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Thermal treatment options

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Technologies and experience worldwide

As municipal solid waste is being generated in increasing amounts all over the world, there is a greater need to reduce waste volumes heading for landfill. Thermal treatment technologies can do just this – more, they can offer an effective way of recovering valuable energy.

Many countries are at a crucial junction on the way to tackling the ever-increasing waste problem. A fresh look at their strategic options suggests that processes such as waste-to-energy (WTE) could play a more important role. This neglected energy source could also have a major impact on power generation at a local level. It would resolve some of the potential future electricity generation problems while conserving landfill space and helping to meet the requirements of the EU landfill directive and other landfill legislation worldwide.

INCREASE IN WASTE ARISING WORLDWIDE

While technological progress over the past three centuries has facilitated population growth through improvements in sanitation, medicine and intensive farming, it has also resulted in much more pollution. Material consumption has also grown to reflect both population growth and increased worldwide industrial globalization. With growth comes waste.

Table 1 contains data for 2001 on MSW generation in selected countries and regions obtained from Eurostat¹ and the websites of national governments. These sources were also used to obtain the data given in Tables 2 and 3.²

Waste-to-energy could play a more important role in waste management

MSW arisings for EU-25 includes eastern European countries where the gross domestic product (GDP) is below that in the EU-15 Member States (i.e excluding the 10 states that joined in 2004). This is reflected in the difference of only 26 million tonnes in the waste arisings between EU-25 and EU-15. In 2001, Japan generated just over 52 millions of MSW – a similar amount to that of Germany. However, the substantially different topographical conditions between the two countries mean that Japan needs to use extensive waste reduction measures to help resolve its disposal problems.

The variations in MSW production due to population differences are highlighted in the data shown for the US, UK, France, Germany, the Netherlands and Luxembourg. The values for waste generated per capita for these countries show significant variations. These are assumed to be a function of cultural and lifestyle differences, such as 412 kg/capita in Japan compared with 730 kg/capita in the US.

There is also a substantial variation in the amount of waste landfilled in the different countries. This is the result of the availability of disposal sites as a function of land mass, the use of other reduction technologies, recycling and local controls/ legislation.

TABLE 1. MSW treatment and disposal, 2001

Country/region	MSW arisings (million tonnes)	Waste generated per person (kg/capita)	Amount landfilled (%)
EU-25	239	516 ^a	54

EU-15	213	556 ^a	49
UK	34.9	590	80
France	32.2	545	43
Germany	48.8	610	25
The Netherlands	9.8	612	8
Luxembourg	0.29	673 ^a	21
US	226	730	56
Japan	52.4	412	7

^a Estimate

Table 2 shows the increase in the amount of MSW collected between 1995 and 2001 for the same areas as in Table 1. The data are shown as kg/capita to normalize the population size. All show a substantial increase (from about 500 to 600 kg/capita) since 1995 – an average 3% year-on-year increase in waste arisings. The only difference is France where the growth is about half that of the other countries, and the US where there has been a 1% reduction in MSW collected per person.

In general, if this growth is maintained up to 2020, the amount of waste generated/collected will double. This will cause even greater pressure on disposal routes. Landfill costs have also started to show dramatic increases; for example, costs in the UK have more than doubled since 2003.

If current growth of MSW generation is maintained to 2020, the amount of waste generated/collected will double

Reuse, recovery and recycling strategies are unlikely to meet the potential growth in MSW. Other options thus need to be considered urgently. Thermal treatment processes offer viable alternatives.

The calorific value of MSW is about 10 GJ/tonne – about a third of that for coal. When burnt in a modern, well controlled mass-burn incinerator, such systems give about 20% efficiency for conversion to electricity. Much higher conversion efficiencies are possible with improved recycling and refining through processes such as mechanical–biological treatment (MBT) to create an energy-rich and consistent material that is better suited as a fuel. It is possible to achieve electrical conversion efficiencies of as high as 40%.

TABLE 2. MSW collected per capita, 1995–2001

Country/region	1995 (kg/capita)	2001 (kg/capita)	Percentage change (%)
EU-25	459 ^a	516 ^a	12.4
EU-15	483	556 ^a	15.4
UK	499	590	18.2
France	501	545	8.9
Germany	533	610	14.4
The Netherlands	549	612	11.48
Luxembourg	591	673 ^a	13.87
US	736	730	-1.0
Japan	407	412	1.0

^a Estimated for the year based on previous consumption during the period

THERMAL TREATMENT PROCESSES

The different types of thermal treatment technologies used in an integrated waste management system can be

classified according to:

- material input
- processing temperature
- related by-products.

In general, they are attached to some form of recovery system such as a bulk material recovery (material recovery facility or MRF) and/or an MBT plant. Product streams from these plants are fed directly to the thermal process. The process could be a mixture of fuel preparation and thermal conversion, which may be sited near bulk recovery plants or as a centralized facility.

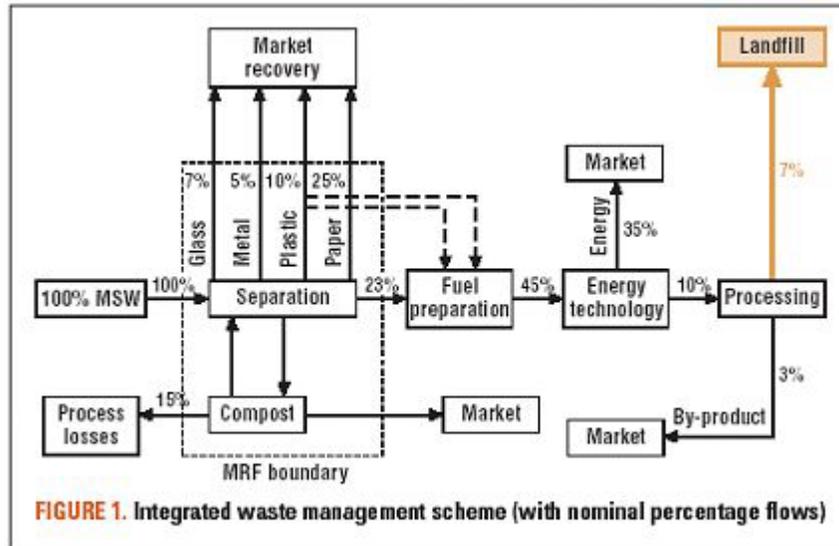


Figure 1 shows a generalized integrated waste management flow incorporating thermal treatment. The flow includes separation, composting, thermal treatment and processes for utilizing the secondary residue. It is assumed that aggregate and cement production are the main beneficiaries of the thermal residue. The nominal percentage flows quoted in Figure 1 represent an ideal material balance. They indicate that landfill is still required and that it amounts to about 7% of the initial MSW.

Figure 2 shows a typical temperature process path for waste treatment. This can be classified as:

- anaerobic digestion – treatment of the organic fraction of the waste stream in the absence of oxygen
- sterilization – a low-temperature pre-treatment process using ‘as received’ MSW followed by a range of waste manipulation processes
- gasification and pyrolysis – flexible process producing a range of outputs including syngas
- direct combustion – the most common form is incineration.

Anaerobic digestion

Anaerobic digestion has a number of environmental advantages and was initially designed to handle farm slurries. The use of anaerobic digestion is gaining acceptance for processing the organic fraction of MSW to obtain biogas and a disposable digestate, a combination of liquor and solid residue. However, there is also interest in using the technology as an amendment to the traditional composting process.

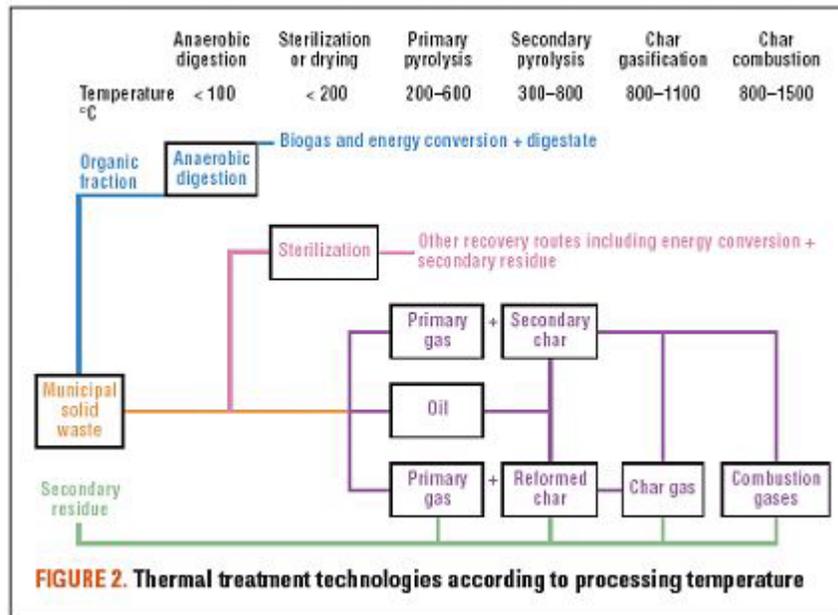
The main factors that affect the economic viability of anaerobic digestors are feedstock, biogas yield and efficiency of utilization. The biogas produced can either support the process or be converted into electricity using a suitable prime mover or generation plant.

There are three main types of digestion processes, depending on temperature.

- Psychrophilic digestion occurs at 5°–15°C. This low-temperature process requires less time for heating, but needs more time to break down the waste material. It is seldom used because it is difficult to maintain the reactor at a constant temperature.
- Mesophilic digestion occurs at 25°–45°C and requires some heat input.
- Thermophilic digestion occurs at 55°–75°C and requires a much larger heat input. The heat input can be

as much as twice that of mesophilic processes, but the material is broken down more quickly.

The size of the digester is a function of the process temperature and the retention time (the time needed to release the maximum energy, taking account of the energy potential of the biogas and the energy required to heat the digester).



Anaerobic digestors are normally used in conjunction with a boiler or combined heat and power (CHP) plant. Byproducts consist of a liquor and solid residue. In some situations the liquor can be used as a liquid fertilizer upon post-treatment, and the solid residue is further treated within traditional composting processes.

Sterilization

Sterilization is commonly regarded as a prerequisite to a 'dirty MRF' where the MSW is accepted in the 'as received' state. Any pathogens in the MSW are killed off and recyclable materials such as cans and glass are cleaned during the process.

Autoclaves are typically used to heat and sterilize the organic fraction of the waste using steam at a temperature up to 175°C. The process is undertaken in batches and recycling is carried out once sterilization is complete. The processing temperature means that the plastics are generally agglomerated for further processing, for instance, as feedstock for a CHP system. The organic fraction (including paper) forms a 'mush', which can be composted.

This type of process has a good potential and has attracted considerable interest. In countries with specific recycling and composting targets, however, there has been concern over the recovery rates (especially those for composting) since a large fraction of the waste is used to generate energy.

Gasification and pyrolysis

These processes are extremely complex. They are highly sensitive to the moisture content and quality of the feedstock and the processing temperature.

There are two main differences between them. First, pyrolysis is undertaken at an equivalence ratio (actual air/air required for complete combustion) of less than 0.2 (typically below 0.15), whereas gasification usually has an operating ratio of between 0.2 and 0.4. Secondly, the processing temperatures for pyrolysis is lower (Figure 2).

Gasification and pyrolysis are rapidly gaining acceptance

Depending on the rate of temperature change with time, pyrolysis can be classified into fast, slow, ablative and flaming processes. Gasification can be classed into fluidizedbed, suspension, up-draft, down-draft and

cross-bed processes. Carbon monoxide, hydrogen and methane are the typical gases generated within the reaction chamber.

Both gasification and pyrolysis are gaining rapid acceptance in the market place as a viable alternative to incineration – especially at throughputs less than 100,000 tonnes/year. The economics are crucial for market acceptability since operating costs can be high; gate fees, available markets for the residues and CHP output are critical factors for commercial viability.

Of the two, gasification is a more robust process, having a wide range of operating conditions and techniques. According to the Energy from Waste Association (EWA) in the UK, average capital costs for a plant with a capacity of up to 360,000 tonnes/year are £8–93 million (US\$14.6–170 million), with equivalent operating costs of around £45/tonne (\$82/tonne). However, such plants have planning horizons of 4–6 months and the design to commissioning timescale is only 12–30 months.

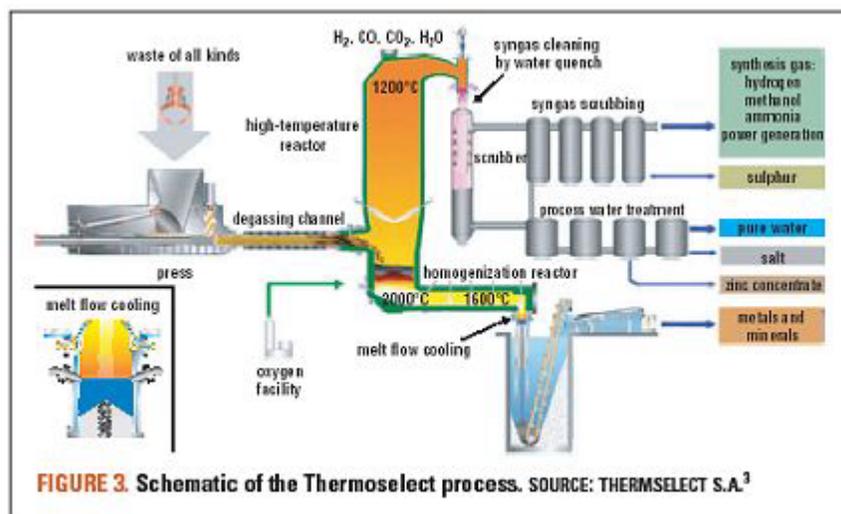
If the waste is used merely a non-homogeneous fuel source, there are major impacts on the calorific value, quality and variability of the syngas produced for further use. The best operational conditions are obtained when the material is sorted and pre-prepared such that uniformity can be maintained. When the syngas, which can be hydrogen-rich, is used to drive a gas turbine, cleanliness and composition are crucial to maximizing power output.

There are a small number of gasification plants operating throughout the world. One of the most recognized systems is the Thermoselect process (Figure 3). Two of such gasification plants are located in Japan. One is at Chiba in greater Tokyo; it has a waste input of about 100,000 tonnes/year and has been operating since autumn 1999. The other, in Mutsu in the north, uses about 50,000 tonnes/year and was commissioned in 2003. For the Chiba plant, about 80% of the syngas is passed on to neighbouring steelworks. A 1.5 MW gas engine is used to generate electricity. Further collaboration is taking place with Toshiba Corporation, where a 200 kW fuel cell is currently undergoing trials for syngas utilization in order to achieve the highest possible efficiencies for the conversion into electricity.



The Thermoselect gasifier at Chiba in Japan.
THERMSELECT S.A

At Cardiff University, our research over a number of years has led to the development of operational prototypes with a thermal size on the scale of megawatt. In addition, our waste research station works in conjunction with large-scale composting research facilities to develop sustainable waste management techniques. At Cardiff, the 'on the ground data' being fed into our research programmes clearly indicate a need for WTE processes to be continually developed to meet the changing face of waste generation.



Direct combustion

Incineration is the best-known process in this technology sector. It operates with equivalence ratios greater than 1 and incorporates the general stages of drying, partial pyrolysis/gasification, followed by final char burning to

eliminate most of the carbon in the ash. This ash can often be used as feedstock for processes such as cement manufacture and is therefore a valuable source of income.

The key variables controlling the incineration process are:

- residence time
- combustion temperature
- moisture content of the waste
- size distribution of the material.

The general types of process using this technology are grate firing, suspension firing and fluidized-bed combustion systems (standard bed design, circulating or revolving). The favoured technology for large-scale plants (greater than 100,000 tonnes/year) is currently the moving-grate design, though there has been some variation to include partial suspension above the grate. This technology has been 'tried and tested' with a range of fuels including MSW.

Incineration is generally accompanied by a large amount of environment legislation. This means that sophisticated back-end processes to ensure discharges are within the limits set by a particular country. An example of a typical WTE plant is the solid waste incinerator serving the city of Long Beach, California, US, which began commercial operation in July 1998. The plant uses mass-burn technology to process around 1000 tonnes/day of MSW while generating up to 38 MW of electricity. Part of the electricity is used to operate the facility and the remainder is sold to the local electric utility, Southern California Edison. Figure 4 shows a schematic of the operation.

TABLE 3. MSW management, 2001

Country/region	Landfilled (%)	Incinerated (%)	Recycled, composted or other treatment (%)
EU-25	54	16	20
EU-15	49	18	33
UK	80	7	12
France	43	32	25
Germany	25	22	53
The Netherlands	8	33	59
Luxembourg	21	44	35
US	56	15	29
Japan	7	77	15

The EWA in the UK confirms that mass burn incineration is the main thermal process at present. Typical capital costs for a plant processing up to 500,000 tonnes/year are £16–100 million (\$29.3–182.9 million), with typical associated operating costs of £45/tonne (\$82/tonne).

Planning time horizons are typically 24–60 months and design-to-commissioning timescales vary from 54–96 months. These timescales indicate a reluctance to promote mass-burn incineration with energy recovery. More importantly, the loss in time will ensure that the UK's waste strategy will not be developed on time. This situation is also faced by many other countries, where new facilities are also required to cope with the increased amount of waste being generated.

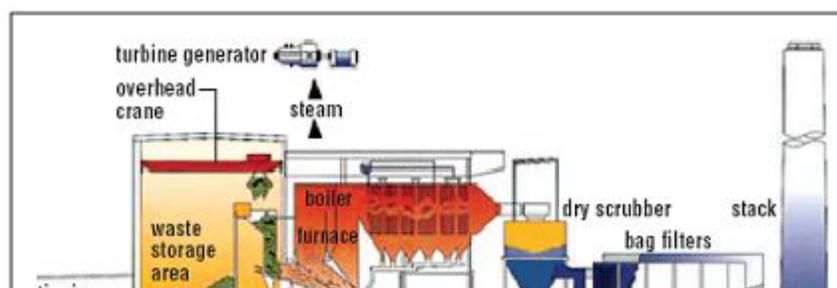




FIGURE 4. Schematic of the Long Beach incinerator. SOURCE: SANITATION DISTRICTS OF LOS ANGELES COUNTY

Incineration tends to be an unfavourable solution due to the public's perceived problems associated with discharges from the process to the environment. 'Mass-burn incineration' is seen as a dirty process – a perception stemming historically from plants being poorly operated. However, modern mass-burn incinerators are highly complex chemical plants with much of the capital cost arising from the complex treatment of the flue gases, solid waste and liquid effluents. Current designs meet all emission/pollution standards. Rebranding is clearly required.



Waste incinerator at Long Beach, California.

SANITATION DISTRICTS OF LOS ANGELES COUNTY

Apart from the poor public perception, the other downside associated with incineration is its low thermal efficiency. This is typically about 20% for power generation, though much higher if CHP is possible (but difficult to justify economically). In addition, typical plant capacities are around 250,000 tonnes/year. This is significantly greater, for example, than the amount of MSW generated by the largest unitary authority in Wales, but process economics are doubtful for small-scale plant.

Table 3 shows the relative use of different waste management options for the countries/regions considered earlier. In terms of incineration, there is a wide variety of usage – ranging from 77% in Japan to only 7% in the UK. Historically, the UK has used landfill as its solution to its waste problem and there has always been a reluctance to use incineration due to poor acceptance and public hostility. In Luxembourg, 44% of MSW is incinerated and, as in Japan, this higher percentage reflects the lack of landfill disposal sites. Typically, 20%–30% of MSW is incinerated in France, Germany and the Netherlands. Again there is some public disquiet over the use of this technology, but realization of the need to reduce the mass going to landfill and the lack of land availability has outweighed public concerns.

Although incineration is the dominant technology in Japan, there is also considerable interest in:

- gasification with ash melting/vitrification attached to the overall process
- thermal decomposition technology for hazardous 'off gases'
- conversion of waste plastics into oil
- stoker furnace technology for improved incineration.

THE WAY FORWARD

With the projected increases in MSW arisings over the next 20 years, many countries are facing real problems in implementing robust workable strategies for processing this waste stream. Thermal treatment offers a significant opportunity to support government drive to reduce waste going to landfill in conjunction with recycling and composting. Many of these plants also have net energy outputs, which could have a significant impact for many countries on power generation since the mix and match of energy as well as security of supply are fundamental issues.

There will be no unique solution for resolving the waste problem. Cultural, waste composition, infrastructure and management practices will dictate the particular wasteprocessing route. The only certainty will be the mix of solutions in which thermal treatment, and hence waste-to-energy, will play a crucial part. However, the public in many countries is very uneasy about the use of this technology. For the 'thermal treatment' sector to grow and hence succeed, political stimulation and public confidence will thus need to be developed alongside further continuing research and development in the technology.

Tony Griffiths is Professor in process engineering and **Keith Williams** is Professor in environmental engineering at the Centre for Research in Energy Waste and the Environment (CREWE), Cardiff School of Engineering, Cardiff University, UK.

e-mail: GriffithsAJ2@cardiff.ac.uk

web: www.wasteresearch.co.uk

NOTES

1. The EU statistical office; <http://europa.eu.int/comm/eurostat>
2. Most of the data quoted is for 2001 due to the time lag within the EU reporting structure, though the report date was 2001–2004. Data for the EU-25 countries were based on some estimated capacities and should be read as being indicative.
3. This diagram was previously published in W. Kaiser and M. Shimizu, 'High-temperature gasification – the Thermoselect process', *Waste Management World*, November–December 2004.

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