Waste-to-energy

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This paper introduces the concepts behind municipal waste management, and then gives more details of the waste-to-energy process in particular. It compares the greenhouse gas emissions of traditional power plants against the WTE process, and gives operational data of tons per capita for different countries. Then it gives detailed information of various countries. It is clear that WTE plants are being deployed rapidly across the globe.

Energy from waste (EfW) or waste to energy (WTE) refers to the process of turning municipal solid waste into a source of heat and then into electrical energy. Municipal solid waste refers to waste generated by households, industries, construction and demolitions, as well as sludge from wastewater in some cases. When MSW is not converted to energy, it is used for landfill, or in developing countries, burned in open-air (and often illegal) dump sites. Although there are facilities geared toward the capturing of gases released by land fill, not all the greenhouse gases (GHG) are captured. This causes high levels of pollution, which WTE addresses.

There are several methods used to convert MSW into energy as illustrated in Fig. 1.

- Pyrolysis is the degrading of MSW under pressure without the presence of oxygen, allowing for the formation of char, pyrolysis oil and syngas. It is accomplished with temperatures between 500 and 1000˚C.
- Gasification involves higher temperatures than pyrolysis, and includes a small amount of oxygen to form syngas.
- Plasma arc is useful for treatment of biomedical waste due to the high temperature at which the process occurs, and involves the decomposition of MSW into its basic elements, resulting in a hydrogen-rich plasma converted gas (PCG).

Refuse derived fuel (RDF) is the process of converting sorted MSW into dense pellets that burn more efficiently than untreated, unsorted MSW. For the combustion process, temperatures vary from 800 to 1000˚C, and combustion is most efficient if the MSW has less than 50% moisture [7].

Process

This paper focuses on the combustion method for WTE, and the electrical energy produced thereby. The combustion process starts with a receiving chamber, as illustrated in Fig. 2. The MSW may already be presorted, with recyclable items already removed. In RDF facilities, the MSW is first shredded to produce a better burning fuel source. The SEMASS facility in Rochester, Massachusetts, in Fig. 3 is a good example of an RDF-type plant. The MSW is then moved to either a mechanical grate that moves the waste through the combustion chamber, or separated with some waste placed in a circulating fluidised bed (CFB) that has upward-blowing jets of air to increase the heat transference. For example, the grate designed by Martin

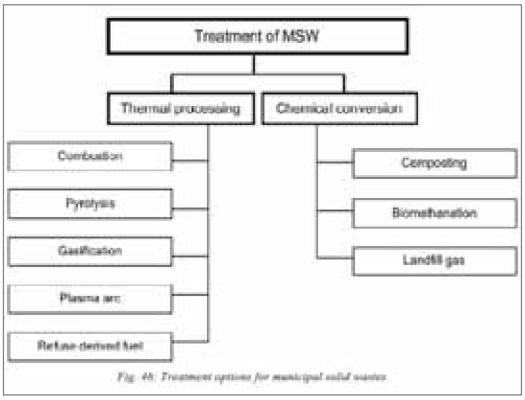

Fig. 1: Treatment options for municipal solid waste [7].

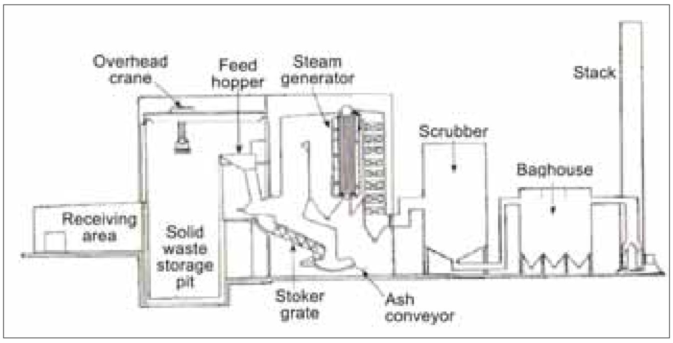

Fig. 2: Planned layout of the Santiago, Chile WTE plant. [24]

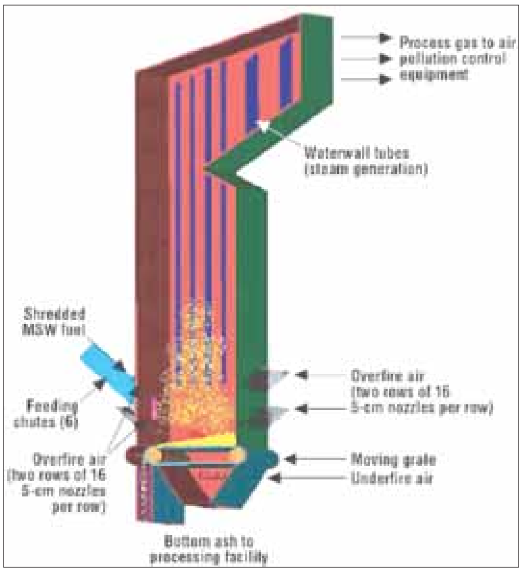

Fig. 3: Example of an RDF type facility, like the SEMASS facility in Rochester, Massachusetts, USA, which has a capacity of 0,9-million tons annually [Themelis, 2003].

Fig. 4: Brescia WTE plant. The plant produces 650 kWh electricity per ton MSW combusted. [Themelis, 2003]

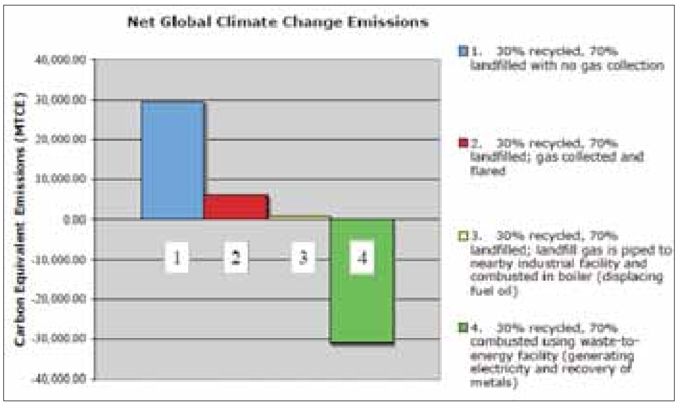

Fig. 5: Nett global climate change emissions. (Michaels, 2007).

Air emissions of waste-to-energy and fossil fuel power plants (Pounds per MW hour)			
Facility type	**Carbon dioxide**	**Sulfur dioxide**	**Nitrogen oxides**
Coal	2249	13	6
Oil	1672	12	4
Natural gas	1135	0,1	1,7
Waste-to-energy	837	0,8	5,4

Table 1: GHG emissions for coal, oil, natural gas, and WTE [Michaels, 2007].

Trents for GHG emissions from waste using (a) 1996 and (b) 2006 PCC inventory guidelines extrapolations and projection ($MtC0_2$-eq, rounded)									
Source	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2030**	**2050**
Landfill CH_4 [a]	760	770	730	750	760	790	820		
Landfill CH_4 [b]	340	400	450	520	640	800	1000	1500	2000
Landfill CH_4 (average of [a] and [b])	550	585	590	635	700	795	910		
Wastewater CH_4 [a]	450	490	520	590	600	630	670		
Wastewater N_2C [a]	80	90	90	100	100	100	100		
Incineration CO_2 [b]	40	40	50	50	60	60	60	70	70
Total GHG emissions	1120	1205	1250	1345	1460	1585	1740		

Notes: Emissions estimates and projections as follows:
[a] Based on reported emissions from national inventories and national communications and (for non-remporting c ountires) on 1996 inventery guidelines and extrapolation (US EPA, 2006)
[b] Based on 2006 inventory gudleines and BAU projection (Monnl et.3el., 2006).
Total includes landfill CH_4 (average), wastewater CH_4 wastewater N_2O and incineration CO_2

Table 2: Comparison of GHG emissions from various waste management systems [Bogner et al, 2007].

GmbH in Munich, Germany, seems to be the most widely used around the world, followed by a company in Switzerland called the Von Roll Inova Corp. [24]. Air is drawn through the receiving chamber to create negative pressure that will draw the gases released by the waste back into the furnace for neutralisation. Heat from combustion is used to create steam which is then used to drive a turbine connected to an electrical generator, or sent out as a source of district heating. The Brescia WTE facility in Italy, shown in Fig. 4, is a good example of a cogeneration plant.

After incineration, the cooled ashes, which may contain metal are sorted using mechanical and electromagnetic devices. Some nitrogen oxides will form during the burning process, and ammonia or urea is injected into the hot flue gas to neutralize them. This is called "selective non-catalytic reduction". Fly ash then goes through the baghouse which collects the fine ash. After the ash has been sorted, it is recycled and can be used at places like cement factories [10, 24].

In addition to creating higher rates of recycling, the WTE process lowers, and in some cases eliminates the emission of GHGs and reduces MSW mass by an average of 90% [21] as illustrated in Fig. 5.

Landfills and wastewater are the two greatest producers of GHGs [9]. Not only do WTE facilities reduce these GHGs, but the energy they produce also helps substitute the need for burning fossil fuels. Table 1 shows how the GHG emissions from WTE, particularly the carbon dioxide, are significantly lower than from burning coal, oil, or natural gas.

Table 2 compares the GHG emissions from various waste management systems, and shows that total emissions have historically increased, but between 1990 and 2003 the percentage of total global GHG emissions from the waste sector declined 14 – 19%.

Operating data

There are several factors that determine whether or not a WTE plant is suitable for a location. These include the region's economic strength; the national policies and laws regarding the handling of MSW; environmental regulations; the infrastructure required to build, supply and maintain a WTE facility; and the public's perception [9]. Municipal jurisdiction usually controls the handling of MSW in a specific region; however, some states have national policies that influence those regions. In other countries municipalities are left to decide on the handling process, possibly leaving the region with low formal recycling rates and a lack of MSW services. A large possible obstacle to the building of a WTE plant is the negative public perception of such facilities. Since the implementation of strict regulations on WTE facilities, these facilities have significantly improved their emissions.[8].

Table 3 shows that the emissions from the SEMASS WTE plant in Massachusetts are significantly lower than the EPA requirements. Emissions from WTE facilities

Comparison of 1999 emissions from SEMASS No. 3 unit with EPA standards		
Emission	**EPA standard[1]**	**SEMASS[2]**
Particulate (gr/dcf)	0,010	0,002
Sulfur dioxide*	30	16,06
Hydrogen chloride*	25	3,6
Nitrogen oxides*	150	141
Carbon monoxide*	150	56,3
Cadmium**	20	1,24
Lead**	200	30,03
Mercury**	80	5,09
Dioxins/furans(ng/dscm)	30	0,86

Gr.dscf: grains/dry standard cubic foot, *ppmdv:parts per million dry volume, ** u/dscm: microgram per dry standard cubic meter; ng: nanogram
[1]The standards and data are reported for 7% O2, Dry basis, and standard condtions.
[2]Average of 1994 – 1988. Boiler N°3.

Table 3: Comparison of emissions for the SEMASS unit (Massachusetts, USA) [Weinstein, 2006].

Emission reductions from WTE facilities between 1990 – 2000 in the US [134]	
Pollutant	**Reduction (%)**
Dioxins/furans	99,7
Mercury	95,1
Cadmium	93,0
Lead	90,9
Particulate matter	89,8
Sulfur dioxide	86,7

Table 4: Emission reductions from WTE facilities in the US over time [Bhada, 2007].

Pollutants	1990 emissions (t/y)	2005 emissions (t/y)	Percent % reduction
CDD/CDF TEQ basis*	4400	15	99%
Mercury	57	2,3	96%
Cadmium	9,6	0,4	96%
Lead	170	5,5	97%
Particulator matter	18 600	780	96%
HCL	57 400	3200	94%
SO_2	38 300	4600	88%
NO_2	64 900	49 500	24%

Table 5: Comparison of emissions from large and small WTE units before and after MACT retrofits [MICHAELS, 2007].

Chemical comparison of waste in developing and developed countries [17]		
	Low-income country	**High-income country**
Moisture content (%)	40 – 80	20 – 35
Density (kg/m³)	250 – 500	120 – 200
Lower heating value (kcal/kg)	800 – 1,100	1,500 – 2,700

Table 6: Chemical comparison of waste in developing and developed countries [Bhada, 2007]

in the US have decreased significantly over time as shown in Table 4. Table 5 compares emission in tons per year for a group of US WTE plants operating in 1990 and after retrofitted with maximum achievable control technology (MACT) by 2005. The 2005 column clearly shows dramatic reductions.

In some countries the national laws regulate the separation of MSW. This could include complete separation by category as found in countries like Germany.The moisture content of MSW is directly related to the level of wealth in a given region. Table 6 illustrates the difference in moisture content, density and lower heating value between a typical low income country and a high income country, and shows that the heating value for high income countries could be as much as twice that of the low income countries. This means that MSW produced in developing countries is less suitable for WTE processing. Developing countries also have lower MSW generation rates than larger, industrialised countries as shown in Table 7. Finally, Table 8 compares the amount of waste generated per person per day for different countries varying from low income to high income countries. Even in developed countries in Europe, the waste incinerated per capita varies greatly as shown in Fig. 6.

Performance data

The potential for energy recovery, as demonstrated by the following case studies, is lower for developing countries than for industrialised ones. Globally, in 2003/4, there were 600 WTE facilities around the world, processing 130-million tons of MSW annually. Many are located in countries that are severely limited in space, with dense populations producing anywhere from around 1 kg of MSW per person per day to 2 kg. In places like Europe, land filling of sorted combustible MSW is illegal, and land filling is taxed. The number of WTE facilities around the world appears in Fig. 7, with Japan and Taiwan in the lead.

Japan, with an average MSW generation of 314 kg per capita annually [or 1,1kg/ per capita/day] (2004) incinerates 80% of its MSW to produce both electricity and heating. This means that 40-million of the 50-million ton of MSW generated annually is incinerated, with Japan's installed capacity at 1000 MW power generation.

Europe (in 2002) had a capacity of 40-million tons annually, from which 41-million GJ of power was generated. The EU-15 (2006) incinerates 20 – 25% of its total MSW in 400 WTE facilities with an average capacity of around 500 tons/day. The distribution of WTE sites around Europe appears in Fig. 8, together with the tons per year incinerated in 2003.

In 2007, there were 87 WTE facilities in the United States, processing 28,7-million tons of MSW, with a generation capacity of 2720 MW. Annually, the US generates approximately 17-billion kWh. While the US processes 8% of its total MSW in WTE facilities, 64% is landfilled and only 28% is recycled [21]. It is estimated that if the US were to incinerate all of its combustible MSW, the power generated would be able to provide 3 – 4% of the nation's electric needs. [6] The US does not have large district heating, decreasing the benefits of cogeneration. With the landfills filling up and some states driving MSW by truck to other states for burial, the prospect of reducing MSW by 90% makes incineration an attractive option. In 2003, 500 – 600 kWh of electricity was produced for every ton of MSW processed. 770 000 t of ferrous scrap metal was also salvaged from the ashes in these facilities. Fig. 9 illustrates the location of WTE facilities in the different states in the US. In 1991 the Integrated Waste Services Association (IWSA) was formed in the US.

Municipal solid waste-generation rates and relative income levels			
Country	**Low income**	**Middle income**	**High income**
Annual income ($/cap/yr)	825 – 3255	3256 – 10065	>10066
Municipal solid waste generation rate (t/cap/yr)	0,1 – 0,6	0,2 – 0,5	0,3 to >0,8

Note: Income levels as defined by world bank (www.worldbank.org/data/wd?2005)
Sources: Bermache-Perez et al., 2001 Callrecovery, 2004, 2005, Diaz and Eggeth, 2002,Griffiths and Williams, 2005 Idris et al., 2003, Kase va et al., 2002 Ojeda-Benitez and Beraud-Lozano, 2003, Huang et al., 2006, US EPA, 2003.

Table 7: Municipal solid waste generation rates and relative income levels [BOGNER ET AL, 2007]

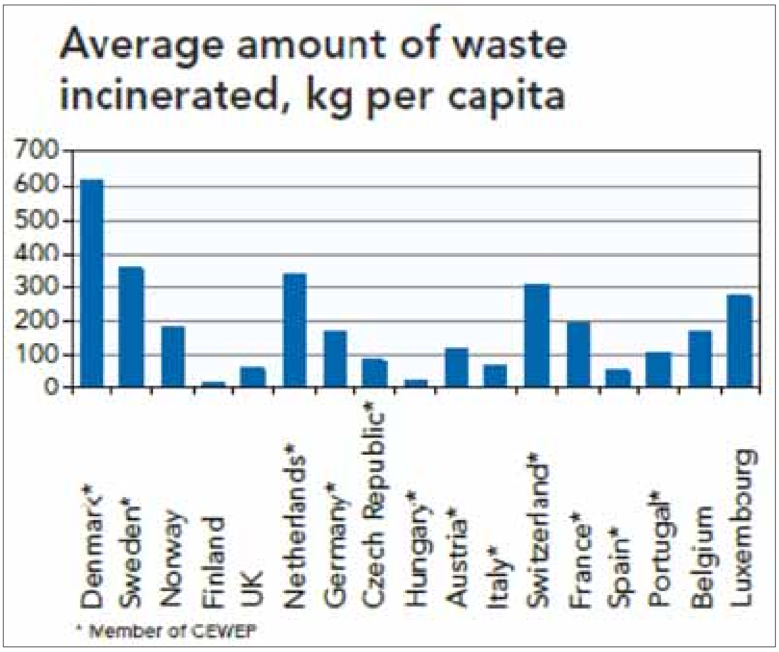

Fig. 6: Average amount of waste incinerated. [Michaels, 2007].

In Germany, roughly 340-million t of waste is produced, of which 48-million are municipal waste. 25-million t of these 48-million are recovered (incinerated) in 50 cogeneration plants, 10 power generation plants, and 9 heat/steam plants [18]. Broken down by capacity, there is 20,2-million t per year incineration capacity; 5-million refuse derived fuel (RDF) capacity, and roughly 2-million for cogeneration. 14-billion kWh of heat is produced annually, as well as 7-billion kWh of electricity. Germany has strict rules for source separation of MSW, and has since 2005 made the land filling of untreated MSW illegal.

Sweden has since 2002, outlawed land filling of presorted combustible MSW [9]. The Swedish population of 9-million produced a MSW rate of 462 kg per person annually. 22 183 000 t was collected, and 46,7% of the household MSW was incinerated for cogeneration. In 2004, 9,3 TWh energy was recovered. [22]. Overall, the Swedish incinerated 3188 000 t of MSW, and generated 740 GWh of electricity and 9300 GWh of overall energy. The Canadian population considered in the proposal was 32-million, and produced roughly 640 kg MSW per capita annually. Overall, 1,017-million t of MSW was collected, and 975 000 t thereof could be incinerated to generate an expected 417 GWh of electricity and 2635 GWh of overall energy. The WTE plant that was used as a base for the Toronto proposal is called Sävenäs, and is located in Gothenburg. It has three furnaces that burn a total of 460 000 t of waste per year.

Denmark was the first European country to ban the land filling of combustible MSW. With 29 facilities, 3,5-million t of waste is treated, including 20% of the sludge from wastewater, equivalent to approximately 26% of the total MSW produced in 2005. In 2003, the total MSW produced was

Waste generation in selected countries (kg/person/day) [150]			
Low-income countries*		High-income countries	
India	0,46	Germany	0,99
Nepal	0,50	Denmark	1,26
Vietnam	0,55	Holland	1,37
China	0,79	Australia	1,89
Sir Lanka	0,89	USA	2,00
*Waste generation rates in urban areas			

Table 8: Waste generation in selected countries. [Bhada, 2007]

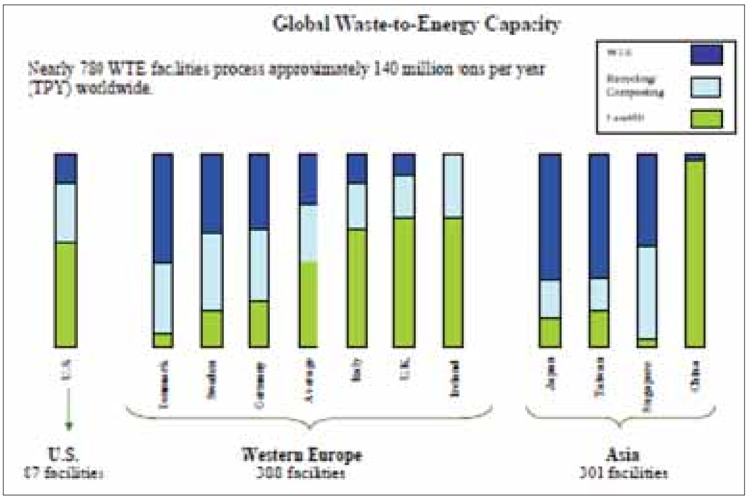

Fig. 7: Number of WTE facilities around the world. [Renosam].

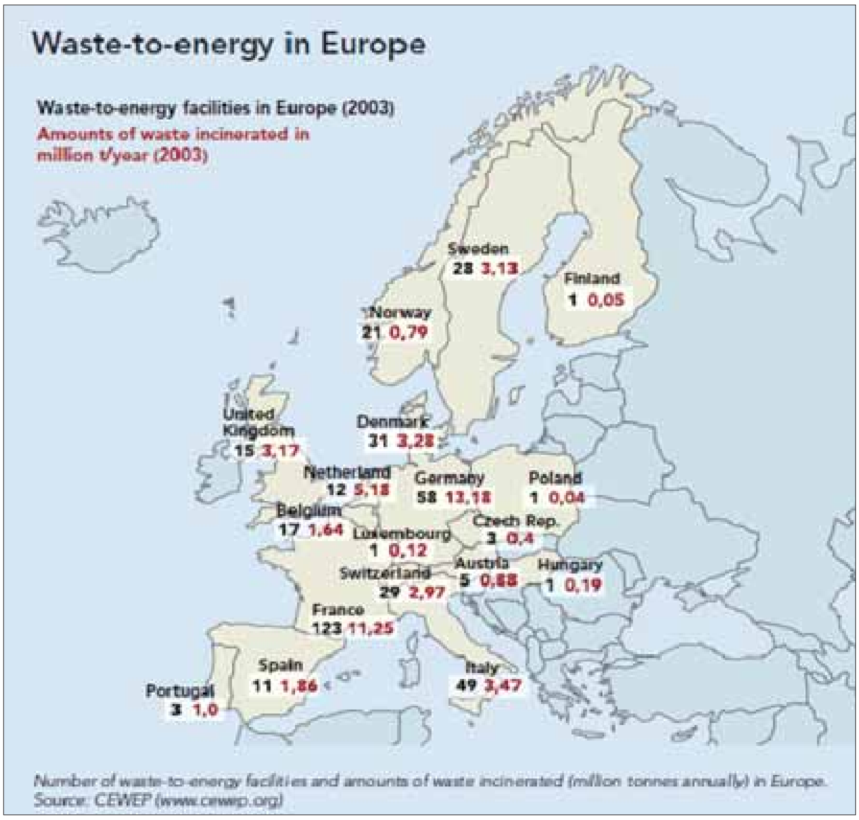

Fig. 8: Amount of waste incinerated in Europe per year. [Renosam].

around 12,7-million t, of which 3,3-million tons were incinerated. For every ton of MSW incinerated, 2 MWh of heat and 0,67 MWh of electricity is produced. In 2003, around 98% of the remaining ash was recycled as well. The overall electricity generated in 2003 was 1,47-million MWh. (Renosam; Danish Environmental Protection Agency).

Switzerland, which since 2000, also requires combustible MSW to be incinerated, and had 3,29-million t of MSW incineration capacity in 2004 for its 28 WTE facilities. [www.swissworld.org].

Taiwan (2005) produces a total of 8,38-million tons of MSW annually, around 381 kg per capita. The average water content of Taiwan's MSW is 50%, leaving the 2005 expectations for power generation in the 21 planned WTE facilities at 1850 000 MWh of electricity annually, while processing 65% of the total MSW generated. Prior to 2005, the expected revenue from the WTE facilities was $47-million [20].

Mumbai, India, has a population of approximately 12-million (2008), and its residents produce an average of 0,18 t of MSW per person per year. In a 2008 proposal by graduate student Perinaz Bhada at Columbia University, an RDF facility at one of the landfill sites was proposed. It would produce 500 kWh per ton of MSW processed [7].

A WTE facility with 1000 metric tons per day capacity, generating 600 kWh per ton of MSW was suggested in 2006 for the city of Santiago, Chile [24]. The plant is expected to produce 720 kWh/ t of MSW, of which 600 kWh could be sold .

A 20 MW WTE plant has been proposed for El Guacal, Colombia to be constructed at a landfill. The facility would take in 650 t per day of MSW and convert it into refuse derived fuel, totalling 400 t per day. The process would generate 20 MW of electricity.. There is a potential for 47 MW capacity in the four main cities in Colombia. It is expected that the facility would generate 470 MWh per day of electricity.

Additional information

For more detailed information on WTE facilities around the world, see: www.industcards.com/ppworld.htm , as well as http://yeroc.us/wte-db

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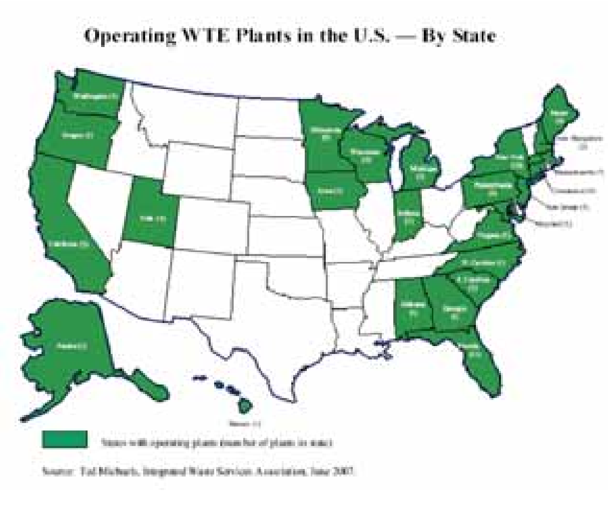

Fig. 9: WTE plants in the US. [Themelis, 2003].

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