INFORMATION NOTE

Thermal waste treatment in the European Union

1. Introduction

1.1 In Europe, the restriction of constructing new landfill sites by the European Union ("EU") and the strict emission targets set under the EU *Landfill Directive*[1] have not only resulted in enactment of environmental legislation to improve waste management, but also precipitated the development of thermal waste treatment programmes. Indeed, thermal waste treatment technologies are commonly adopted by some European countries as part of their waste management strategy to divert the growing volume of waste from landfills. Apart from reducing the volume of waste, thermal treatment also provides a means to enable recovery of energy, mineral and/or chemical content from waste. The purpose of this information note is to provide an overview of thermal waste treatment technologies and the corresponding legislative framework in the EU.

2. Thermal waste treatment technologies

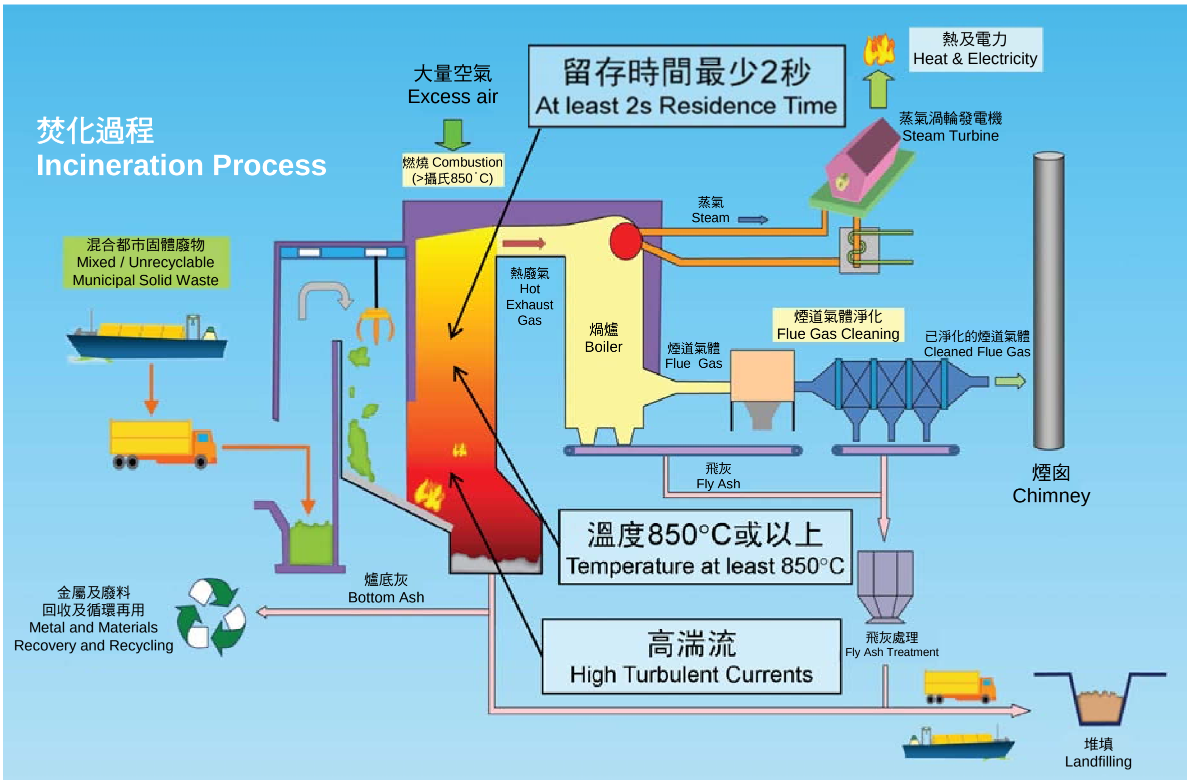
2.1 Thermal waste treatment is a term given to any waste treatment technology that involves high temperature in the processing of waste feedstock. It includes incineration and other treatments, such as Advanced Thermal Treatments ("ATT") (principally pyrolysis, gasification and plasma gasification). Salient features of various thermal waste treatment technologies are compared in Appendix.

1 For example, under the amended Council Directive 1999/31/EC of 26 April 1999, all EU member states are required to reduce the total amount of biodegradable municipal waste sent to landfills to 75% of the quantity generated in 1995 by 2006, 50% by 2009 and 35% by 2016. The target aims to achieve the progressive diversion of biodegradable municipal waste from landfills.

Incineration

2.2 Incineration is a thermal waste treatment technology used to reduce the volume of waste requiring final disposal. The technology can typically reduce the waste volume by over 90% and it is one of the widely used technologies for treating municipal solid waste prior to disposal at landfills. Most modern incineration plants incorporate heat recovery as well as power generation facilities to recover the heat energy in the waste.

Figure 1 — Modern incineration technology — process flow diagram



Source: Environmental Protection Department (2011).

2.3 Incineration usually involves the combustion of raw residual waste. To allow the combustion to take place, a sufficient quantity of oxygen is required to fully oxidize the fuel (i.e. waste). Typically, incineration plant combustion temperatures are in excess of 850°C for more than two seconds with sufficient supply of air so as to ensure complete burning of the waste and prevent the formation of dioxins and carbon monoxide. Any non-combustible materials (e.g. metals and glass) remain as solid, known as bottom ash, which can be processed to be used as filler material for construction works such as motorways, roads and bridges.

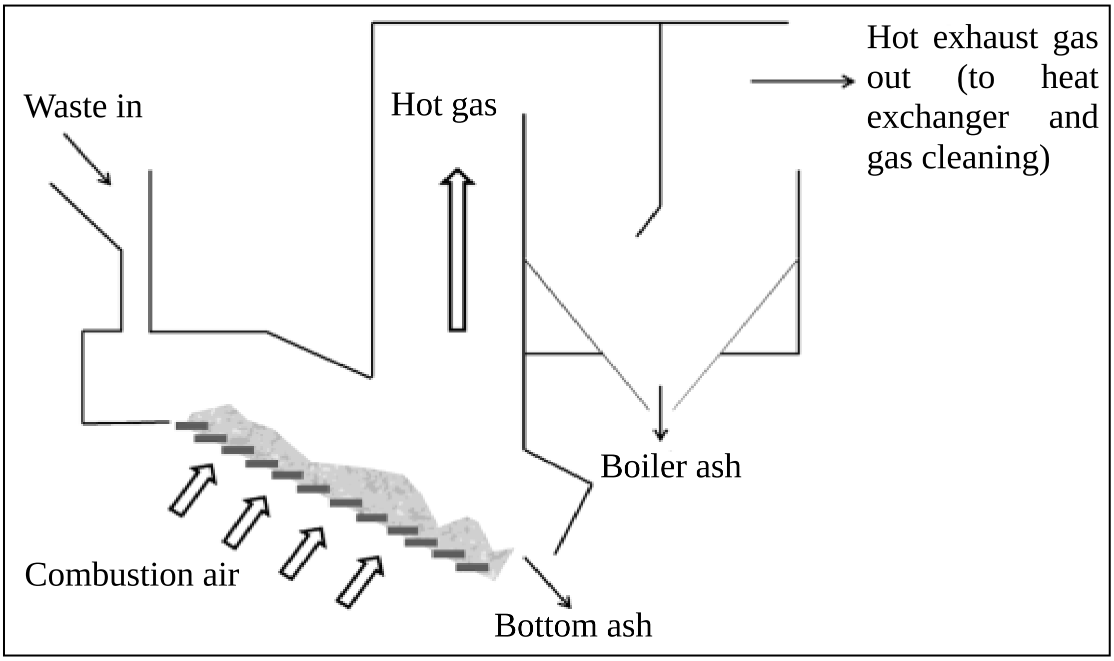
2.4 When the waste is burnt, the heat from the combustion can be used to produce high pressure steam in the boiler, which is used to generate electricity via a steam turbine and/or used for heating purpose. The exhaust gas, or flue gas, from the boiler is first cleaned for eradication of pollutants before going into atmosphere.

Moving grate incineration

2.5 Moving grate incineration technology is commonly adopted by incineration plants for waste management. The moving grate enables the movement of waste through the combustion chamber to be optimized to allow a more efficient and complete combustion.

2.6 The waste is introduced by a waste crane through the "throat" at one end of the grate, from where it moves down over the descending grate to the ash pit in the other end. The grate is made up of moving parts, which push the waste through the combustion chamber. Primary air is injected through the grate from below and secondary air is injected above the grate into the flame region.

Figure 2 — Schematic of a moving grate incinerator



Source: Harrison, R.M. (2014).

2.7 If heat from the incinerator is to be used, the combustion gases will pass through a heat exchanger. The heated fluid from the exchanger may be used to produce steam that powers a turbine and produces electricity, or the hot fluid may carry energy elsewhere.

Advanced Thermal Treatment

2.8 ATT primarily comprises pyrolysis, gasification and plasma gasification. The waste is heated to extract energy from it but, unlike incineration, ATT technologies require pre-processing to remove oversize items, non-combustible materials (such as metals and glass) and excess moisture. The waste is then shredded to ensure that it degrades more evenly during the treatment process. In addition, the pollution control strategies for ATT are typically on a smaller scale than for incineration technologies due to the reduction in the volume of process air required.

2.9 ATT creates a mixture of products from the thermal step that still have a lot of chemical energy stored in them (e.g. gases and oils). These can be burnt and used to raise steam. However, these products also have the potential to be cleaned and burnt directly in gas engines or gas turbines, or converted to transport fuels or synthetic natural gas. The latter routes have the potential to convert the energy from the waste more efficiently than through steam generation, which makes them attractive. However, they are technically difficult and some of the generated energy is used to power the process, reducing the overall benefits.

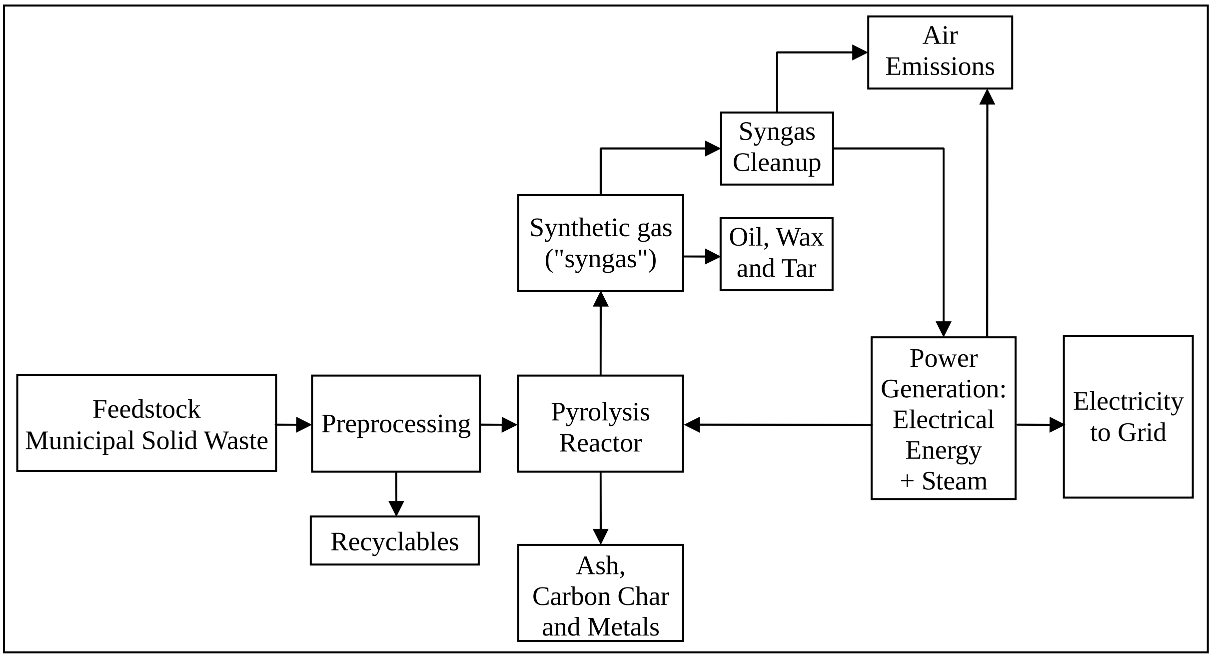
Pyrolysis

2.10 In contrast to incineration, pyrolysis is the thermal degradation of a substance in the absence of oxygen. This process requires an external heat source to maintain the temperature required. Typically, lower temperature of between 300°C and 850°C is used during pyrolysis. Raw residual waste is usually not appropriate for pyrolysis and typically will require preparation and separation of glass, metals and inert materials (such as rubble) prior to thermal treatment.

2.11 The pyrolysis process produces a solid residue of non-combustible materials and carbon (also known as "char") and a gas mixture of hydrogen and carbon monoxide known as synthetic gas ("syngas"). The char can be disposed in landfill, or treated further to reduce the carbon content by gasification or incineration into bottom ash which can then be recycled as secondary aggregates. As for syngas, it can be further condensed to produce oil, wax or tar, or combust to generate steam and produce electricity and/or heat for use on-site and export off-site.

2.12 As the pyrolysis process is highly sensitive to the presence of air, any accidental incursion of air can result in process upsets and increase the risk of explosive reactions. Moreover, pyrolysis processes need consistent feedstock where the size of feed particles, their moisture content and composition are more or less the same over the long period. In addition, pyrolysis generates low energy output, and there is a very limited track record of commercial scale pyrolysis plant accepting municipal waste in the world.[2]

Figure 3 — Process flow chart of a pyrolysis plant



Source: Young, G.C. (2010).

[2] See Department for Environment, Food and Rural Affairs (2013c).

Gasification

2.13 Gasification can be considered a process between pyrolysis and incineration in that it involves the partial oxidation of a substance. This means that oxygen is added but the amounts are not sufficient to allow the fuel to be completely oxidized and full combustion to occur. The temperatures employed are typically above 650°C. Heat may be required to initialize and sustain the gasification process. Similar to pyrolysis, pre-treatment is required for raw residual waste prior to thermal treatment. The main products of gasification are syngas which can be burnt to generate electricity, and bottom ash which can be recycled as secondary aggregates.

2.14 In Europe, the development of gasification technology is in its infancy as the technology tends to have higher operating and capital costs in comparison with incineration facilities, given the requirement for waste pre-processing and the added complexity of the technology.[3]

Plasma gasification

2.15 Plasma gasification refers to the thermal process based on the gasification principle with the use of plasma torches as the heat source, as opposed to conventional fire and furnaces. The process uses electrical energy and high temperature to decompose waste into syngas. The extreme heat, which can reach 2 000ºC or above, causes the inorganic portion of the waste to become a liquefied slag, of which the solid form can be used for road bedding and other construction applications. Meanwhile, syngas is generally combusted in a second stage to produce heat and electricity for use by local markets.

2.16 For municipal solid waste, application of plasma gasification entails pre-treatment of mixed waste to a more homogenous feedstock. As this technology operates at an oxygen-deficient condition, less pollutant such as nitrogen oxides is generated. The resultant emissions from the reactor are cleaner and there is no bottom ash.

3 See Stantec Consulting Limited (2013).

2.17 Currently, there is limited commercially proven record on the treatment of municipal solid waste under plasma gasification.[4] The primary reason appears to be high capital and operational costs for these facilities. The wear on the plasma chamber is high and redundant plasma chambers are needed to keep the process operating. Furthermore, since plasma gasification requires significant amount of energy input, the overall energy recovery rate tends to be low.

Debate over the use of thermal waste treatment technologies

2.18 Thermal waste treatment is viewed as one of the widely used technologies for treating municipal solid waste prior to disposal at landfills. While the technology may not replace the need for landfilling, it can significantly reduce the waste volume by over 90%, and by extension, the amount of greenhouse gas emissions from landfills.[5]

2.19 Thermal waste treatment also comes with a number of other benefits. For example, it allows for the recovery of heat and/or power during the process, thereby providing a substitute for fossil fuel combustion. Thermal waste treatment also enables the recovery of minerals and chemicals from the solid waste stream which can then be reused or recycled. In addition, bottom ash generated from thermal waste treatment facilities provides a low cost aggregate for construction works.

2.20 According to some green groups, even the most technologically advanced thermal waste treatment facilities release significant levels of pollutants into the environment.[6] Modern pollution control devices may not prevent the escape of hazardous emission of ultra-fine particles such as dioxin and furan into the atmosphere.

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4 See Stantec Consulting Limited (2013).

5 According to the Environmental Protection Agency of the United States, greenhouse gas emissions from landfills are two to six times higher than those generated from thermal waste treatment facilities, when measured per unit of electricity generated. If the waste incinerated had instead been buried in landfills, the decomposition would have led to greater atmospheric harm through the release of methane, a greenhouse gas that is 25 times more potent than the carbon dioxide released by incineration plants

6 See, for example, Global Alliance for Incinerator Alternatives (2012).

2.21 Another problem with thermal waste treatment is the long-term contracts that thermal waste treatment facilities sign with the municipalities for the supply of waste. Thermal waste treatment facilities are expensive to build and facility operators need a guaranteed stream of waste to make a profit and repay investors. These operators usually sign contracts with municipalities to guarantee the supply from the latter a certain volume of waste over a long period of time, often 20 or 30 years. This will effectively commit the municipalities to generating a certain amount of waste, possibly rendering them to have lower recycling rates than would otherwise be possible. In this connection, the incentive for engaging in further recycling may be lost with the adoption of thermal waste treatment.

3. European Union legislative framework

3.1 Thermal treatment of waste is covered by the *Industrial Emission Directive* ("IED"), which is issued by the EU to recast the *Waste Incineration Directive* and six other Directives previously issued related to industrial emissions in a single directive. IED came into force on 6 January 2011 and had to be transposed into national legislation by all EU member states by 7 January 2013. The objectives of IED are to reduce emission into air, soil, water and land and prevent the generation of waste, thereby achieving a high level of protection of the environment taken as a whole.

3.2 IED is divided into seven Chapters comprising a total of 84 Articles and 10 Annexes. To minimize pollution from industrial sources, IED defines the obligations to be met by industrial activities with major pollution potential[7], including waste incineration. Any industrial installation which carries out the activities covered under IED must meet the following environmental requirements: (a) preventive measures are taken against pollution; (b) the best available techniques are applied; (c) no significant pollution is caused; (d) waste is reduced, recycled or disposed of in the manner which creates least pollution; (e) energy efficiency is maximized; (f) accidents are prevented and their impact is limited; and (g) sites are remediated when the activities come to an end.

[7] The list of industrial activities covered under IED includes waste management, energy industries, production and processing of metals, mineral industry, chemical industry, and rearing of animals. See Annex I to IED.

3.3 IED also stipulates that all EU member states are required to set up a system of environmental inspections of the installations concerned. As such, all installations are to be covered by an environmental inspection plan, which shall be regularly reviewed and updated. Based on the inspection plans, the competent authority is required to regularly draw up programmes for routine environmental inspections, including the frequency of site visits for different types of installations.

3.4 In addition, IED requires the establishment of an Europe-wide register – the European Pollutant Release and Transfer Register – to provide the public with detailed information on the emissions from waste incineration plants and other industrial facilities across the EU. The register adds transparency to waste incineration activities and enhances public participation in environmental decision-making.

3.5 There are also specific requirements set out in IED (particularly Chapter IV and Annex VI) governing waste incineration, including scope of regulated facilities, permit applications and conditions, operating conditions, control and monitoring of emissions, delivery and reception of waste, residues, and reporting and public information.

Scope of regulated facilities

3.6 IED applies to waste incineration plants and waste co-incineration plants which incinerate or co-incinerate solid or liquid waste. For pyrolysis or gasification plants, they will be exempted if the gases resulting from the thermal treatment of waste are purified to such an extent that they are no longer a waste prior to their incineration and they can cause emissions no higher than those resulting from the burning of natural gas.

Permit applications and conditions

3.7 Incineration plants with a capacity exceeding three tonnes per hour (for non-hazardous waste) or 10 tonnes per day (for hazardous waste) must have a permit to carry out their activities. The permit is issued by the competent authority on the condition that the requirements defined in IED are complied with. The permit specifies the categories and quantities of waste which may be treated, the plant's incineration capacity, and the procedures used for sampling and measuring air and water.

Operating conditions

3.8 In order to guarantee complete waste combustion, IED requires all plants to keep the incineration gases at a temperature of at least 850°C for at least two seconds. If hazardous waste with a content of more than 1% of halogenated organic substances is incinerated, the temperature has to be raised to 1 100°C for at least two seconds. Moreover, any heat generated by the incineration process has to be recovered as far as practicable.

Controlling and monitoring of emissions

3.9 Annex VI to IED sets out the limit values for emissions aired out of incineration plants[8] as well as discharges of waste water resulting from the cleaning of waste gases. It also requires the installation of measurement systems to monitor the parameters of relevant emissions, which must be measured continuously or periodically in accordance with the Directive.

Delivery and reception of waste

3.10 During delivery and reception of waste, incineration plant operators must take all necessary precautions to prevent or limit negative effects on the environment and risks to people. Furthermore, prior to accepting hazardous waste at the incineration plants, the operators must have at their disposal the administrative information on the generating process, physical and chemical composition of the waste, as well as the hazardous characteristics of the waste.

Residues

3.11 Incineration residues must be reduced to a minimum and, as far as possible, recycled. When dry residues are transported, precautions must be taken to prevent their dispersal in the environment. Tests must be carried out to establish the physical and chemical characteristics, and polluting potential of residues.

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[8] The limits cover heavy metals, dioxins, furans, carbon monoxide, dust, total organic carbon, hydrogen chloride, hydrogen fluoride, sulphur dioxide and nitrogen oxides.

Reporting and public information

3.12 Applications for new permits must be made accessible to the public so that the latter may comment before the competent authority reaches a decision. For plants with a nominal capacity of two tonnes or more per hour, the operators must provide the competent authority with report on the functioning and monitoring of their plant, to be made available to the public. A list of plants with a nominal capacity of less than two tonnes per hour must be drawn up by the competent authority and made available to the public.

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Appendix

Table — Comparison of salient features of various thermal waste treatment technologies

	Incineration	Gasification	Pyrolysis	Plasma gasification
Process	• Thermal process typically carried out at above 850°C with sufficient quantity of oxygen.	• Thermal process typically carried out at above 650°C with oxygen not sufficient to completely oxidize the fuel.	• Thermal process typically carried out between 300°C and 850°C in the absence of oxygen.	• Thermal process typically carried out at above 2 000°C with oxygen not sufficient to completely oxidize the fuel.
Years of adopting the technology for treating municipal solid waste ("MSW")	• More than 100 years.	• Recently applied with a limited track record.		
Feedstock requirements	• Minimal pre-processing of waste is required.	• Pre-processing of waste is required.		
Products generated during the thermal process	• Flue gas and bottom ash.	• Synthetic gas (with less tar[1]) and bottom ash.	• Synthetic gas (with higher content of tar), char and pyrolysis oil.	• Synthetic gas (with no tar) and inert slag.

Note: (1) The deposition of tar can cause blockages in plants and has been associated with plant failures and inefficiencies at a number of pilot and commercial scale facilities.

Appendix (cont'd)

Table — Comparison of salient features of various thermal waste treatment technologies (cont'd)

	Incineration	Gasification	Pyrolysis	Plasma gasification
Energy generation	• Heat and/or electricity can be directly generated from the thermal process.	• Synthetic gas produced from the thermal process can be combusted to generate heat and/or electricity.		
Efficiency[2]	• Electrical efficiency between 18% and 30%.	• Electrical efficiency between 10% and 20% if adopting similar energy recovery systems used in incineration plants. The process efficiency can potentially be higher if synthetic gas can be cleaned and burnt directly in gas engines/turbines, or converted to transport fuels or synthetic natural gas. But these involve higher technological requirements.		
Production of electrical energy	• About 0.5MWh to 0.6MWh per tonne of MSW (for older facilities). • About 0.75MWh to 0.85MWh per tonne of MSW (for newer facilities).	• About 0.4MWh to 0.8MWh per tonne of MSW.	• About 0.5MWh to 0.8MWh per tonne of MSW.	• About 0.3MWh to 0.6MWh per tonne of MSW (plasma facilities tend to consume more energy to operate than other types of facilities).
Plant capacity (by MSW quantity)	• Ranging from less than 4 000 tonnes per annum ("tpa") to over 800 000 tpa. One of the largest plants can process up to 850 000 tpa.[3]	• Typically smaller than incineration plant. One of the largest plant can process 250 000 tpa.	• Typically smaller than incineration plant. One of the largest plant can process 150 000 tpa.	• Typically smaller than incineration plant. The largest plant which can process 350 000 tpa will come into operation in 2014.

Notes: (2) Efficiency is the ratio of useful energy produced to energy input. For electrical efficiency of thermal waste treatment, the energy input is mainly the chemical energy content of waste and the energy output is the amount of electrical energy generated. Efficiency figures for electricity production are used for comparison. See Department for Environment, Food and Rural Affairs (2013b).

(3) This plant is part of a facility which can process about 1 400 000 tpa of MSW in total.

Appendix (cont'd)

Table — Comparison of salient features of various thermal waste treatment technologies (cont'd)

	Incineration	Gasification	Pyrolysis	Plasma gasification
Area of land required[4]	• 27 000m^2 to 307 000m^2.	• 16 800m^2 to 137 600m^2.		
Residual waste to disposal	• Reduce waste volume by 90% to 95%.	• Reduce waste volume by 90% to 95%.	• Reduce waste volume by up to 90%.	• No residual for disposal.
Emission	• Higher emissions, including heavy metals, dioxin and furans.	• Lower emissions.	• Lower emissions.	• Zero/limited emissions.
Reliability for treating MSW	• Numerous facilities operating worldwide with proven operational success. • Less complex than other thermal waste treatment technologies.	• Relatively new for treatment of MSW and with limited records. • Operational problems have been documented. • Complex operation.		
Current installations worldwide	• Around 1 000.	• Less than 100.	• Around 25.	• Around 15.

Note: (4) Scanty information is available in the public domain relating to the area of land occupied by thermal waste treatment plants. For reference, the data shown in the Table are based on those available for the thermal waste treatment plants in the United Kingdom, which cover the land area occupied by the plants and their supporting infrastructure. See Department for Environment, Food and Rural Affairs (2013a and 2013c).

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