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Thermal treatment review

Global growth of traditional and novel thermal treatment technologies

by Nickolas J. Themelis

Thermal treatment facilities built in the 21st century have been based mostly on the grate combustion of 'as received' municipal solid waste (MSW). Three dominant technologies - those developed by Martin, Von Roll, Keppel-Seghers - have shown consistent growth of about three million metric tonnes of new waste-to-energy (WTE) capacity each year since 2000. In terms of novel technologies, direct smelting (JFE, Nippon Steel), fluidized bed (Ebara) and circulating fluidized bed (Zhejiang University) have accounted for an additional estimated growth of another one million tonnes per year.

Although some of the new processes are called 'gasification', in fact they are 'gasification-combustion' processes where the calorific value of the MSW is recovered in the form of steam (as in conventional WTE processes). The only true gasification process at an industrial scale is the Thermoselect process, currently operating at seven facilities built by JFE, a major Japanese steel maker.

This review examines the growth of dominant technologies and the emergence of novel solutions in the thermal treatment of waste. The global perspective on the current position of thermal treatment highlights how significant WTE is becoming worldwide. A look at thermal treatment technologies in China and Japan gives a sense of some of the novel solutions emerging in the market.

A global perspective

The Waste-To-Energy Research and Technology Council (WTERT), headquartered at Columbia University in New York City, keeps a close watch on the thermal treatment technologies used worldwide. In 2006, nominations were solicited for the 2006 WTERT Industrial Award to be presented to an operating WTE facility judged by an international committee to be among the best in the world on the basis of the following criteria:

- energy recovery in terms of kWh of electricity plus kWh of heat recovered per tonne of MSW, and as the percentage of thermal energy input in the MSW feed
- level of emissions achieved
- optimal resource recovery and beneficial use of WTE ash
- aesthetic appearance of the facility
- acceptance of the facility by the host community.

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TABLE 1. Finalists for the WTERT 2006 Award

Name/operator	Location
Afval Energie Bedrijf (AEB)	Amsterdam, Netherlands
ASM Brescia	Brescia, Italy
Covanta Energy	Montgomery County, Maryland, USA
Veolia Environmental Services Waste-to-Energy (Veolia ES WTE)	Montgomery County, Pennsylvania, USA
SELCHP (Veolia)	London, UK
SEMASS (Covanta Energy) - RDF plant developed by Energy Answers Corporation	Massachusetts, USA
Spittelau	Vienna, Austria
SYSAV	Malmo, Sweden
Umeå Energi	Dåva, Sweden
Veolia Environmental Services Waste-to-Energy (Veolia ES WTE)	York County, Pennsylvania, USA

From the nominations, 10 finalists were selected and requested to submit a specified set of 2005 operating data. The list of finalists included nine stoker grate (mass burn) facilities and one refuse-derived fuel (RDF) plant (Table 1).

The competition was fierce, as all 10 finalists had demonstrated high availability and very low emissions; Table 2 compares the emissions of the three top contenders for the award and gives the average emissions of all 10 plants, along with corresponding EU and US environmental standards. The WTERT 2006 Industry Award was won by the ASM Brescia facility which had the best combination of energy recovery, emissions and aesthetic appearance.

Greater capacity, lower emissions

Life-long opponents of waste-to-energy usually cite dioxin emissions as the main reason for their opposition. It is interesting to note that the 0.02 ng/nNm3 highlighted in Table 2 corresponds to an emission rate of 0.2 grams of dioxins per million tonnes of MSW combusted in these WTEs.

Opponents of combustion with energy recovery also claim that 'incineration is dead'. Indeed a book of this title can be found on the internet. Of course, the term 'incineration' is too broad and should not be used to describe facilities that in fact are power plants using MSW as fuel. For example, in the USA there are over 1600 incinerators of all types but less than 300 units that combust MSW and recover energy.

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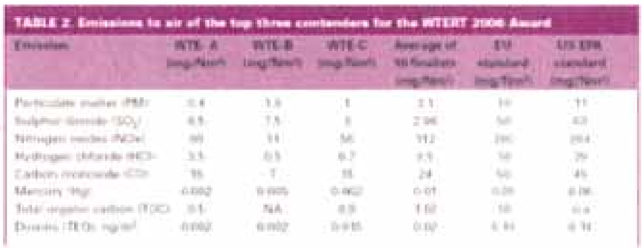

TABLE 2: Emissions to air of the top three contenders for the WTERT 2006 Award

A recent review of the WTE industry by WTERT has shown that, since the beginning of this century, global capacity has increased steadily at the rate of about four million tonnes of MSW per year. This is illustrated in Table 3 (opposite), which summarizes the reported annual construction of new WTE capacity by only three technologies - Martin, Von Roll and Keppel-Seghers - at an average of 2.78 million tonnes per year. The contribution of all other technologies is estimated to about 1.2 million tonnes.

China

The foremost university in China for the study of waste management is Zhejiang University where Professor Cen Kefa and his colleagues have developed the circulating fluidized bed (CFB) reactor used in several WTE facilities in China. According to estimates by the group at Zhejiang University, 668 cities in China landfilled 140-160 million tonnes of MSW in 2002 and the annual growth in MSW generation amounts to 6%-8%. These numbers suggest that as little as 187 million tonnes or high as 235 million tonnes of MSW could be landfilled in 2007. The accumulated amount of MSW in non-regulated landfills in China was estimated at 6 billion tonnes.

Total thermal treatment capacity in China is estimated at about 4 million tonnes in less than 50 facilities. About 4100 tonnes/day uses stoker grate technology - some provided from Europe (Martin, Alstom and Keppel Seghers) and some of domestic design.

The total installed capacity of Zhejiang University's CFB technology is 3800 tonnes/day and another 3200 tonnes/day are under construction. The high efficiency of scavenging recyclable materials in China means that the calorific value of Chinese MSW can be as low as 5000 MJ/kg, i.e. half of that in the EU. For this reason, the Zhejiang CFB process mixes a small amount of coal with the MSW feed.

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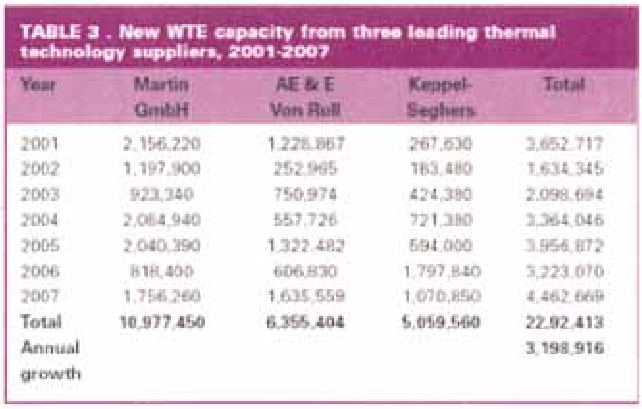

TABLE 3 . New WTE capacity from three leading thermal technology suppliers, 2001-2007

Year	Martin GmbH	AE & E Von Roll	Keppel-Seghers	Total
2001	2,156,220	1,228,867	267,630	3,652,717
2002	1,197,900	252,965	183,480	1,634,345
2003	923,340	750,974	424,380	2,098,694
2004	2,084,940	557,726	721,380	3,364,046
2005	2,040,390	1,322,482	594,000	3,956,872
2006	818,400	606,830	1,797,840	3,223,070
2007	1,756,260	1,635,559	1,070,850	4,462,669
Total	**10,977,450**	**6,355,404**	**5,059,560**	**22,92,413**
Annual growth				**3,198,916**

It is interesting that, in a developing nation, a high cost technology such as the CFB process is gaining ground over landfilling. The two main reasons are the ability to recover indigenous energy and the scarcity of land in China for future landfills.

Japan

Japan is the largest user of thermal treatment of MSW in the world (40 million tonnes). The principal technology used is grate combustion of 'as received MSW' (i.e. mass burn). The major supplier is Mitsubishi Heavy Industries (using the Martin technology), followed by JFE.

However, there are over 100 thermal treatment plants using relatively novel processes such as direct smelting (JFE, Nippon Steel), the Ebara fluidization process and the Thermoselect gasification and melting technology process. These processes have emissions as low or lower than the conventional WTE combustion process, but produce a vitrified ash that can be used beneficially outside landfills. Table 4 shows the installed capacities of these processes in Japan.

Selected technologies: the emergence of new solutions

The JFE direct melting process

JFE is the new company resulting from the merger of NNK Steel and Kawasaki Steel, which have built several plants where MSW is first converted to refuse-derived fuel (RDF). Glass and metal particles are removed and the remaining MSW is dried in a rotary kiln and then extruded under pressure into 20-mm long by 15-mm diameter cylindrical particles. The material produced in several RDF facilities is then transported to a regional direct smelting (DS) facility, where it is combusted with energy recovery.

For example, the Fukuyama DS plant, which I visited in March 2006, is supplied by seven RDF facilities. The RDF is fed by means of a corkscrew feeder on top of a vertical shaft furnace that resembles a small iron blast furnace. As the RDF descends through the furnace, it is gasified and inorganics are smelted to slag and metal, which are tapped at the bottom of the shaft. The gas product is combusted in an adjoining boiler to generate steam which is used to generate electricity in a steam turbine, much as in conventional WTE.

The combined process can handle up to 65% water in the MSW (the usual range is 40%-50%), which in the drying kiln is reduced to 5%-6%. The process requires the addition of coke (about 5% of RDF), which is also added at the top of the shaft along with sufficient lime to form a fluid slag at the bottom of the furnace. The JFE process produces slag and metal (10% of RDF) and fly ash (2% of RDF), which contains volatile metals and is landfilled.

Air is introduced into the furnace through primary, secondary and tertiary tuyeres located along the height of the shaft. The primary air, near the bottom of the shaft, is enriched to about 30% oxygen in order to generate the high temperatures required to melt slag and metal at the bottom of the furnace.

The availability of the Fukuyama facility is 90% (i.e. the hours of operation at design capacity divided by the total hours in a year) and the refractory lining of the shaft has a lifetime of 3-4 years. An estimated 5000 Nm3 of gas is generated per tonne of RDF, i.e. the same order of magnitude as conventional WTE facilities. The slag and metal overflow from the furnace and are quenched in a water tank to form small spherical particles of metal and slag. The copper content of the metal fraction is apparently too high to be used in steelmaking and too low to be suitable for copper smelting; its main use is as a counterweight in cranes and other ballast applications.

As shown in Table 5, JFE has also built several mass burn plants using the Danish Volund grate technology. However, it has developed its own JFE Hyper grate system, which consists of movable and fixed grate bars. The grate is horizontal but each grate bar is inclined 20° upward in the direction of the waste flow, i.e. towards the ash discharge end. The movable grates slide upward over fixed grates, and the movement of waste through the furnace is controlled by the length of the stroke and the speed of the movable grates.

The Ebara fluidized bed process

The Ebara process consists of partial combustion of debagged and shredded MSW in a fluidized bed reactor followed by a second furnace where the gas produced in the fluidized bed reactor is combusted to generate temperatures up to 1350°C such that the ash is vitrified to slag. There is no oxygen enrichment. The largest application of the Ebara process is a three-line 900-tonne per day Madorito plant in Spain.

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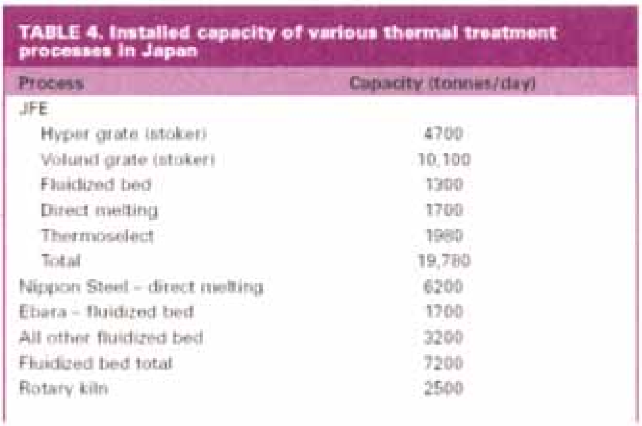

TABLE 4. Installed capacity of various thermal treatment processes in Japan

Process	Capacity (tonnes/day)
JFE	
Hyper grate (stoker)	4700
Volund grate (stoker)	10,100
Fluidized bed	1300
Direct melting	1700
Thermoselect	1980
Total	19,780
Nippon Steel - direct melting	6200
Ebara - fluidized bed	1700
All other fluidized bed	3200
Fluidized bed total	7200
Rotary kiln	2500

The ash overflow from the fluidized bed is separated from the sand used in the reactor for fluidization. Separation is by means of an inclined vibrating screen with 3-4 mm openings. Thus the sand can pass through while glass and metal particles cannot. Bottom ash in Japan cannot be used for applications such as road construction and therefore has to be melted into slag, which is the final solid product and can be used in construction. I was told by Ebara engineers that the Madorito plant provides 21 MW of electricity to the grid, i.e. about 560 kWh per tonne of RDF.

Thermoselect technology

The Thermoselect gasification and melting process was developed in Switzerland between 1985 and 1992. A demonstration facility with a capacity of 110 tonnes/day was built in Fondotoche, Italy, and used to validate the technology; the facility operated under a commercial licence from 1992 until 1999.

A larger commercial facility with a capacity of 792 tonnes/day was built at Karlsruhe in Germany and started up in 1999. The plant operated until a commercial dispute led to its being 'mothballed' at the end of 2004, pending the outcome of litigation. Recent information suggests that the dispute is about to be settled and that the future operation of the facility is being studied.

In the 1990s, Kawasaki Steel Corporation of Japan also became interested in the Thermoselect process and, in 1999, started up the first Thermoselect plant in Japan - at Chiba City close to Tokyo. In 2001, Kawasali Steel merged with NKK Corporation to form JFE - the fifth large steelmaker in the world and a major engineering company within Japan in the construction of WTE facilities (see above).

The second Thermoselect plant in Japan began operations in 2003 at Mutsu. Four more plants were built in 2005 and a seventh started operation in 2006 (at Yorii). Six of these plants were built after the JFE merger. The fact that this major engineering company, with a reference list of over 80 thermal treatment plants, has proceeded to build six Thermoselect plants is noteworthy. The seven JFE plants operate a total of 16 Thermoselect units and have a total daily capacity of nearly 2000 tonnes (Table 5).

In 2005 and 2006, New York City and Los Angeles sponsored preliminary evaluations of alternatives to landfilling, but excluding conventional combustion with energy recovery (WTE) because of political opposition within these cities to 'incineration'. The Thermoselect technology was one of the many examined in these two independent studies and, in both cases, was rated at the top or near the top of the proposed alternatives. In spring 2007, the Earth Engineering Center of Columbia University undertook an in-depth analysis of the present status of the Thermoselect process and its future potential for replacing landfilling. The study included visits to the Chiba and Kurashiki JFE Thermoselect plants in Japan.

The first Thermoselect plant at Chiba was the testing ground where many minor problems were overcome through design and operating changes which were adopted in the other six plants built by JFE. The availability of the operating plants (i.e.

the hours of operation at design capacity divided by the total hours in a year) is about 80%. As is the usual experience with new processes, the accumulating operating experience should increase availability.

A tonne of typical MSW contains about 2800 kWh of chemical energy. The quenching of the high temperature syngas means that the JFE TS process has an inherent loss of about 400 kWh/tonne in the conversion of MSW to syngas. An additional debit in the energy account is the use of natural gas or syngas for drying and pre-heating the MSW in the gasification and the homogenization channels. A third debit of electricity is in the production of the oxygen needed for the process, estimated at about 100 kWh/tonne MSW. However, an inherent advantage of the JFE TS process is that the generated syngas can be used to power a gas turbine or engine at a thermal efficiency of 40%, which is double the thermal efficiency of the conventional WTE process.

As noted above, a major advantage of the Thermoselect plants in Japan is that the ash is transformed to slag particles which can be used as a substitute for stone aggregate and other applications. This is a requirement for all WTE operations in Japan. Conventional grate systems in Japan therefore require a second furnace - either a submerged electric arc furnace or a thermal plasma reactor - to vitrify the ash produced in the WTE. In contrast, the Thermoselect process generates a vitrified ash in a single furnace.

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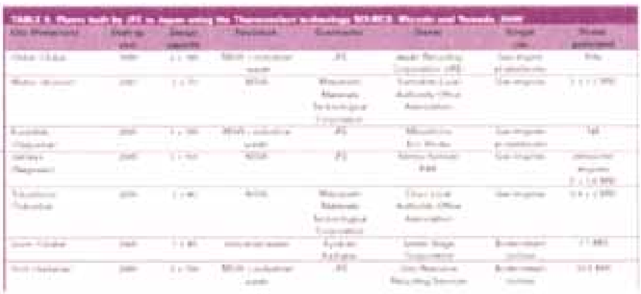

Visitors to the Kurashiki JFE Thermoselect plant feel they are visiting a traditional WTE plant. MSW collection trucks drive into an enclosed building and discharge their contents into a bunker. Crane operators sitting in an adjoining glass-walled room pick up waste from the bunker and deposit it on top of the chutes that feed the horizontal chamber where the MSW is compressed by a piston and dried before it reaches the vertical rectangular shaft where its is fully gasified and smelted. However, a definite aesthetic advantage of the Thermoselect plant is the absence of a tall stack.

The syngas produced in the Thermoselect furnace is quenched and then cleaned before it is used in gas turbines or engines to generate electricity. The amount of gas produced per tonne of MSW is much lower than in conventional combustion and steam generation units. However, cleaning a reducing gas is more complex than for combustion process gas.

Impact of global WTE capacity on reducing landfill emissions

Sustainable management of MSW requires every possible effort to be made to separate recyclable or compostable materials from the MSW stream. Experience has shown that it is best for these materials to be separated at source, i.e. at households, businesses and institutions. The cost of source separation is then shared by the generators (in terms of time and effort to separate recyclable materials) and by the municipalities (in terms of separate collection vehicles and systems).

However, it is essential that the source-separated materials can be marketed, otherwise they will end up in landfills. An example of the lack of markets is the fact that over 80% of the plastic wastes generated in the USA are landfilled; only less than 10% are actually recycled and another 10% or processed in WTE facilities for energy recovery.

There are two possible routes for post-recycling MSW:

- thermal treatment facilities where their energy is recovered;
- landfilling where up a one fifth of the energy content can be recovered in the form of landfill gas (LFG).

In 2006, WTERT conducted a study of global landfilling and of the generation and capture of landfill gas.2 More recent information on the amount of MSW landfilled in China resulted in a downward revision of the global disposition of MSW in large methane-generating landfills to about one billion tonnes annually; the USA contributes about 20% of the total. In comparison, the MSW processed in thermal treatment facilities globally was estimated at 160 million tonnes annually. These numbers were used in a 2007 joint study by the Goddard Institute of Space Studies (GISS) and the Earth Engineering Center (EEC), University of Columbia. The detailed results will be presented in October 2007 at the 11th Waste Management and Landfilling Symposium (Cagliari, Sardinia)3 and are summarized below.

The GISS-EEC study estimated that global landfilling contributes about 30-35 million tonnes (30-35 Tg) of methane annually to the world's total annual methane emissions of ~550 Tg. It is estimated that waste generation will more than double by 2030, suggesting that methane emissions (CH_4) have the potential to rise substantially in the absence of strong policies to reduce landfilling rates.

To investigate the potential for future mitigation of methane emissions from landfills, the study developed four scenarios of WTE growth ranging from very conservative (2000-2007 growth rate in capacity remains constant through to 2030) to very aggressive (government intervention to increase annual growth rate of WTE to 10%/year for 2010-2030). Based on these scenarios, global CH_4 emissions predicted for 2030, including recycling reductions, range from 86 Tg (most conservative) to 27 Tg (most aggressive).

Although the current annual growth of the global WTE industry is impressive, the GISS-EEC study has shown that it will not be enough to curb landfill methane emissions in the next 25 years. The reason is that increased population and economic development mean that the projected rate of global landfilling is far greater. The only way to reduce landfill greenhouse gases (GHG) between now and 2030 is by achieving a 7.5% growth in thermal treatment capacity on a global scale.

References

1. Miyoshi, F. and Yamada, S. Gasification method for solid waste gasification and melting - current state of Thermoselect operations. In Japanese, translation by M. Nakamura. Kankyo joka gijutsu [Environmental Solution Technology], 5(11). 2006.
2. Themelis, N.J. and Ulloa, P.A. Methane generation in landfills. Renewable Energy, 32(7), 1243-1257. 2007.
3. Matthews, E. and Themelis, N.J. Potential for reducing global methane emissions from landfills. In: Proceedings

Sardinia 2007, 11th International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2007, pp. 2000-2030.

4. Themelis, N.J. and Ulloa, P.A. Capture and utilization of landfill gas. In: Renewable Energy 2005, pp. 77-81. www.sovereign-publications.com/renewable-energy2005-art.htm

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