Waste-To-Energy Research
and Technology Council

Energy recovery from Global Waste-to-Energy

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Summary

If there were a social ladder of fuels, hydrogen would be at the top followed by methane, fuel oil, coal, wood chips and so on. Municipal solid wastes (MSW) would be in the lower middle class and food wastes at the bottom rung. In fact, the first generation incinerators were not designed to recover energy but simply to get rid of wastes. However, as people became aware of environmental impacts and the cost of fossil fuels and of landfilling increased, the incinerators of the past were gradually transformed to the modern waste-to-energy (WTE) power plants that are fuelled by MSW. These plants are the most expensive power generators in the world but they use a renewable fuel that brings in substantial revenues. The global WTE industry processes about 140 million tons of MSW, that is one ninth of the wastes buried in large landfills. E.U. is the biggest user, followed by Japan and the U.S. The electrical and thermal energy recovery of these systems and their global potential for conserving fossil fuels are discussed in this paper. The energy productivity of WTE facilities can be doubled by co-generation and district heating or cooling. Another way to increase the thermal efficiency of WTE facilities is by combining them with a natural gas turbine generator.

U.S. and Global generation of municipal solid wastes

Invariably, economic development has been accompanied by increased consumption of materials and a corresponding increase in the generation of municipal solid wastes (MSW). This is true both in developed and in developing nations. As an example, the 2004 survey of MSW waste management in the U.S., by the Earth Engineering Center of Columbia University and BioCycle journal (BioCycle, April 2006), showed that the generation of MSW increased from 336 million tons in 2002 to 353 million tons in 2004, i.e., at the rate of 2.5% per year. In the two-year period, recycling had increased by 10 million tons and landfilling by nearly the same amount. The per capita generation of non-recycled MSW is per capita remained at 2.3 kg/day, the highest in the world.

Table 1. U.S. MSW generation and disposal in 2002 and in 2004

	MSW Generated	Recycled or composted	Waste-to- Energy WTE)	Landfilled
2004, million tons	352.6	100.4	26.3	226.0

2004, percent	100%	28.5%	7.4%	64.1%
2002, million tons	335.8	89.6	25.8	215.3
2002, percent	100%	26.7%	7.7%	65.6%

BioCycle/EEC surveys (BioCycle, Jan. 2004 and April 2006)

Figure 1 shows that most of the recycling is done in coastal states and most of the waste-to-energy facilities are on the East coast.

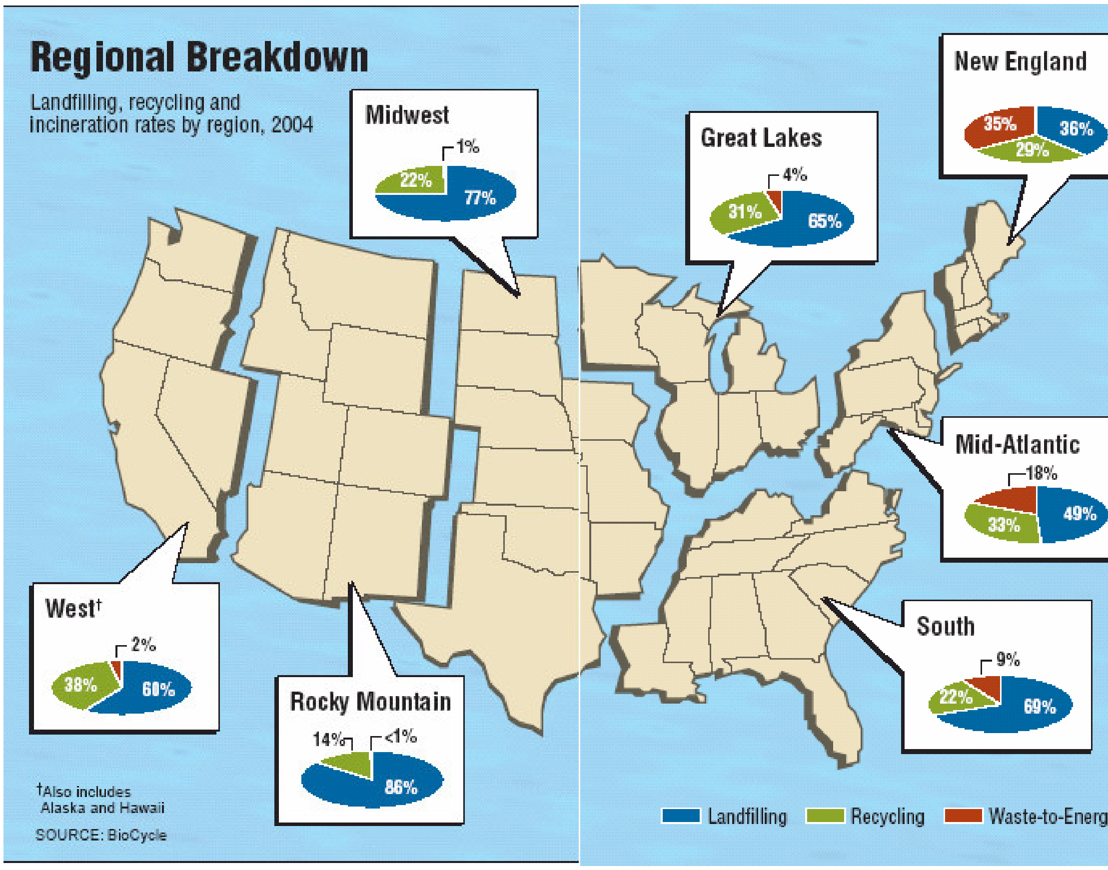

Figure 1. Breakdown of disposition of MSW by region (BioCycle, April 2006)

In comparison, the per capita generation of non-recycled MSW in E.U. ranges from 0.9 to 1.6 kg/day, and in the urban areas of Asia from 0.7 to 1.5 kg/day. The global generation of MSW that end up either in waste-to-energy plants or urban landfills has been estimated by the author at about 1,500 million tons. The estimated global use of WTE is about 143 million tons, i.e. only 10% of the non-recycled MSW.

Table 2. The Global Waste-to-Energy

Nation	Million metric tonnes to WTE
EU 25	48.8
Japan	40.0
USA	26.3
Taiwan	7.0
Singapore	4.0
China	3.0
Switzerland and Norway	3.8
South Korea	1.0
All other	9
Total	143

Energy generation by the U.S. WTE power plants

There are 89 waste-to-energy power plants operating in 27 states. They are fuelled by 26.3 million tons of MSW and the dominant technology (Table 3) is combustion of as-received fuel (stoker-type grate systems).

Table 3. U. S. Waste-to-Energy Plants

Technology	Number of plants	Capacity, short tons/day	Capacity, short tons/year
As-received fuel	65	71,354	22.1
Refuse derived fuel (RDF)	15	20,020	6.3
Modular	9	1,342	0.4
Total	89	92,716	28.8

Source: Integrated Waste Services Association (www.wte.org)

According to the U.S. Department of Energy, the U.S. WTE facilities provide to the electricity grid 13.5 billion kWh of electricity annually (Table 4). In addition, the U.S. WTEs generated an estimated 1.3 billion kWh of thermal energy. Therefore, the average energy generation was 563 kWh per ton of MSW combusted. Table 4 shows that WTE is greater than all other renewable sources of electricity, with the exception of geothermal and also hydroelectric energy that is not included in this tabulation. For comparison, wind power provided 5.3 billion kWh and solar energy 0.87 billion kWh. It is interesting to note that although the tonnage of MSW landfilled in the U.S. is eight times greater than that combusted in WTE facilities, the electricity obtained from landfill gas is one half of the WTE energy.

Table 4. Generation of renewable energy in the U.S. in 2002, excluding hydropower
(www.eia.doe.gov, DOE-EIA, Annual Energy Outlook 2002)

Energy source	**Billion kWh generated**	**% of renewable energy**
Geothermal	13.52	28.0%
Waste-to-Energy*	13.50	28.0%
Landfill gas*	6.65	13.8%
Wood/biomass	8.37	17.4%
Solar thermal	0.87	1.8%
Solar photovoltaic	0.01	0.0%
Wind	5.3	11.0%
Total	48.22	100.0%

* *http://www.eia.doe.gov/cneaf/solar.renewables/page/mswaste/msw.html*

Energy generation by WTEs in Europe

There are 409 WTE facilities in Europe (Figure 2), about two thirds of the world total. As was shown in Table 2, the E.U. is the largest user of WTE with Japan and the U.S. following. The Confederation of European Waste-to-Energy Plants (www.cewep.org) commissioned a recent study of 97 EU WTE plants by Dr.-Ing Dieter O. Reimann (Bamberg, Germany). In total, these plants process 24 million tons of MSW and generate or co-generate a mix of electricity and thermal energy. The weighted mean calorific value (Lower Heating Value) was 10 MJ/kg, i.e., 2774 kWh of chemical energy per ton of MSW combusted. Table 5 shows that in contrast to the U.S., where little use is made of the so-called "waste" steam, the European plants produce more thermal than electrical energy.

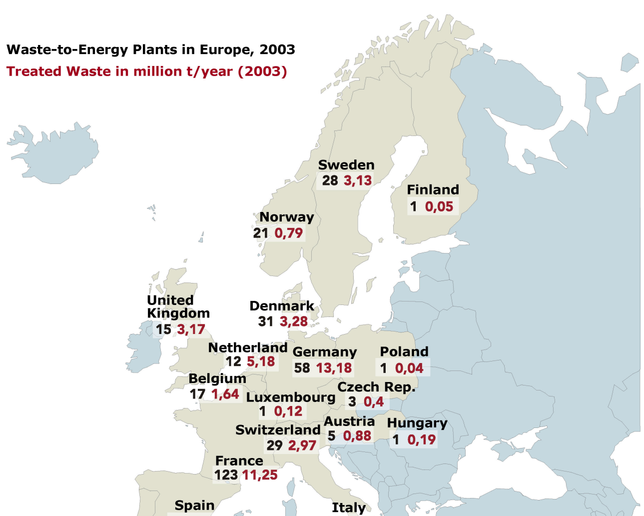

Figure 2. European WTE facilities (source: CEWEP)

Table 5. Results of analysis of 97 plants by CEWEP (from data provided by Ella Stengler)

MSW processed, million tons	24.1
Weighted mean thermal energy in MSW, kWh/ton	2774
Net electricity to grid, kWh/ton	302
Net thermal energy to district heating, kWh/ton	878
Total energy use, assuming equivalence of thermal and electric energy	1180
Overall thermal efficiency, assuming equivalence of thermal and electric energy (1302/2780)	40.3%

In Table 2, we added the electrical and thermal energies as if they were equivalent. However, the IPCC (Integrated Pollution and Prevention Control) provides weighting factors based on the fact that different amounts of fuel are used to produce electricity and steam. The IPCC BREF (Best Available Technology Reference Document) specifies that 1 kWh of electricity is equivalent to 2.4 kWh of heat. Therefore, according to BREF, the overall thermal efficiency of the 97 EU plants would be 57.8%. By the same token, the BREF efficiency of the U.S. plants that produce an average of 515 kWh of electricity would be about 44%.

WTE District Heating –The neglected resource

In her presentation at the 2006 North American WTE Conference (NAWTEC), Bettina Kamuk of Ramboll (Denmark) called WTE district heating "the neglected resource". The truth of this statement is evident by comparing the thermal energy efficiency (19-20%) of the U.S WTE facilities that sell only electricity, to the 40.3% thermal efficiency of the 97 EU WTEs that sell both heat and electricity.

Figure 3. Distribution of Danish WTE facilities (Bettina Kamuk, Ramboll)

According to Kamuk, the energy efficiencies obtained in Danish WTEs are much higher than those shown in Table 5: On the average, they provide about 450 kwh of electrical and 1970 kWh of thermal energy per ton of MSW combusted. Denmark has a population of 5.4 million and 31 WTE facilities distributed all over the nation (Figure 3). The conventional wisdom of "economies of scale" is defied in Denmark because the relatively small WTEs are sited as close as possible to the communities they serve, in order to use the "waste" steam for district heating. This also reduces the waste transport distance. Kamuk reported that Danish WTE plants derive US $60/ton of MSW from the sale of thermal energy and US $40/ton from the sale of electricity. The thermal energy revenue allows for considerably lower disposal fees to be paid by citizens to the WTE, than in the U.S.

Combination of gas turbine and WTE power plant

Another way to increase the energy efficiency of WTE plants is to combine them with a gas turbine generator, as has been done at the Zabalgarbi WTE facility near Bilbao, Spain (Figure 4) and in several other WTE facilities, including that in Sakai, Japan (Figure 5).

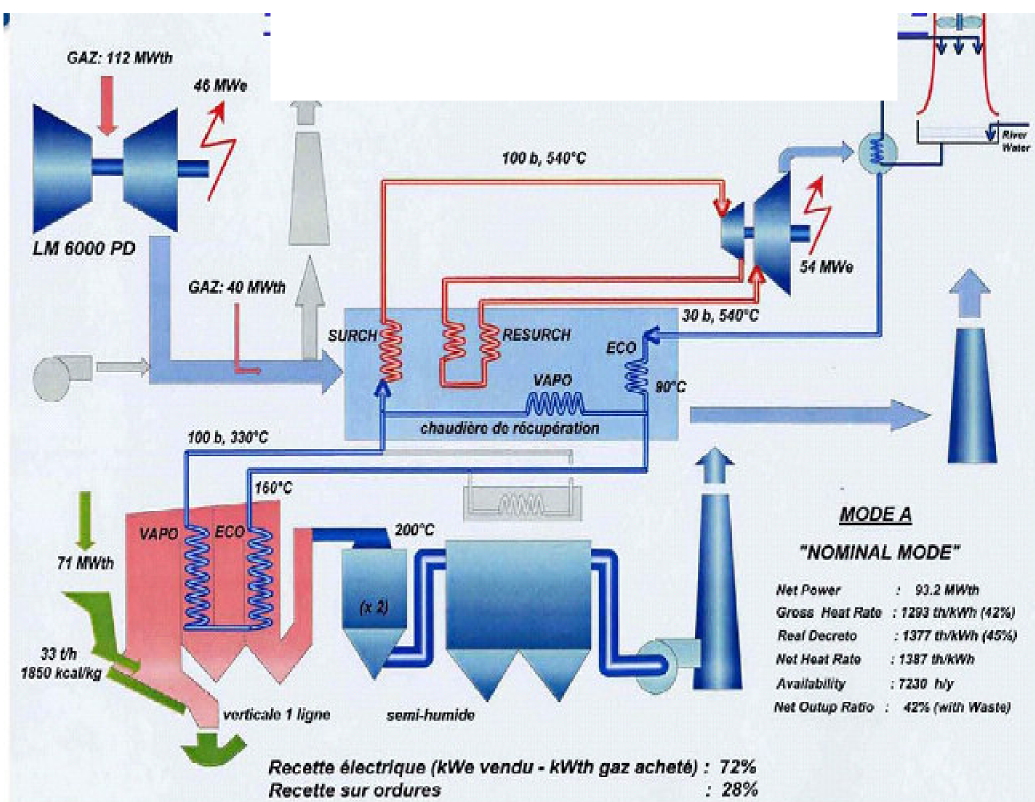

Figure 4. Combined gas turbine and WTE power plant at Zabalgarbi, Spain (J. Martin, WTERT 2004 Meeting, New York City)

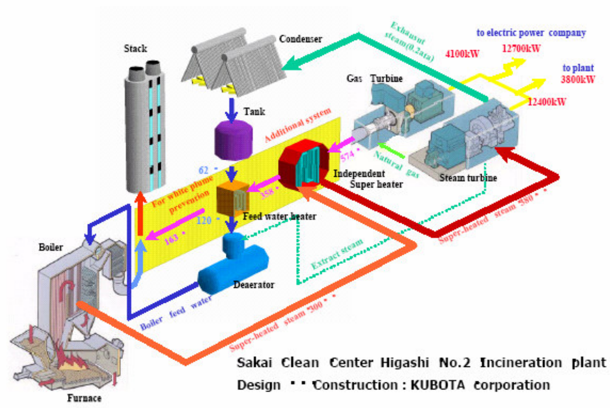

Figure 5. The Sakai, Japan combined gas turbine-WTE power plant (Source: Tohru Nishioka, Environmental Division, Sakai City, Japan)

The basic concept of the gas turbine-WTE combination is the use of the exhaust gases of the turbine to superheat the steam generated in the WTE boiler. This has two benefits: It allows for operation of the WTE boiler at a lower steam temperature, thereby reducing tube temperature and corrosion rate; also, by superheating the WTE steam to a higher temperature than is possible in the corrosive environment of WTE combustion gases, more energy is recovered from the WTE power plant in the steam turbine. For example, the Zabalgarbi WTE reports recovering close to 800 kWh of electrical energy per ton of MSW, that is 20% higher than a conventional stand-alone WTEs of the same size and age.

Figure 6 shows that, at the Sakai City WTE, the energy in the natural gas input to the gas turbine is used very efficiently to generate electricity in the turbine, superheat the steam from the WTE boiler, preheat the water feed to the boiler, and finally control the temperature of the cleaned exhaust gases so as to prevent the formation of a steam plume in the stack gas.

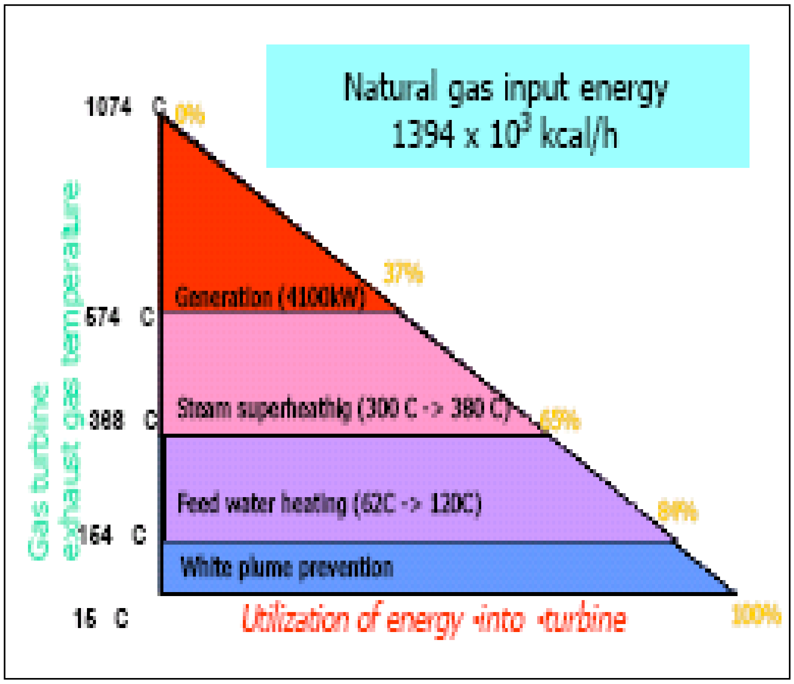

Figure 6. Utilization of natural gas input energy at Sakai WTE (Source: Tohru Nishioka, Environmental Division, Sakai City, Japan)

Current and potential generation of energy by global WTE

If we assume that the 97 WTE plants in the CEWEP study (Table 5) are representative of the rest of the European WTEs, the generation of WTEs in Europe is 15.9 billion kWh of electricity and 46.2 billion kWh of thermal energy. As shown earlier, the U.S. WTEs generate another 13.5 billion kWh of electricity. Japan is a big user of WTE but most of the WTE facilities are relatively small, do not provide much district heating and use electricity for vitrifying the WTE ash. Therefore, on the average, they generate an estimated 250 kWh per ton for a total of 10 billion kWh of electricity. The rest of the global WTEs generate an estimated 7 billion kWh of electricity, bringing the global energy generation to about 46 billion kWh of electricity and the same amount of thermal energy.

To appreciate the contribution of the global WTE industry to the conservation of fossil fuels, it should be mentioned that the energy it generates reduces the use of coal by about 25 million tons. This environmental benefit would be increased five-fold, if the thermal efficiency of the CEWEP study were to be achieved globally. It would increase by another factor of ten if the MSW that is now going to landfills were combusted in thermally efficient WTE facilities.

N.J. Themelis, May 10, 2006