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An overview of the municipal waste incineration industry in Asia and the former Soviet Union

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Abstract

Municipal waste incineration development is reviewed for Japan, Taiwan, China, India, Korea and the former Soviet Union nations of Russia and the Ukraine in the context of the cultural factors and overall waste management practices in each country and how they influence municipal waste incineration development. Environmental regulations and pollution control technologies used by selected facilities are described.

Keywords: Municipal waste; Solid waste; Asia; Soviet Union; Incineration; Environmental regulations; Pollution control; Waste management and resource recovery

1. Introduction

There is great diversity in the development of municipal waste incineration among the countries of Asia and the former Soviet Union. These differences are reflective of the varying levels of industrialization, scarcity of land for landfill development, consumption habits and wealth among the countries. An overview of waste generation and waste characteristics is presented for Japan, Taiwan, China, India, and the former Soviet Union nations of Russia and the Ukraine. Municipal waste incineration is reviewed for each of these countries and for Korea in the context of the cultural factors and overall waste management practices in each country which influence municipal waste incineration development.

2. Overview of waste generation and characterization

Waste generation on a per capita basis is typically reflective of the level of wealth and industrialization in each country. As indicated in Table 1, waste generation rates

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Table 1
Waste generation rates of selected countries

Country	Waste generation (kg/person/day)	Population (millions)	Total estimated waste generation (million t/y)
Japan	1.95	125	89[a]
Taiwan	1.1[b]	21	8
China	0.5	1170	200[c]
India	0.36–0.45[d]	886	116–146
Russia	0.64	150	35[e]
Ukraine	0.6[f]	52	11
United States	1.9	257	178[g]

[a] Source: Reference [1], includes residential and commercial solid waste and excludes industrial solid waste and recycling.
[b] Source: Reference [2], includes residential and commercial waste.
[c] Source: Reference [3], includes residential solid waste.
[d] Source: Reference [4], 1982 waste disposal rates measured for areas under the jurisdiction of the Municipal Corporation of Delhi and Delhi Cantonment, respectively. Quantities include residential, commercial and institutional waste after recycling and composting.
[e] Source: Reference [5], includes residential and commercial waste before recycling.
[f] Source: Reference [5], average residential generation rate for Soviet cities.
[g] Source: Reference [6], generation of municipal solid waste including durable goods, non-durable goods, containers and packaging, food wastes and yard trimmings and miscellaneous inorganic wastes from residential, commercial, institutional and industrial sources.

in Japan approach waste generation rates of the United States, while waste generation rates in India, China and the former Soviet Union are a fraction of the generation rates of the United States.

Waste composition in each country is also reflective of wealth and the level of industrialization. For example, in China, coal is generally used in the home for heating and cooking and coal ash is the largest component of solid waste. The Chinese also use little preprocessed and packaged food; resulting in a high food waste fraction and a low paper, plastic, glass and metal fraction. In contrast, in Japan, paper and plastics comprise a much higher proportion of the solid waste generated reflecting greater industrial and commercial development. Waste composition in each country reviewed and for the United States is outlined in Table 2.

2.1. Japan

Japan has more waste-to-energy facilities than any other country in the world. Waste incineration is considered a critical element of an integrated approach to solid waste management driven by limited land space, high costs of landfilling and concerns for environmental protection.

In Japan, an extensive recycling network reduces the amount of solid waste that is collected for incineration or disposal. Appliances, automobiles, glass bottles and batteries, for example, are collected by retailers for recycling. Recycling firms also collect recyclable paper, newspaper, magazines and other recyclable materials from

Table 2
Waste composition: Percentage of total solid waste by weight

Material	Japan[a]	Taiwan[b]	China[a]	India[a]	Russia and the Ukraine[a]	United States[a]
Glass	—	8	1	1	7	8
Metals	5	7	1	1	4	9
Organics	16	33	45	36	38	26
Paper, cardboard	37	27	5	3	22	41
Plastics	15	21	1	—	6	6
Textiles	4	3	—	4	3	—
Wood	—	—	—	—	2	—
Wood, leather, rubber, linoleum, textiles	3	—	1	—	2	8
Fine waste, minerals	6	—	—	—	—	—
Misc. inorganics (ash, dirt, etc.)	—	1	46	50	—	2
Others	14	—	—	5	16	—
Total	100	100	100	100	100	100

[a] Source: Reference [3].
[b] Source: Reference [7].

Table 3
Residential recycling rates in Japan

Material	Residential waste recycling rate (%)
Waste paper	48.2
Glass bottles	47.6
Aluminum cans	42.5
Steel cans	40.2

Source: Reference [1].

households. As a result of these efforts, it is estimated that recycling rates approach 50% of the residential waste generated [1]. Table 3 lists estimated residential recycling rates for selected materials. Similar recycling rates are achieved for industrial waste.

The Japanese Institute of Public Health, of the Ministry of Health and Welfare, estimates that approximately 1 kg/day per capita of municipal solid waste (MSW), after recycling, is generated by a population of approximately 125 million resulting in approximately 48 million tonnes per year of MSW that is managed through public treatment and disposal facilities [1]. As indicated in Table 4, approximately 73% of the total solid waste generated after recycling is managed through incineration.

There are approximately 1900 waste incineration facilities operating in Japan today including over 360 continuous throughput waste-to-energy facilities [8]. The largest waste-to-energy facility is a 1800 tonne per day plant in Tokyo. However, the

Table 4
Quantity of municipal waste managed annually in municipal treatment and disposal facilities in Japan

Type of treatment or disposal facility	Quantity of waste managed (t/y)	Percent of total waste managed (%)
Incineration facilities	33 800 000	72.5
Bulk refuse processing facilities	763 000	1.6
Composting facilities	56 000	0.1
Recycling facilities	1 390 000	3.0
Landfill without treatment	10 600 000	22.8
Total	46 609 000	100.0

Source: Reference [1].

average size facility has a capacity of less than 100 tonnes per day and many facilities are small, batch-type or intermittently operated [9]. The size of facilities is often limited by the cost of transporting waste and a number of smaller, strategically located facilities are often preferred to a single large facility to reduce the economic and environmental impact in any one area.

The market for waste-to-energy development in Japan is dominated by four vendors: Takuma Co. Ltd.; Mitsubishi Heavy Industries, Ltd.; Hitachi Ship Building Co.; and Nippon Kokan K.K. From 1968 through 1986, these four firms provided nearly 70% of the incineration capacity built in Japan [9]. Table 5 provides an overview of the technology used and the number of operating facilities in Japan for each of these and other major incineration vendors.

Public opposition is often a major obstacle in the development of waste incinerators. Organized opposition movements often cite technical defects of existing plants which have resulted in higher emission levels than anticipated, potential reduction in community property values and the nuisance of garbage truck traffic [8]. To promote public acceptance, waste incinerators are often developed as community

Table 5
Major waste incineration vendors in Japan

Vendor	Technology	Number of plants[a]
Mitsubishi Heavy Industries	Mitsubishi-Martin reverse acting stoker Mitsubishi reciprocating grate, and Mitsubishi traveling stoker	97
Nippon Kokan	Volund parallel reciprocal step-forward stoker, NKK-DG type incinerator with radiant ceiling	38
Hitachi Ship Building	Von Roll	N/A
Takuma	Takuma step-reciprocating grate	261
Kawasaki Heavy Industry	Kawasaki swing/reciprocating grate; DBA roller grate; Kawasaki-DBA fluidized bed	101
Ebara	Ebara twin interchanging/revolving fluidized bed	34

[a] Number of plants in operation or under construction as of 1988.
Source: Reference [9].

Table 6
National emissions limits and local emissions limits for selected facilities in Japan

	Particulates ($g/N\,m^3$)	HCl (ppm)	NO_x (ppm)	SO_x (ppm)
National Emission Standard	0.15[a]	430	250[b]	Varies[c]
Sohka City Plant	0.05	25	200	30
Mitaka City Plant	0.03	25	120	30

[a] This is the ordinary standard for plants with a flue gas volume greater than or equal to 40 000 $N\,m^3/h$. Stricter standards apply in selected areas.

[b] This is the standard for all plants constructed after 10 August 1979.

[c] The national emission standard for SO_x varies based on facility location, stack height and velocity of the emission gases.

Source: Reference [8].

centers with recreational and educational facilities. These facilities may include swimming pools, tennis courts, baseball fields, playgrounds, and classrooms. The facilities are generally clean and meticulously maintained to promote further community acceptance.

The national government subsidizes the construction of waste incinerators covering up to 25% (50% in polluted areas) of the capital cost of the facilities. Municipalities typically provide the balance of funding and plants are typically municipally owned and may be municipally operated or operated under contract by private firms.

Although energy recovery is a recognized benefit, the primary purpose of incineration facilities in Japan is seen as volume and toxicity reduction. In addition, electrical utilities in Japan are not required to purchase electricity generated at waste-to-energy facilities. So although electricity is generated for sale in approximately 100 waste incineration facilities, recovered energy is often utilized within the facility complex, or exported in the form of steam or hot water for use in other public facilities, greenhouses, or for district heating. National standards have been set for emission limitations for HCl, NO_x, SO_x and particulates. However, prefectural and local governments are free to impose stiffer standards for these pollutants as well as impose limitations for additional pollutants. National emission standards for these pollutants, along with the local standards for several selected facilities are listed in Table 6. National guidelines also limit dioxin emissions to 0.5 $\mu g/N\,m^3$. In addition to these standards, many facilities operate under restrictions on emissions of metals such as cadmium, lead and zinc. Air pollution control equipment typically include bag filters to achieve the emission standards. In order to increase public confidence and acceptance, many of the larger facilities operate large scoreboard type displays which are visible for several blocks and which display current emission measurements.

National standards for putrescible matter in ash is limited to 5%. Mixed fly ash and bottom ash are often disposed in landfills or ash monofills equipped with leachate control. Cementing, ashpalting, sintering and melting of ash prior to disposal are also practiced in some facilities [10].

2.2. Taiwan

In Taiwan, government plans for immense improvements in infrastructure nationwide include substantial national investment in waste-to-energy facilities to help manage Taiwan's municipal solid waste. Taiwan's six year $328 billion development plan includes projects in transportation, power generation, telecommunications and environmental protection. These plans include the development of over 20 waste-to-energy facilities throughout the country.

Landfills currently handle the bulk of MSW disposal in Taiwan. However, most cities in Taiwan are located on the narrow plains between the inland mountains and the sea. Space for landfill development is expensive and difficult to find. The flat, low lying terrain is often unsuitable for landfill development. Many existing landfills are built above the existing grade. As the country becomes more industrialized, and as population increases, increasing rates of waste generation have added pressure to find alternatives to landfills for waste management.

Taiwan currently has one operating waste-to-energy facility. This is a 900 tonnes per day facility, constructed by Takuma in Nei-hu, a suburb of Taipei, Taiwan's largest city. At least eight others are currently being designed or constructed and at least six additional facilities are currently in the proposal process. Takuma is currently completing the construction of a 1500 tonnes per day plant in the Mu-Cha area of Taipei. Nippon Kokan K.K. is currently constructing a 900 tonnes per day plant in Tai-Chung which utilizes the Volund technology. Mitsubishi Heavy Industries (MHI) is constructing plants of 900 and 1350 tonnes per day in the Hsin-Tien and Shu-Lin areas of Taipei, respectively. Both plants will utilize the Martin technology. More are being planned. Table 7 provides an overview of plants which are currently under construction or are in various phases of planning or design.

The government requires that the contracts for these facilities be awarded to local firms. Waste-to-energy vendors from around the world are vying for the development of future plants as subcontractors to local firms. Bidding on recent projects, for example, have included the teams of Formosa P.C. and Takuma (Japan); Far

Table 7
Status of waste-to-energy facilities currently in planning, design or construction in Taiwan

Location	Capacity (tpd)	Project status	Planned start-up
Mu-Cha, Taipei	1500	Performance testing	1994
Shih-Lin, Taipei	1800	Detailed design	1997
Tai-Chung	900	Under construction	1995
Chiayi	300	Under construction	1996
Hsin-Tien, Taipei	900	Performance testing	1994
Shu-Lin, Taipei	1350	Under construction	1994
Tainan	900	Under construction	1996
Shin-Chu	900	Detailed design	1997
Pa-Li	1350	Detailed design	1997

Note: Four other plants are currently in the Request for Proposals (RFP) development phase of planning.
Source: Reference [11], and Sinotech Engineering Co., Taipei.

East Machinery and D.B (Italy); China Steel Corporation and W & E (Switzerland); and Taiwan Cement Corporation and Stein (France).

The Taiwan National Environmental Protection Agency (EPA) or local EPA offices typically provide oversight for the development of waste-to-energy facilities in Taiwan. The EPA determines the need for a facility in cooperation with local governments and issues a contract for the development of a Request for Proposals (RFP). Engineering firms in Taiwan generally provide the lead for development of the RFP's although foreign firms may also participate in the planning on a sub-contract basis.

Although Taiwanese facilities use state-of-the-art technologies from around the world, there are considerations for the design of waste-to-energy facilities which are unique to facilities in Taiwan.

The composition of waste influences the design of the facilities. Table 2 provides an overview of the waste composition derived from a sampling project conducted in Taipei in 1991. Overall, the MSW in Taiwan has a high moisture content, averaging 50–60%, with high putrescible matter due to the high concentration of food waste. The resulting heating value for the waste is comparatively low. Analysis of samples taken during 1991 in Taipei yielded a lower heating value (LHV) of approximately 1700 kcal/kg. In Japan, LHVs of approximately 2400–2600 kcal/kg have been reported with a new facility reportedly being designed for a LHV of 3000 kcal/kg. In the United States, the average LHV of MSW recorded in some areas is approximately 2400 kcal/kg. As Taiwan becomes increasingly industrialized and as the consumption habits of the people of Taiwan change, it is anticipated that the heating value of the MSW will increase.

The trend toward increasing waste heating value influences the design of waste-to-energy facilities in Taiwan. Failure to provide adequately for future increases in the heating value of MSW may result in reduced throughput capability in the future. Facilities now in planning in Taiwan are being designed to accommodate a wide range of heating values. For example, facilities in Ren-wu, Hsin-feng, and Hsi-chou are currently being planned to have the capability to receive MSW with LHVs in the range 1400–2600 kcal/kg.

As with facilities in Japan, facilities in Taiwan are generally planned to include on-site recreational facilities for the use of the local community. The facility in Taipei includes an indoor swimming pool, outdoor running track, a fully equipped playground, a restaurant and other facilities for public use.

Table 8 lists the national emission limitations for pollutants currently in effect in Taiwan. Semi-dry scrubbers and baghouses are the preferred means for achieving emission standards. Due to the high moisture content and putrescible nature of the MSW, facilities are typically designed with extra consideration for odor control. Generally, the waste storage pit is completely separated from the tipping floor. Waste delivery vehicles discharge their loads through chutes into the pit. Hydraulically operated doors cover the openings to the chutes when they are not in use to prevent the escape of odors from the pit. Tipping floors and storage bunkers may also incorporate chemical deodorant spray systems to provide additional masking of odors.

Table 8
National pollutant emission limitations for waste incinerators in Taiwan

Pollutant	Emission limitations	Units
Particulates	$1364.2 \times Q^{-0386}$	mg/N m^3
Opacity	10	%
Hydrochloric acid	40	ppm
Sulfur oxides	80	ppm
Nitrogen oxides	180	ppm
Carbon monoxide	120	ppm
Lead	2	mg/N m^3
Cadmium	0.3	mg/N m^3
Mercury	0.3	mg/N m^3

Source: Reference [11].
All emission levels are at 10% O_2, dry basis.
Q is flue gas flow rate.

2.3. China

Over 1 billion people in Mainland China generate in excess of 200 million tonnes of household solid waste each year [3]. This is equivalent to approximately 0.5 kg per capita per day.

Typically, in many cities in China, residents carry their refuse to collection points along the streets. In Shanghai, for instance, the city maintains iron and brick containers between 2 and 4 m^3 in volume. Each container serves between 200 and 300 households. In many cities, open trucks are provided to pick up waste from these collection points. In parts of the country, however, roads are narrow and trucks are expensive. Here, hand-powered carts are the primary means of picking up and transporting wastes. In Guiyang, garbage collectors simply pull carts by hand through the streets. They ring bells as they go, signalling the residents to bring out their refuse.

Open dumping of waste is the primary means for waste disposal in China. In Shanghai, waste is delivered to transfer stations on the Huang Pu River and Shouzhou Creek where it is loaded onto barges. Convoys of up to ten barges carry the waste to open dumping sites downstream from the transfer stations. In other cities and rural areas, waste is simply piled along the roads or used as fill in low lying areas. Traditionally, after a suitable period of time for decomposition, farmers screen the waste and spread it on their fields as a fertilizer and soil conditioner. This method of fertilization has been practiced for hundreds of years, and around Guiyang, it is reported that the layer of soil containing waste is over 12 in deep [12].

Recycling activities are widespread. The state organized recycling industry has operated over 100 000 waste recovery shops across the country and between 400 and 450 processing facilities employing between 300 000 and 500 000 people [13]. In addition, a large, informal economy is based on scavenging for additional recyclables from garbage piles.

Because of the high food and ash content, the waste stream is high in moisture and non-combustible materials and is typically unsuitable for incineration. However, in some urban areas, where oil is replacing coal as a heating source, and where a more affluent population consumes more processed and packaged products, the incineration of solid waste is being considered as an alternative waste disposal method. Shanghai, for example, has considered the development of a 300 tonne per day waste-to-energy facility, and Shen Zhen City reportedly has one operating waste-to-energy facility developed by Mitsubishi Heavy Industries.

2.4. India

There are a number of similarities between waste management in India and waste management in China. In India, as in China, the fractions of inorganic waste and food waste are high, exceeding 90% of the total waste generated. As in China, most waste in India, over 90%, is disposed in landfills or open dumping areas [3].

Composting of waste is also practiced in India. As of 1985, it was reported that 25 mechanical composting systems were operating in the country [3].

Recycling in India is primarily accomplished through scavenging. For example, in New Delhi, tens of thousands of ragpickers, mostly children, scavenge through collection bins and disposal areas for recyclables which are marketed to trash dealers Ragpickers can earn up to $1.00 per day, nearly twice the average national income.

Waste combustion is not a common practice in India. One 120 tonne per day incinerator was built during the 1930s in Calcutta but was operated for only a short period. It is reported that the City of New Delhi has planned the implementation of one waste-to-energy facility.

2.5. Korea

The Korean Ministry of Environment began controlling solid waste with the enactment of the Waste Management Act in 1986 because of increased pollution and environmental problems. In 1991 the Waste Management Act was amended, classifying solid wastes into two groups: general wastes characterized as non-hazardous wastes and specified wastes characterized as hazardous wastes [14].

Korean government run corporations, industrial complexes and municipalities currently landfill most of their general wastes; however, of the total specified wastes in 1990, 57.9% was recycled and 24.3% was incinerated, as shown in Table 9 [15].

Due to high land prices, odor and unsanitary conditions of existing garbage collection systems, local city governments plan to improve garbage collection by separating recyclable waste and either landfill or incinerate the remaining waste. With waste-to-energy seen as a cost-effective alternative to landfill disposal, the Korean government plans to build incinerators in large industrial complexes and heavily populated cities [16]. In 1993, the Korean Ministry of Environment promulgated an enforcement decree under the Waste Management Act of 1986 requiring installations of landfills and incinerators in industrial complexes which were constructed after 1988. The current number of industrial complexes in Korea begun after 1988

Table 9
Generation and treatment methods of hazardous wastes in 1990 in Korea

Type of wastes	Amount of wastes (t per year)					
	Reuse/recycle	Landfill	Incineration	Other methods	Storage	Total
Total (%)	577 790 (57.9)	39 459 (4.0)	242 058 (24.3)	90 085 (9.0)	48 359 (4.8)	997 751 (100)
Hazardous waste	17 492	17 820	27 773	13 851	3958	80 894
Waste oils	84 747	7150	68 312	29 556	11 506	201 271
Resinous	103 572	12 849	145 973	13 022	30 057	305 471
Acid/ alkali	371 979	1640	0	33 658	2838	410 115

Source: Reference [15].

is approximately 49 [17]. Under the proposed decree, industrial complexes fall under the following categories:

- industrial complexes greater than one million square meters or which generate greater than 30 000 tonnes of waste annually must install a landfill and incinerator;
- industrial complexes between 300 000 and one million square meters or which generate between 10 000 and 30 000 tonnes of waste annually must install a landfill and incinerator; however, requirements for an incinerator may be waived if there already exists a large-scale incinerator in the vicinity of the complex;
- and industrial complexes less than 300 000 m^2 meters or which generate less than 10 000 tonnes of waste annually are recommended to install a landfill or incinerator or obtain professional waste handling companies to treat their waste [17].

Table 10 shows the proposed number of incinerators and budget planned for Korea's large cities and industrial complexes from 1992 to 1996. A total of 50 incinerators were planned with an average budget of 60.6 million US dollars per incinerator [16].

2.6. *Russia and the Ukraine*

Decades of accelerated productivity coupled with long-term neglect of the solid waste management system by the former Soviet Union have had adverse effects on solid waste management. Ninety-seven percent of household and commercial waste is

Table 10
Incinerators and budget for Korea's largest cities and industrial complexes

Year	Number of incinerators	Budget (US dollars)
1992	13	700 million
1993	12	1.1 billion
1994	8	500 million
1995	6	200 million
1996	11	530 million

Source: Reference [16].

Table 11
Incinerator facilities in the former Soviet Union

City	Republic	Technology	Facility size (t/day)	Year of commission
Dnepropetrovsk	Ukraine	DBA[a]	1584	1987
Kharkov	Ukraine	DBA	1188	1982
Kiev	Ukraine	DBA	1584	1988
Moscow	Russia	Martin	440	1974
Moscow	Russia	Volund	1200	1983
Murmansk	Russia	DBA	792	1984
Pyatigorsk	Russia	DBA	1188	1982
Rostov	Russia	DBA	1188	1983
Saratov	Russia	DBA	1188	1986
Soc	Russia	DBA	792	1982
Vladimir[b]	Russia	—	200	1982
Yalta	Ukraine	DBA	1188	1981

[a] DBA is Deutsche Babcock Ablagen.
[b] Soviet developed mass burn plant.
Source: Reference [5].

reportedly disposed in substandard landfills, open dumps, or deteriorating incinerators [18].

Typically, in many cities in the former Soviet Union, refuse is collected daily from apartment buildings where most residents live. Apartments more than five stories are equipped with refuse chutes that feed waste into storage containers located in the building basement. In many cities, packer trucks are provided to pick up waste from these collection points. In parts of St. Petersburg, baled wastes are placed into carts that transfer the bales on a compressed air driven underground rail system to the city's composting plant [5].

Landfills are the primary means for solid waste disposal in the former Soviet Union. As of 1989, however, there were 12 incinerators operating in the former Soviet Union, as shown in Table 11. Russian industries depend on these incinerators for disposal. The incinerators were typically located in areas where they could complement a city's district heating system.

In Moscow, there are two incinerators that process approximately 343 000 tonnes of solid waste per year. Energy is recovered from the incineration process in the form of steam. Electrostatic precipitators are used for air pollution for the incinerators [3]. Unfortunately, replacement of worn-out parts have presented problems for Russia's incinerators. One Moscow incinerator has been shut down since August 1992 because of the lack of available parts [18].

Planning for the rebuilding of the Russian solid waste management infrastructure includes the development of new waste-to-energy facilities. For example, in Moscow, current plans call for incineration of up to 88% of the 2.3 million tonnes of municipal solid waste generated annually by the City's nine million inhabitants by 2010. To accomplish this, the City anticipates developing ten waste-to-energy facilities, each with a capacity of approximately 300 000 tonnes per year.

3. Summary

The diversity in the development of municipal waste incineration among the countries reviewed reflects differences in the level of industrialization, scarcity of land for landfill development, consumption habits and wealth among the countries. Japan is a highly industrialized and wealthy nation with a scarcity of land for landfill development, and has developed more municipal waste incineration facilities than any other country in the world. On the other hand, China and India are less industrialized and less wealthy and have developed almost no municipal waste incineration facilities. Between these extremes are the former Soviet Union countries of Russia and the Ukraine, with limited municipal waste incineration, and the increasingly industrialized countries of Taiwan and Korea which are rapidly moving forward with the development of municipal waste incineration.

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