Proceedings of NAWTEC16
16th Annual North American Waste-to-Energy Conference
May 19-21, 2008, Philadelphia, Pennsylvania, USA

NAWTEC16-1927

DEVELOPMENTS IN THERMAL TREATMENT TECHNOLOGIES

Nickolas J. Themelis
Director, Earth Engineering Center, Columbia University
Chair Waste-to-Energy Research and Technology Council

ABSTRACT

A 2007 WTERT survey (1) showed that the global waste-to-energy capacity (WTE) increased in the period 2001-2007 by about 4 million metric tons per annum. By far, the principal technology used globally for energy recovery from municipal solid wastes is combustion of "as received" MSW on moving grates ("mass burn" or stocker technology). The three dominant grate technologies, by Martin, Von Roll, and Keppel-Seghers, represent about 75% of the total growth in capacity. In the same period, Japan and China built several plants that were based either on the direct smelting or on fluid bed combustion of solid wastes. In China, there have been some mass-burn new plants and also over forty circulating fluid bed WTEs, using technologies developed by the Institute of Thermal Power Engineering of Zhejiang University and by the Institute of Engineering Thermophysics of the Chinese Academy of Sciences. WTE technologies in China are actively supported by the national and local governments and many more plants are projected as sprawling cities are running out of landfill space. Japan is the largest user of thermal treatment of MSW in the world (40 million tonnes) and some of the newest plants use stoker technology, such as the Hiroshima WTE designed by the famous architect Taniguchi and the Sendai WTE that uses advanced oxygen enrichment technology. However, there are also over 100 thermal treatment plants based on relatively novel processes. The Direct Smelting and the Ebara fluid bed technologies developed in Japan require pre-processing of the MSW, combust the resulting syngas to generate steam, and produce a vitrified residue. The Thermoselect Gasification and Melting technology, originally developed in Europe, has been adopted successfully in seven Japanese facilities by JFE, a company with extensive experience both in high temperature metal processing and with various MSW thermal treatment technologies, including mass burn. This paper also includes a brief report on the results of a study by WTERT on ways to increase beneficial uses of WTE ash in the U.S.

DEVELOPMENTS IN GLOBAL WTE

Global growth

Thermal treatment facilities built since the beginning of this century have been based mostly on the grate combustion of "as received" MSW (mass burn of stoker technology). According to a 2007 WTERT survey, the three major stoker technologies reported 2001-2007 capacity growth of 11 million tons (Martin), 6.4 million tons (A& AE VonRoll), and 5.1 million tons (Keppel-Seghers) (1). In terms of novel technologies, direct smelting (JFE, Nippon Steel), fluidized bed (Ebara), Thermoselect (JFE), and circulating fluidized bed (Zhejiang University; Chinese Academy of Sciences) have accounted for an additional estimated growth of another one million ton per year.

China

There are about 50 WTE facilities in China. The rapid development of WTE has been aided greatly by the enlightened Renewable Energy policy of this nation: Coal-fired power plants receive 4-6 cents/kWh while WTE plants are considered to be renewable energy and receive an additional 3 cents, that is 7-9 cents/kWh. Tipping fees are very low, ranging from $10-30/ton of MSW. The rapid growth of the WTE industry in China has also been helped by relatively low capital costs, reported to be as low as $50,000 per daily ton of capacity. On the minus side, moisture in Chinese MSW is high at 40-50% and average plant availability was reported to be about 80% vs. 90+% of the US mature industry. WTE plants in China are of two main types: Stoker grate and Circulating Fluid Bed (CFB) (Figure 1). The latter are smaller units and they are co-fired with coal, up to 15% of the feed, to make up for the low calorific value of Chinese MSW

The total thermal treatment capacity in China is estimated at about 4 million tons in about 50 facilities. About one third of this is treated in stoker type plants, most of European origin (Martin, Alstom and Keppel Seghers) and some of domestic design. In 2007, the author visited two of these facilities (Shanghai, Chongxing) that use the Sity 2000 grate of Martin GmbH (Figure 2). Both facilities looked very much like WTEs in the western world, in particular the Chongxing WTE, a joint venture between Chongxing Steel and Covanta Energy of the U.S.

Circulating fluid bed WTEs (CFB) in China have been based on technologies developed by the Institute of Thermal Power Engineering of Zhejiang University, headed by Prof. Kefa Cen, and also by the Institute of Engineering Thermophysics of the Chinese Academy of Sciences, headed by Prof. Yunhan Xiao. The total installed capacity of Zhejiang University's CFB technology was reported to be 3800 tons/day; another 3200 tons/day are under construction. The high efficiency of scavenging recyclable materials in China results in a low calorific value of Chinese MSW that was stated to be as low as 5000 MJ/kg, i.e. half of that in the EU or the U.S. For this reason, the Zhejiang CFB process mixes up to 15% of coal with the MSW feed. However, the two stoker WTEs visited by the author in 2007 dealt with the high moisture problem by providing for dewatering of the feed in the pit and treating of the liquid effluent.

In view of one of the arguments of the habitual opponents of WTE in the U.S. that "it is too costly", it is interesting to note that WTE is gaining ground over landfilling in a developing nation; during the 2007 visit of the author in China, some very knowledgeable people expressed the opinion that "there will be "over one hundred" new WTE facilities" in the near future. The three main reasons are the ability to recover indigenous energy, the scarcity of land near cities for future landfills, and outright government support for WTE, such as the electricity credit mentioned above.

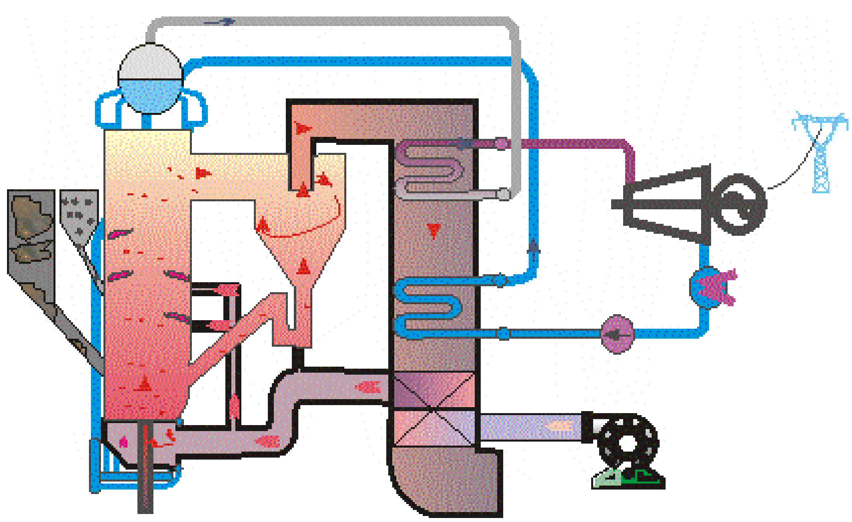

Figure 1. Schematic of the Zhejiang University Circulating Fluid Bed WTE

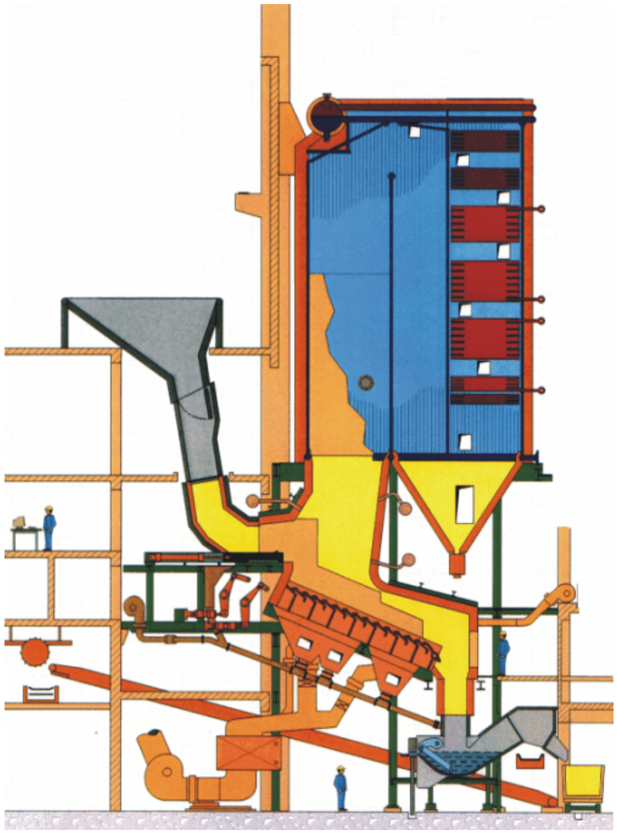

Figure 2. The Sity 2000 grate unit of Martin GmbH

Japan

Japan is the largest user of thermal treatment of MSW in the world (40 million tons). The principal technology used is grate combustion of 'as received MSW' (i.e., stoker or mass burn). The major supplier is Mitsubishi Heavy Industries, a licensee of the Martin technology, followed by JFE. Some of the newest plants use stoker technology, such as the very impressive Hiroshima WTE that is build at the beginning of the main street of the city and is a monument to human ingenuity by the famous architect Taniguchi who also designed the new Museum of Modern Art in New York City. Another recent WTE, in Sendai, uses the advanced oxygen enrichment technology developed by Martin and Mitsubishi Heavy Industries.

However, there are also over 100 thermal treatment plants in Japan (1) using relatively novel processes such as direct smelting (JFE, Nippon Steel), the Ebara fluidization process and the Thermoselect-JFE gasification and melting technology process. These processes have emissions as low or lower than the conventional WTE combustion process and produce a vitrified ash that can be used beneficially.

Transportation of "as collected" MSW from one municipality to another is not encouraged in Japan. As a result, the existing stoker WTE facilities are relatively small or MSW is pre-processed to RDF that is then transported to a central WTE that serves several communities. Stoker type plants are also required to vitrify their ash by means of electric furnace or thermal plasma processing. These conditions result in high cost thermal treatment of MSW which is made possible by the infusion of public funds and by regulations that make landfilling prohibitively expensive, if not impossible.

The JFE direct melting process

JFE is a new company resulting from the merger of NNK Steel and Kawasaki Steel. The JFE Direct Smelting reactor, resembles a small iron blast furnace where RDF particles are fed through the top of a vertical shaft (Figure 3). Several Direct Smelting (DS) MSW plants have been built by JFE and also, in another version of direct smelting, by Nippon Steel. MSW is first shredded and converted to refuse-derived fuel (RDF) by removing glass and metal particles, drying the organic fraction in a rotary kiln and then extruding the product 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 facility, where it is combusted with energy recovery. For example, the Fukuyama Direct Smelting plant, visited by the author in 2006, is supplied by seven RDF facilities located at municipalities surrounding the DS facility. The RDF is fed by means of a corkscrew feeder on top of the shaft furnace. As the feed descends through the furnace, it is gasified and its inorganic components 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 that is used to generate electricity in a steam turbine, much as in conventional WTE.

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 transform the ash to molten slag and metal.

The RDF-DS combination 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 Direct Smelting process produces slag and metal globules (10% by weight of the RDF feed), that are used beneficially, and fly ash (2% of RDF), which contains volatile metals and is landfilled.

The availability (i.e., hours of operation at design capacity divided by total hours in a year) of the Fukuyama facility is 90% and the refractory lining of the shaft was reported to have a lifetime of 3-4 years. An estimated 5000 Nm3 of gas is generated per tonne of RDF, i.e. about the same as in a conventional WTE facility. 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; one use is as a counterweight in cranes and other ballast applications.

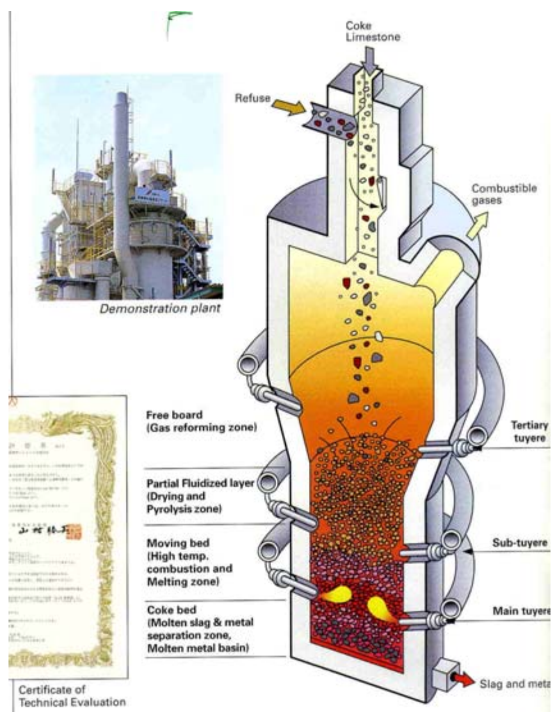

Figure 3. The JFE Direct Smelting Process

The Ebara fluidized bed process

The Ebara process, described in detail at NAWTEC 15, 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 1350ºC so that the ash is vitrified to slag and metal. There is no oxygen enrichment. The largest application of the Ebara process in 2006 was a three-line, 900-tonne per day Madorito plant in Spain.

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. As of 2006, the largest Ebara plant was the Madorito plant in Spain that processes 900 tons per day and provides 21 MW of electricity to the grid, i.e. about 560 kWh per ton of RDF.

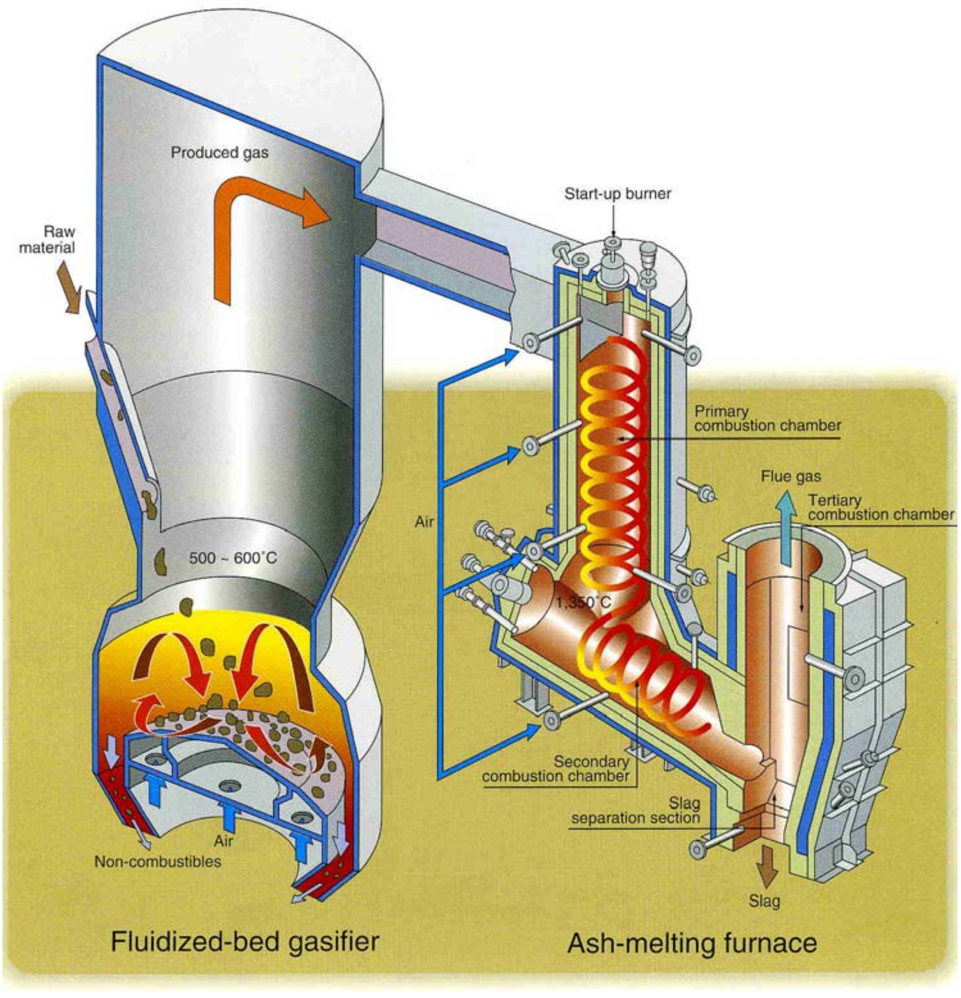

Figure 4. The Ebara Fluid Bed process

The Thermoselect Gasification and Melting Process

This process is discussed in another paper presented at the 2008 NAWTEC 16 meeting. It was developed in Switzerland between 1985 and 1992 and a demonstration facility of 110 tons/day capacity was built in Fondotoche, Italy, to validate the technology. A larger commercial facility of 700 t/d capacity was started up at Karlsruhe, Germany, in 1999. The plant operated until a commercial dispute led to its being 'mothballed' at the end of 2004. In the 1990s, Kawasaki Steel Corporation of Japan licensed the Thermoselect technology and, in 1999, started up the first Thermoselect plant in Japan - at Chiba City close to Tokyo (3). In 2001, Kawasaki 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 of all types. JFE built a second Thermoselect plant at Mutsu, Japan, in 2003. Four more plants were built in 2005 and a seventh started operation at Yorii in 2006. The seven JFE plants operate 16 Thermoselect units of a total daily capacity of about 2000 tons (1).

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 process gas per ton 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. The Thermoselect process requires the use of some of the electricity generated to produce the industrial oxygen used for partial oxidation and gasification of the MSW. However, the syngas product can be combusted in a gas turbine to generate electricity at a much higher thermal efficiency than is possible in a conventional WTE plant using a steam turbine.

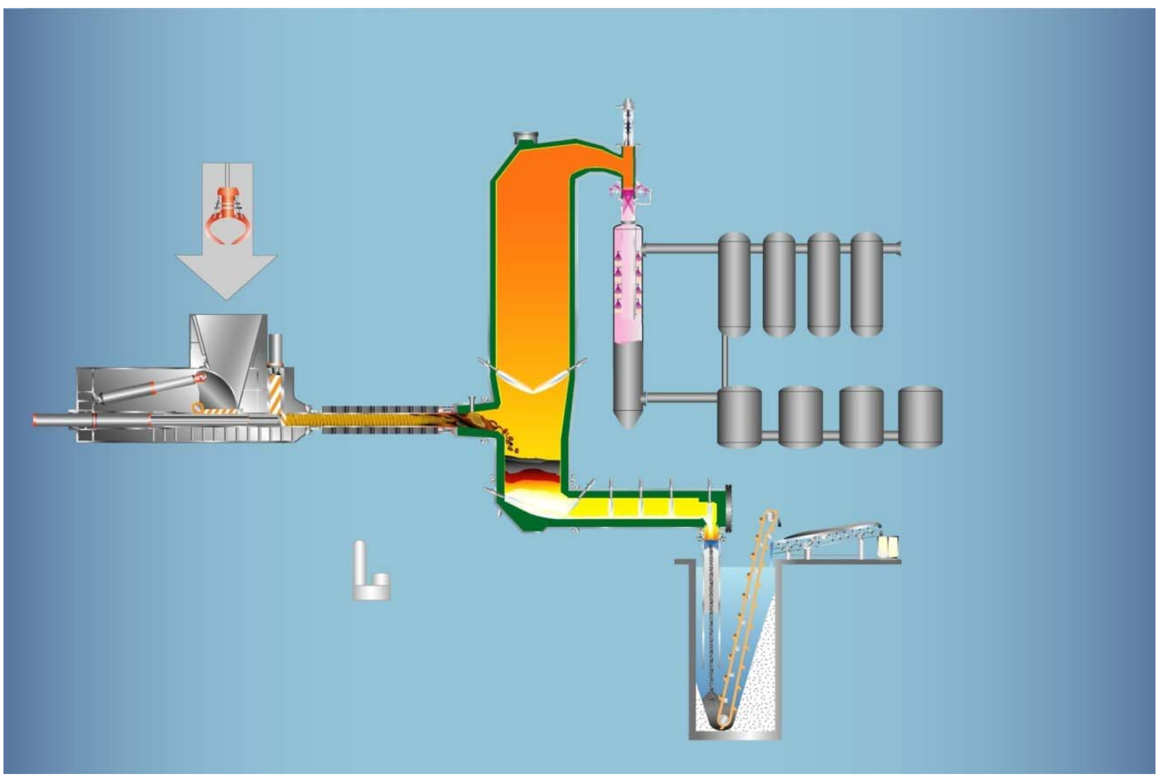

Figure 5. The Thermoselect Gasification and Melting Process

REPORT ON WTERT STUDY ON BENEFICIAL USE OF WTE ASH

The residues of waste-to-energy facilities are bottom ash (20-25% of the MSW by weight) and "fly" ash collected in the Air Pollution Control (APC) system (2-3% of the MSW). As the APC systems of WTE facilities have improved tremendously, the captured heavy metals, dioxins, and other undesirable contaminants end up in the APC residues. At the present time, most of the WTE facilities mix these two types of ash to form a "combined" ash that is chemically inert and is used for landfill maintenance and daily cover. Since the U.S. is the world's largest landfiller (about 250 million short tons of MSW are landfilled), there is a big "market" for use of WTE ash in landfills. However, since there are no alternative beneficial uses of WTE ash outside landfills, the WTE companies do not get much benefit from supplying it to landfills. In fact, its disposal for landfill maintenance represents a substantial operating cost for the WTE industry.

Bottom ash does not contain dioxins and volatile metals and its chlorine and sulfur concentration are very low. It can be used beneficially in road construction, remediation of extinct mines, and other uses. Numerous demonstration programs, in the U.S. and abroad, have proven scientifically that ash can be processed to generate an engineered and environmentally sound aggregate for diverse construction applications. In fact, the WTE facility of AEB Amsterdam (1.5 million tons of MSW annually) processes its ash in a novel way so that only 1% by weight of the MSW combusted has to be landfilled.

A perceived obstacle by many WTEs in the U.S. to developing bottom ash uses outside landfills is that if bottom ash is not mixed with fly ash, the latter would be a hazardous waste and thus very expensive to dispose of. In 2007, WTERT investigated the treatment of APC ash so that it can pass the TCLP test of EPA and be landfilled, without mixing it with bottom ash. The means examined were phosphate treatment (the Wheelabrator WES-Phix process), the ferrox process, and mixing with a small amount of cement and palletizing. The results showed that the WES-Phix process is fully satisfactory in treating APC ash. In fact, this has been proven consistently and at an industrial scale at two WTE facilites, in Barnaby, BC (Montenay-Veolia) and Savannah, GA (Veolia ES WTE). The laboratory tests conducted by WTERT agreed with these results. The cement pelletization process was not satisfactory because during the 24-hour TCLP mixing test, the pellets undergo extensive abrasion and the final particles of the ash pellets are very small. Therefore, the benefit of pelletization is effectively lost during the TCLP test. The proven fact that the APC ash can be fixed without mixing it with bottom ash opens the way for U.S. WTE companies to pursue the development of beneficial uses of bottom ash outside landfills.

In a separate but relevant study, we examined the removal of chloride from APC residue by washing with water at different liquid-solid ratios and temperatures. The motivation for this study was the termination of a large test in Pennsylvania where hundreds of thousands of combined ash from the Essex County WTE of Covanta Energy were used in the rehabilitation of an extinct coal mine. Regrettably, this test was terminated for the sole reason that the chloride concentration in adjacent surface waters increased appreciably. The results of our study showed that the origin of the soluble chloride was in the APC ash. In the future, this could be avoided by either not mixing fly ash with bottom ash, or by pre-treating the fly ash to remove soluble chlorides.

A final conclusion of the WTERT study was that it will be to the advantage of the U.S. WTE industry to take steps that will result in beneficial uses of ash outside landfills. As per the usual relation of supply and demand, broadening the "market" for ash will have the side effect of increasing the value of ash for landfill uses, or at least decreasing the "tipping" fee paid by WTE facilities for landfillng ash.

REFERENCES

1. Themelis, N.J., "Global Growth of Traditional and Novel Thermal Treatment Technologies", Waste Management World, Review Issue International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2007, pp. 2000-2030.
2. Themelis, N.J. and L.N. Themelis, WTERT 2007 Visit of Chinese WTE Facilities, WTERT web, 2008
3. 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.

4. EPA Report, GHG emissions of solid wastes (http://www.epa.gov/climatechange/emissions/downloads/08_Waste.pdf)
5. Themelis, N.J. and Ulloa, P.A. Methane generation in landfills, Journal of Renewable Energy, 32 (7), 1243-1257. 2007.
6. Themelis, N.J. and Ulloa, P.A. Capture and utilization of landfill gas. In: Renewable Energy 2005, pp. 77-81. www.soverign-publication.com/renewable-energy2005-art.htm

