park Victoria, 3174 Australia Tel: +61 3 9554 2300 Fax: +61 3 9790 5600 Web: http://www.cfcl.com.au/	Ceramic Fuel Cells Limited provide solid oxide fuel cell technology for power generation. Generally the fuel cells are powered by hydrogen generated from the reforming of natural gas, however, they can configured to run on renewable fuels such as biodiesel (requires simple pre-processing).
UTC Fuel Cells	UTC Fuel Cells 195 Governor's Highway South Windsor, CT 06074 USA Voice: (860)-727-2200 Fax: (860)-727-2319 Web: http://www.utcfuelcells.com/	UTC Fuel Cells provide a variety of fuel cells for different applications including residential, industrial, transportation and commercial applications. They have been operating for over 40 years and are solely devoted to developing fuel cell technology.
Siemens Westinghouse	Siemens Westinghouse Power Corp. Science and Technology Center	Solid oxide fuel cells with a particular focus on a new

Manufacturer/ Supplier	**Contact details**	**Equipment supplied/developed**
	Fuel Cells Division 1310 Beulah Road Pittsburgh PA 15235-5098 USA http://www.siemenswestinghouse.com/en/fuelcells/	tubular design. The electrodes are rounded so that the overall cell takes on a tubular shape, air is passed through the centre of the cell and the fuel flows on the outside of the cell.
Toshiba International Fuel Cells	Toshiba International Fuel Cells Corporation 1-1,Shibaura 1-chome, Minato-ku, Tokyo 105-8001, Japan (Toshiba Building 13 F) Tel: 81 3 3457 3622 Fax: 81 3 5444 9199 Web: http://www.toshiba.co.jp/product/fc/fce/index.htm	Range of fuel cells with particular interest in polymer electrolyte fuel cells and proton exchange membranes.

Operational Sites

UTC Fuel Cell/Toshiba Corp installation at Hog Farm in Guangzhou (Canton) city China

http://www.utcfuelcells.com/news/archive/121701a.shtml

In 2001 UTC Fuel Cells combined with Toshiba to install a fuel cell power unit at a hog farm in the Guangzhou (Canton) city, in the Guangdong province of China. The unit is used to generate power for electrical equipment on the farm and surplus power is exported to users outside the farm. The units were initially fuelled by liquefied petroleum gas but after initial start up they will be powered by methane rich biogas produced from hog waste.

Columbia Boulevard Fuel Cell, Portland USA

http://www.energy.state.or.us/biomass/FuelCell.htm

Columbia Boulevard is a wastewater treatment plant in Portland USA. The facility handles approximately 82 million gallons of wastewater per day and produces biogas as a by-product of the sewage treatment process.

A phosphoric acid fuel cell (manufactured by ONSI Corporation, a   ubsidiary of UTC Fuel Cells) has been installed which uses the biogas to generate electricity. This power is sold to Portland General Electric.

Biogas from organic waste and household collection used to power fuel cell, Germany

German waste treatment company RPS Altvater owns and operates a fuel cell power plant that uses biogas produced from the anaerobic digestion of household and organic wastes as the fuel feedstock. The plant generates biogas at a capacity of 18,000 tonnes per year; translating to 1.8 million m^3 of raw biogas and an energy equivalent of almost 10 million kWh. Conversion of the biogas into electric power and heat takes place in two gas engines.

Figure C2 Molten carbonate fuel cell power plant

(Renewable Energy World)

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