



WASTE TO ENERGY

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

FINAL REPORT

Prepared for:

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Attention: Tony Wakelin, Section Head Industrial Air Emissions

Dear Mr. Wakelin:

Reference: Waste to Energy: A Technical Review of Municipal Solid Waste Thermal Treatment Practices – Final Report

Attached is the final report *Waste to Energy: A Technical Review of Municipal Solid Waste Thermal Treatment Practices*.

The report was prepared by Stantec Consulting Ltd., with assistance from Rambol Denmark A/S. We also acknowledge the assistance and input from the Ministry of Environment in the preparation of this comprehensive review of the Waste to Energy industry.

On behalf of Stantec, we would like to thank you for the opportunity to be of service to BC Environment in the preparation of this document. We look forward to working with you on similar projects in the future.

Respectfully submitted,

Stantec Consulting Ltd.

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EXECUTIVE SUMMARY

The province of British Columbia is committed to achieving ambitious goals for sustainable environmental management, including realizing greenhouse gas reductions, leading the world with the best air quality bar none and ensuring municipal solid waste (MSW) is managed to minimize environmental impacts. Representing approximately 3% of the province's available biomass resources, a portion of the municipal solid waste stream is a bioenergy source produced in all our communities that has the potential to be used as a fuel supply for the generation of electricity or for the generation of hot water or steam for community energy systems.

Anticipating increased interest in Waste to Energy (WTE) projects, the province is considering updates and revisions to the 1991 Emission Criteria for Municipal Solid Waste Incinerators. This WTE background report supports the Ministry of Environment's scoping phase, and is intended to be used as a supporting document for subsequent steps, including preparation of emission guidelines. This background report addresses the concept of what constitutes good performance, based on best practices in the WTE field in order to provide guidance on potential stack emissions limits and the design and operation of WTE facilities.

The report was prepared through the collaborative efforts of Stantec Consulting Ltd. and Ramboll Denmark A/S. Stantec has direct recent experience with the WTE sector in North America and Ramboll brings thermal treatment experience from the European Union.

The report includes the following main sections:

Thermal Treatment Technologies

A review of the thermal treatment processes applied to the MSW stream has been summarized. Both current, conventional combustion technologies and emerging WTE technologies are described in general terms. Conventional mass burn thermal treatment systems are most common in the industry, with some application of waste gasification, plasma arc and pyrolysis technologies. Emerging technologies include gasplasma, thermal cracking, thermal oxidation and waste-to-fuels technology.

WTE Facility Discharges

The report includes a discussion of typical discharges from WTE facilities, including emissions to the atmosphere, liquid effluent, and solid residues. Air emissions include, but are not limited to, particulate matter (total particulate, PM₁₀ and PM_{2.5}), sulphur oxides (SO_x), nitrogen oxides (NO_x), certain volatile organic compounds (VOCs), and carbon monoxide (CO). The section also describes additional air emissions of interest, sometimes described as Hazardous Air Pollutants (HAPs). These typically include acid gases, organic constituents, trace metals, mercury, polycyclic aromatic hydrocarbons, and dioxins and furans. Point source air emissions (from stacks) and fugitive emission sources are described. The management of liquid wastes produced by WTE facilities is described. The primary potential sources of liquid wastes are certain air pollution control equipment (wet scrubbers). Liquid wastes typically require on-site treatment prior to recycling and/or discharge to the sanitary sewer system.

Air Emission Control Systems

The report reviews air emission control systems commonly applied to thermal treatment technology, including operational controls and air pollution control (APC) system equipment. Operational controls relate to the handling of the MSW and how the operators control the combustion parameters to optimize facility performance. There are a wide variety of primary APC systems available for WTE facilities and typically these are used in combination to minimize the potential emissions. The APC system train selection is generally made after first selecting the scrubber system (dry, semi-dry or wet), and then other components that are complementary to the scrubber selection are added. The use of wet or dry scrubbers to control acid gases has been documented to achieve 87 – 94% removal of HCl and 43 – 97% removal of HF. Nitrogen Oxide control is accomplished using either Selective Catalytic Reduction (SCR) or Selective Non-Catalytic Reduction (SNCR) approaches, which use ammonia to react with oxides of nitrogen in the flue gas to reduce the concentration of NO_x. A reduction of NO_x in the order of >90% is typically achieved for SCR and 30% to over 75% for SNCR. Particulate removal efficiencies of up to 99.9% have been documented for both baghouses and electrostatic precipitators.

Expected Emission Rates

This section provides an overview of the typical emissions rates from combustion and control systems and the factors that affect the quality and quantity of emissions. Reported facility emission data for the WTE sector for facilities in Metro Vancouver, Ontario, USA, China and the European Union are tabulated for comparison. The factors that affect emission concentrations and rates from a WTE facility are discussed in overview.

Refuse Derived Fuel – An Overview

Refuse derived fuel (RDF) has the potential to be used as an industrial facility fuel supply for specific applications. RDF is typically defined as processed MSW, but can also include waste generated through construction and demolition (C&D). Examples of the use of RDF and C&D wastes in power boilers and cement kilns as fuel substitutes is discussed, with specific application to British Columbia. The potential effect of the use of such fuels on emission profiles and rates from industrial facilities are discussed.

Associated Costs and Energy Efficiency

As part of the comparison of WTE technologies, the report includes a review of costs and energy efficiency for the various thermal treatment and APC technologies. The capital and operating cost for WTE facilities varies on a per tonne basis depending on the scale of the facility and specific design parameters. Generally, actual cost information is difficult to verify, and much of the available cost data is based on vendor information that has been provided outside of formal procurement processes. The sale of recovered energy in a WTE facility, in the form of electricity or as heat (steam), is typically critical to the financial viability of the facility, particularly when compared to other MSW management options.

The report includes an overview of the European Energy Equation (Equation) and its application to the WTE sector. The Equation originated with the European Union (EU) Waste Framework Directive

(WFD) and is applied to categorize waste incineration facilities as recovery facilities, as opposed to waste disposal facilities which are lower on the waste hierarchy, where energy recovery/efficiency above a specified target (0.6 to 0.65 in accordance with the Equation) can be shown. Facilities that cannot meet this target are classified as waste disposal facilities. The ministry's Environmental Protection Division operational policy already states a preference for any MSW incineration facilities to meet energy recovery criteria (over disposal, determined using an approach similar the Equation). There are also aspects of the "*The BC Energy Plan: A Vision for Clean Energy Leadership*" related to efficiency and alternative energy within which a similar equation (modified to suit the BC context) could play a role to support development of efficient WTE approaches.

Monitoring Systems

An overview of emission and ambient monitoring systems is provided. This includes continuous emissions monitoring, periodic (non-continuous) source testing and ambient air quality monitoring techniques. References to the applicable monitoring procedures are provided. A discussion on averaging periods for continuous and periodic stack testing methods is included in relation to determining compliance with emission criteria and permit limits.

Emission Limits and Application

The report includes a discussion of the regulatory environment and regulatory practices in various jurisdictions, including Canada, USA and the EU, with specific focus on the generation and application of criteria and permit limits in BC. The Ministry's Environmental Protection Division has an interim Best Achievable Technology (BAT) policy to be used in the identification and setting of new waste discharge standards and criteria. A brief overview of the interim policy is provided.

This section also includes review of regulatory emission limits for Criteria Air Contaminants (CACs) and Hazardous Air Pollutants (HAPs) for the WTE sector. Two tables comparing emission limits are provided. One is a summary of maximum allowable concentrations of CACs and other parameters for WTE facilities as defined by criteria or standards in various jurisdictions. The second table is a comparison of actual permitted limits (from Permits or Certificates of Approval/Authorization) from actual facilities. Typical WTE facilities are capable of achieving emissions that are below maximum permitted hourly or daily average limits.

This section also contains a table summarizing emission limits by parameter and their corresponding averaging periods. The comparison includes the 1991 BC Emission Criteria for Municipal Solid Waste Incinerators, the new Ontario A-7 standard (October 2010), and the European Union's Waste Incineration Directive (WID) limits and 2006 BREF guidelines (European Union Best Achievable Technology Reference Documents).

This section concludes with proposed amendments to the 1991 Emission Criteria for Municipal Solid Waste Incinerators for BC, including the numerical value of the criteria by parameter and the recommended corresponding measurement and averaging methods. The proposed amended guidelines are also provided in the Recommendations (Section 11).

Ash and Residue Management

This section discusses the composition of bottom ash, fly ash and APC residues from WTE facilities. The quality of the residues is directly linked to the quality of the MSW input to the facility and some ash and APC residue quality data from EU facilities is presented. Gasification process residues are also described. The degree of sorting and source separation has a large effect on the quality of the ash. The report discusses beneficial use of these residues, including recovery and recycling of metals and the use of bottom ash as a construction aggregate or as a feedstock to the cement industry.

The section also describes the regulatory environment governing WTE residuals management in BC, North America and the EU. The section then focuses on the specifics for management of ash and residues in BC, including determining if the material is hazardous waste, identifying potential alternative uses, and safe disposal options.

Posting of financial security may be necessary where the land filling of ash from a WTE facility poses a potential risk to the environment. The report discusses in general terms how the need for financial security is determined in BC for contaminated sites and how the value of the financial security is determined. Financial security is based on a site-specific risk determination.

Conclusions and Recommendations

Conclusions and recommendations reached following the review of technologies, BAT, Best Available Control Technology (BACT) and the regulatory approaches in other jurisdictions, and considerations for updates to emissions criteria in B.C. are summarized as follows:

Conclusions

1. Mass burn incineration continues to be the most common method of thermal treatment for WTE facilities. It is reasonable to anticipate that this technology would be proposed for new WTE facilities contemplated in BC.
2. Other thermal treatment technologies such as gasification, plasma gasification and pyrolysis have historically had certain limitations due to their complexity, difficulty in handling variations in the waste stream (which can be managed by waste pre-treatment), and lower net energy recovery (electricity and heat energy) once in-plant parasitic consumption is accounted for. These factors tend to make these other thermal treatment technologies less viable. However, the industry continues to evolve and facilities that treat a portion of the waste stream are being proposed, developed and commissioned. As more actual performance data is generated, it will be better understood if the limitations of these approaches can be resolved.
3. The 1991 BC Emission Criteria for Municipal Solid Waste Incinerators (1991 BC Criteria) cut off between small and large facilities of 400 kg/hour (equivalent to 9.6 tonnes per day) was put in place to differentiate between small facilities used for remote locations and/or on-site waste management and larger WTE facilities. In Europe WTE operations generally handle an average of 20 to 30 tonnes of MSW per hour (480 to 720 tonnes per day). To-date, various studies indicate that it is difficult for commercial WTE facilities to be economically viable at annual capacities less than 10 tonnes per hour (equivalent to 100,000 tonnes per

year actual throughput), unless there is a local economic driver (e.g., high value local market for heat energy, high transportation costs and/or difficult logistics associated with other disposal options). In some jurisdictions (e.g., Ontario) the differentiation between large and small facilities results in differentiation of approvals processes (large WTE requires full Environmental Assessment (EA) Screening, small WTE does not) however, in regards to air emissions the same criterion/limits apply regardless of size to all WTE applications except for very small scale research applications. Other jurisdictions (e.g., United States Environmental Protection Agency (US EPA)) apply different criterion/limits for smaller scale WTE approaches. For the purpose of regulating MSW incineration in the BC context, it seems reasonable that the cut-off of 400 kg/h between small and large facilities should be maintained.

4. The 1991 BC Criteria currently include the key substances of concern that would be released from the main stack (point source) of an existing or new WTE facility. The 1991 BC Criteria do not, however, provide limits for speciated total particulate matter in the 10 micron (PM_{10}) and 2.5 micron ($PM_{2.5}$) size fractions. This approach is consistent with emission limits observed in other jurisdictions evaluated in this report. The value of specifying limits for speciated particulate matter has not been demonstrated and thus limits for these parameters have not been identified in the proposed revisions.
5. The 1991 BC Criteria do not consider fugitive emissions including dust, odour, and Volatile Organic Compounds (VOCs).
6. The specification of temperature and retention time in the combustion zone varies between North America and the EU, although generally these jurisdictions define the combustion zone in a similar fashion (measured after the last point of air injection). In North America, a minimum temperature of 1,000°C with a retention time of 1 second is typical. In the EU, the specification is minimum 850°C with a retention time of 2 seconds. Operated correctly within the design criteria for the incinerator, both specifications should produce an acceptable quality of emission before entering the APC. Flexibility in specifying these operating parameters should be considered and the appropriate balance of temperature and retention time applied on a facility-specific basis.

In most jurisdictions, guidance on design and operation of WTE facilities is provided including recommendations related to combustion temperature and residence time, and also for other parameters such as combustion air distribution, oxygen availability, operation of APC systems and ash management. In these jurisdictions as in BC, the recommendations are not intended to restrict technology development or to dictate facility design or equipment selection. Alternative designs and operating conditions may be proposed for approval, and considered by the regulatory authority, provided that the systems are designed and operated such that the Emission Limit Values (ELVs) can be achieved. Proponents are expected to provide sufficient technical information to the regulatory authority to justify alternative design and operational parameters. Once approved, these parameters are reflected in the operational permit(s) and/or conditions set out for the facility.

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7. The most common and effective air pollution systems applied to WTE facilities are dry/semi dry, wet and semi wet systems. Several types of “end of pipe” air pollution controls have been applied to WTE facilities. The selection of best technology (either BACT or BAT) depends on the nature of the waste, design of the combustion process, flue gas composition and fluctuation, energy supply, energy recovery and a number of other considerations.
8. Modern WTE facilities are capable of achieving substantial emission reduction through the use of emission control technology. Reductions in the contaminants of concern across the air pollution control system (APC) typically range from 90% up to 99.95% through the application of typical APC systems.
9. Management of NO_x can be accomplished through both Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction (SCR) systems, with economics in the form of direct costs (including reagent and energy consumption) or financial incentives (e.g., tax regimes) playing a role in the decision regarding which system is selected and in how the system is operated. Lower NO_x emissions can regularly be achieved through SCR. With SNCR, the level of NO_x reduction achieved is often linked to immediate economic drivers since increasing quantities of ammonia injection (i.e., use of additional reagent) are required to achieve lower emission levels. There is also a trade-off with SNCR, as the odour associated with ammonia slippage (stack ammonia releases due to excess ammonia not reacting with NO_x) must be considered.
10. Emission releases from WTE facilities have decreased substantially in the US between 1990 and 2005. SO_x and NO_x have been reduced by 88% and 24% respectively. The reductions have resulted from improvements in thermal treatment technology and operational control, improvements in waste diversion and source separation prior to thermal treatment, and improvements in the design and operation of the APC equipment.
11. The EU Energy Efficiency Equation will be adopted by EU member states by the end of 2010 as a means of differentiating between the energy recovery performance of WTE facilities. In general, the formula can be used for differentiating between energy recovery and disposal within a waste hierarchy. The application of the equation varies between the various EU member states. Further development and definition of the scope and application of the equations is expected. The ministry's Environmental Protection Division operational policy already states a preference for any MSW incineration facilities to meet energy recovery criteria (over disposal, determined using an approach similar the Equation). Therefore, it may be reasonable to modify the Equation to suit a BC context (i.e., modify the energy equivalency factors for electrical and thermal energy as appropriate) as part of future policy development in the Province. However, new WTE facilities in BC may not be able to achieve an energy efficiency of 60% without further development of infrastructure such as district heating that would facilitate the use of heat generated by a WTE facility, recognizing that a high efficiency is difficult to reach through the production of electricity alone.

12. In regards to the use of Refuse Derived Fuel (RDF) as substitute fuel in existing industrial or power generating facilities, the majority of jurisdictions examined in this study use a regulatory approach that combines some facets of the regulatory environment associated with WTE facilities (e.g., many of the same stack emissions limits, the same AAQO requirements) but also tailor these approaches in a more industry specific fashion. Generally, the approach applied to regulate use of RDF in other jurisdictions includes:
- a) Ensuring that the composition of the RDF is similar in regards to fuel value and general chemical composition to the primary fuel source for the intended combustion facility (e.g., use of cellulosic waste materials in wood-fired boilers).
 - b) Requirement for RDF fuel analysis and comparison to current fuels to determine the potential shift in contaminant mass balance and thus facility emissions.
 - c) The requirement to complete test burns and stack testing to measure and validate predicted shifts in emission quality, if any.
 - d) Application of RDF quality standards, specific to parameters that cannot be reasonably managed in the proposed industrial application (e.g., avoidance of fuels with high PVC content if the control of acid gases is unfeasible).
 - e) Application of the same stack limits applied to WTE facilities, for parameters that are directly associated with fuel quality (e.g., heavy metals, persistent organic pollutants (POPs)) but not for emission parameters that are driven largely by the primary purpose and design of the facility (e.g., not including SO_x emissions for cement kilns as these emissions are largely driven by raw material quality).
13. In the EU, it is common for emission limits to be linked to monitoring techniques and corresponding averaging periods. Typically, one-half hour average limits are specified for parameters measured by continuous monitors, whereas daily average limits are specified for parameters measured by periodic monitoring. For some parameters, limits for both continuous and for periodic monitoring are specified. In the US, daily average emission limits are specified regardless of the monitoring method. The industry trend is towards increased use of continuous monitoring devices where they can be correlated as equivalent to periodic monitoring techniques.
14. In the EU, where one-half hour average limits and daily average limits are specified for a parameter, the one-half hour limit is numerically higher than the daily average limit. The dual limits acknowledge that the daily average takes into account the fluctuations in the emission over time, whereas the one-half hour limit more closely represents the maximum allowable discharge concentration over the shorter averaging period.
15. This report highlights the potential use of the dual standards for some parameters as applied in the EU. When comparing the emission limits proposed in this report to the 1991 BC Criteria, the potential monitoring methods applicable for each parameter must be considered. The proposed limits allow for continuous monitoring where appropriate and technically feasible and in general these values are greater than the daily average. The limits also allow for periodic monitoring for parameters that require stack testing and these

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proposed daily average limits are equal to, or more stringent than, the 1991 BC Criteria. New Ministry of Environment policy indicates that all WTE projects will be required to go through an Environmental Impact Assessment process. This is similar to the approach in jurisdictions such as Ontario, where all WTE projects (above a minimum size limit) are required to go through screening under the *Ontario Environmental Assessment Act*.

16. The BC Hazardous Waste Regulation specifies the methodology for testing leachability of a waste material and determining if it is classified as hazardous waste. Bottom ash, fly ash and APC residue should be subjected to the TCLP test and the ash should then be handled according to the classification.
17. Bottom ash is normally not classified as hazardous waste and it is acceptable practice to deposit bottom ash in a permitted sanitary landfill or for the ash to be utilized for a beneficial use, such as intermediate cover, concrete or asphalt aggregate substitution or road base material. Jurisdictions such as Ontario, recognize that bottom ash from facilities that process non-hazardous municipal waste and that has organic content of less than 10%, is a non-hazardous material and do not require that TCLP testing be carried out on such ash. Fly ash and air pollution control (APC) residue are more likely to contain leachable contaminants and be classified as hazardous waste. Fly ash and APC residue must be disposed of in a secure landfill authorized to receive this class of material. Alternatively, the fly ash/APC residue may be pre-treated/stabilized to reduce leachability prior to deposition in a municipal sanitary landfill site. There is limited opportunity for beneficial use of fly ash and APC residues in BC, even when stabilized, at the present time.
18. The Waste to Energy sector continues to evolve with the advent of new incineration and new pollution control equipment technology and the further advances in municipal waste diversion and separation technologies. Regulatory agencies including Ontario Ministry of the Environment and the US EPA have either recently revised or are considering revisions to current regulations and criteria. The BC Ministry of Environment should take into account both the technical and regulatory advances underway in comparable jurisdictions when developing revised guidelines.

Recommendations

1. The 1991 BC Criteria for municipal solid waste incineration should be updated to reflect advancements in thermal treatment and pollution control technology and standards applied in other jurisdictions. A table summarizing the recommended emission limits is provided at the end of this section.
2. It is recommended that the Waste Discharge Regulation (WDR) exemption for remote incinerators to accommodate fewer than 100 persons (section 3(7)) remain in place for remote operations. If a facility is serving over 100 persons and is processing less than 400 kg/hr of municipal solid waste, site specific emission limits should be authorized by the Ministry. Facilities over the 400 kg/hr capacity limit should be required to meet new revised emission guidelines as set by the Ministry.

3. The design and operation requirements in the 1991 criteria should continue to apply including the recommended minimum incineration temperature of 1,000°C and minimum residence time of 1 second (after final secondary air injection ports). This requirement should be maintained as the default specification; however proponents should be provided an opportunity to seek an alternate temperature/retention time specification that would result in equivalent thermal destruction efficiencies without impacting emission quality. Flexibility in the application of the temperature and retention time specification is possible, as long as the quality of the emission is maintained for a specific facility. A minimum temperature of 850°C with a retention time of 2 seconds could be considered equivalent, depending on the proposed technology. Adjustments to the temperature profile and retention time for a proposed facility should be demonstrated as equivalent by a facility proponent at the application stage, and would be reflected in the approved operating conditions set out for the facility.
4. The potential for fugitive emissions from WTE facilities should be addressed through site specific design considerations such as maintaining appropriate areas of the facility (e.g., receiving and tipping floor) under negative pressure, using indoor facility air for combustion and specific measures for loading, transfer, storage, accidental loss of containment, as well as the handling of auxiliary fuels and reagents for the APC systems. Revisions to the 1991 BC Criteria should address fugitive emissions with references to Best Management Plans, meeting ambient objectives and/or odours at the fence-line or other enforceable criteria.
5. The revised emission limits presented at the end of this section (also as Table 8-21) should be considered by the Ministry as proposed new emission criteria for WTE facilities in BC.
6. The recommended revised emission criteria generally reflect two approaches to setting in-stack emissions limits. The one-half hour limit is intended to be used where the facility uses continuous monitoring techniques. The one-half hour limit generally represents the maximum allowable concentration of a contaminant not to be exceeded at any time. The daily average limit applies when periodic stack sampling is used to characterize the emissions. The daily average limit should be considered to be the default limit where the facility must use periodic sampling to determine compliance or where continuous monitoring methods are not available or practical. Both the daily average and one-half hour limits should apply to parameters for which continuous monitoring is feasible and conducted, and where periodic stack sampling is required.
7. The recommended revised emission criteria for particulate, adopts a hybrid approach to emission limit values from other jurisdictions. Where continuous monitoring systems are used, it is proposed that the concentration of total particulate be less than 9 mg/Rm³ for 97% of the operating period on a 12 month rolling average, and less than 28 mg/Rm³ for 100% of the operating period on a 12 month rolling average. Where continuous monitoring systems for particulate are used, opacity monitoring may not be necessary as a compliance parameter unless the continuous monitoring system is not functioning. During this scenario, opacity monitoring can be used as a temporary surrogate until the continuous monitoring system for particulate is reinstated.

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8. The recommended revised emission criteria for trace metals lead (Pb), arsenic (As) and chromium (Cr) should be set as the sum of the three metals as determined by periodic sampling with the ELV being set at 64 ug/Rm^3 .
9. Where a non-MSW thermal treatment facility intends to substitute fuel with RDF, or C&D waste, the facility should be required to meet these revised WTE emission criteria for parameters that are directly associated with fuel quality, such as trace heavy metals and persistent organic pollutants. For particulate emissions, the facility could be required to meet new applicable guidelines (for biomass boilers the Ministry may set new limits of 35 mg/m^3 for facilities ranging in size from 3 to 39 MWh, and 20 mg/m^3 for facilities of 40 MWh and larger). The facility should still meet their permitted emission parameters that are established based on the primary purpose and design of the facility, such as SO_x , CO and NO_x . The range of permitted emission parameters that are established based on the primary purpose and design of the facility will vary as appropriate between specific types of existing industrial installations. This approach is permissive by allowing fuel substitution to occur but also protective by requiring compliance with the appropriate, more stringent, limits for potentially harmful contaminants related to the substituted fuel.
10. Generally, the approach applied to regulate use of RDF in BC should be similar to that used in other jurisdictions, including application of the following sequence of steps during the permitting process:
 - a) Ensuring that the composition of the RDF is similar in regards to fuel value and general chemical composition to the primary fuel source for the intended combustion facility (e.g., use of cellulosic waste materials in wood-fired boilers).
 - b) Requiring RDF fuel analysis and comparison to current fuels within the applications to use RDF, along with analysis that identifies the potential shift in contaminant mass balance and thus facility emissions.
 - c) For use of dissimilar fuels and/or use of RDF where there is some potential for more significant shifts in emissions or concern regarding the degree of emissions shift demonstrated through desk top analysis, in addition to the fuel tests/analysis there should be a requirement to complete test burns and stack testing to measure and validate predicted shifts in emission quality.
 - d) Development and application of RDF quality standards and specifications, specific to parameters that cannot be reasonably managed in the proposed industrial application (e.g., avoidance of fuels with high PVC content if the control of acid gases is unfeasible). This would include development of a definition for various fractions of sorted MSW and construction and demolition waste, for example defining what constitutes 'clean' versus 'contaminated' wood waste suitable for use as a substitute fuel for wood waste boilers.
 - e) Application of the same stack limits applied to WTE facilities, for parameters that are directly associated with fuel quality (e.g., heavy metals, POPs) but not for emission parameters that are driven largely by the primary purpose and design of the facility

(e.g., not including SO_x emissions for cement kilns as these emissions are largely driven by raw material quality). For those parameters that are driven largely by the primary purpose and design of the facility, facility specific ELVs will be determined and applied, potentially resulting in some adjustment to the ELVs for these parameters as set out in the operating permit.

The above represent preliminary recommendations. Further study is required to determine the appropriate RDF fuel quality specifications applicable in BC, and to determine the approach to stack emissions that would be most applicable to each of the major sectors (pulp mill boilers, lime kilns, cement kilns) that would represent industrial users of RDF in BC. The Province should consider development of specific regulatory instruments to address RDF composition (similar to other jurisdictions that regulate RDF composition for various applications) and use as a fuel alternative.

11. Dispersion modelling should be conducted to assess risks associated with the location and potential operation of a new WTE facility. Modelling results should show in all cases that AAQOs established or accepted by the Ministry would not be exceeded with a wide margin of safety for all conceivable modes of operation including upsets.
12. Potential effluent discharges from a WTE facility originating from process wastewater (associated wet flue gas treatment), originating from bottom ash storage, or from other process wastewater streams (boiler feed water, sanitary wastewater, storm water (either contaminated or clean) or used cooling water should be authorized as part of the Solid Waste Management Plan or under a waste discharge permit with limits determined on a site specific basis.
13. The current approach in BC used for leachability testing of bottom ash, fly ash and APC residues is consistent with other jurisdictions. Testing the leachability of the ash continues to be critical in the decision process for reuse and /or disposal of the bottom ash and APC residues. The TCLP leachate extraction test prescribed in the BC HWR is a suitable test method and widely accepted. Bottom ash found to be non-leachable is not hazardous waste and can have some beneficial use or can be deposited in a permitted landfill. APC residue from MSW treatment systems will likely be leachable and require stabilization prior to disposal in a landfill or should be managed as hazardous waste.
14. Separate handling of bottom ash and APC residues represents best practice in order to optimize recovery and/or beneficial use of bottom ash. New incineration technologies should be required to identify the characteristics of the facility residuals. If residuals are determined to have beneficial use characteristics the proponent should demonstrate the associated environmental benefits and liabilities. If beneficial reuse is not practical, consideration for comingling the ash for landfilling, with stabilization as may be necessary, may be permitted.
15. In the development of revised WTE guidelines, BC Ministry of Environment should take into account ongoing technical and regulatory advancements currently evolving in Ontario, the EU and USA.

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Table 1: Proposed Revisions to Emission Criteria for Municipal Solid Waste Incineration in British Columbia

Contaminant	Concentration Units	RECOMMENDED EMISSION LIMITS				
		C: Continuous P: Periodic ⁽¹⁾	Daily Average	Average Period and Monitoring Method	Half Hourly Average	Average Period and Monitoring Method
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	C (P for existing facilities)	9	Existing facilities without CEMS may use the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	9 ⁽²⁾ 28	1/2 hour average as determined by a continuous emissions monitoring system, achieved 97% of the operating period on a 12 month rolling average. 1/2 hour average as determined by a continuous emissions monitoring system, achieved 100% of the operating period on a 12 month rolling average
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	C	50	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	100	1/2 hour average as determined by a continuous emissions monitoring system
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	C	50	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	190	1/2 hour average as determined by a continuous emissions monitoring system
Nitrogen Oxides (NO _x as NO ₂)	mg/Rm ³ @ 11% O ₂	C	190	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	350	1/2 hour average as determined by a continuous emissions monitoring system
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	C	10	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	60	1/2 hour average as determined by a continuous emissions monitoring system
Hydrogen Fluoride (HF)	mg/Rm ³ @ 11% O ₂	P/C	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	4	1/2 hour average as determined by a continuous emissions monitoring system ⁽³⁾ .
Total Organic Carbon	mg/Rm ³ @ 11% O ₂	C	10	Calculated as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	20	1/2 hour average as determined by a continuous emissions monitoring system
Arsenic (As)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr group	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Cadmium (Cd)	µg/Rm ³ @ 11% O ₂	P	7	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Chromium (Cr)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr group	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Lead (Pb)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr group	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Sum of Lead (Pb), Arsenic (As), Chromium (Cr)	µg/Rm ³ @ 11% O ₂	P	64	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	P or C ⁽⁴⁾	20	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	N.D.	

Contaminant	Concentration Units	RECOMMENDED EMISSION LIMITS				
		C: Continuous P: Periodic ⁽¹⁾	Daily Average	Average Period and Monitoring Method	Half Hourly Average	Average Period and Monitoring Method
Chlorophenols ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.		N.D.
Chlorobenzenes ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.		N.D.
Polycyclic Aromatic Hydrocarbons ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	5	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.		N.D.
Polychlorinated Biphenyls ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.		N.D.
Total Dioxins and Furans (as PCDD/F TEQ)	ng/Rm ³ @ 11% O ₂	P	0.08	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.		N.D.
Opacity ⁽⁶⁾	%	C (P optional for existing facilities)	N.D.		5	1/2 hour average from data taken every 10 seconds, measured by a CEMS

NOTES:
Concentration units: Mass per reference cubic metres corrected to 11% oxygen. Reference conditions: 20°C, 101.3 kPa, dry gas
N.D. = Not Defined
⁽¹⁾ Where Periodic stack test measurements (P) are indicated, the daily averaging period applies. For Continuous monitoring (C), the 1/2 hour averaging period applies. P/C indicates both technologies are available; ELV will be linked to sampling method.
⁽²⁾ 97% of the half-hour average values over an annual rolling average will not exceed 9 mg/Rm³. 100% of the half-hour average values will not exceed 28 mg/Rm³.
⁽³⁾ This requirement may be omitted at the discretion of the Regional Manager should treatment stages for HCl demonstrate that the ELV for HCl is not exceeded.
⁽⁴⁾ Daily Average ELV for mercury applies regardless of monitoring method.
⁽⁵⁾ Proponents may be able to demonstrate that monitoring both Total Organic Carbon (TOC) and Total Dioxin and Furans could negate the need to monitor Chlorophenols, Chlorobenzenes, Polycyclic Aromatic Hydrocarbons and Polychlorinated Biphenyls.
⁽⁶⁾ Opacity will not be required for compliance purposes for facilities utilizing continuous particulate monitoring systems. Opacity monitoring is recommended for operational monitoring purposes. However, monitoring opacity can be used as a temporary surrogate for total particulate monitoring in the event of a particulate monitoring system failure. Under these circumstances, the ELV of 5% opacity over a 1/2 hour averaging period should apply.

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Appendix ADatabase of Current Technology Vendors and Thermal Treatment Technologies
Appendix B BC Emission Criteria for MSW Incinerators (June 1991)

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GLOSSARY

AAQC	Ambient Air Quality Criteria
AAQO	Ambient Air Quality Objectives
APC	Air Pollution Control
APC residues	Air Pollution Control residues comprise: (i) dry and semi-dry scrubber systems involving the injection of an alkaline powder or slurry to remove acid gases and particulates and flue gas condensation/reaction products (scrubber residue); (ii) fabric filters in bag houses may be used downstream of the scrubber systems to remove the fine particulates (bag house filter dust); and (iii) the solid phase generated by wet scrubber systems (scrubber sludge). APC residues are often combined with fly ash.
BACT	Best Available Control Technology meaning the technology that can achieve the best discharge standards relative to energy, environmental and economic impacts. BACT is often used more specific for 'end of pipe' control technologies such as Air Pollution Control systems, as opposed to BAT which can also refer to operating systems.
BAT	<p>Best Achievable Technology or Best Available Technology. Best Available Technology represents the most effective techniques for achieving a high standard of pollution prevention and control. BAT mechanisms in the USA and the EU are designed to provide flexibility to balance technical and economic feasibility, and weigh the costs and benefits of different environmental protection measures. This approach is referred to as Best Achievable Technology.</p> <p>BCMOE has an interim Best Achievable Technology policy to be applied when setting new discharge parameters for any discharge media and to be used as the basis for setting site specific permit limits.</p> <p>Within the EU, the concept of BAT was introduced as a key principle in the IPPC Directive 96/61/EC (Directive 2008/1/EC codified version).</p>
BATAEL	Best Achievable Technology (or Best Available Technology) Associated Emission Levels
BCEAA	<i>British Columbia Environmental Assessment Act</i>
BCMOE	British Columbia Ministry of Environment
Bottom Ash	Comprises heterogeneous material discharged from the burning grate of the incinerator (grate ash) and material that falls through the burning grate to be collected in hoppers below the furnace (grate riddlings).

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BPEO	Best Practicable Environmental Option is a set of procedures adopted by Great Britain which considers a range of environmental, social and economic factors that should be taken into account when making decisions on the future management of waste.
BREF	European Union Best Available Technology Reference Documents
CAC	Criteria Air Contaminants
CEAA	Canadian Environmental Assessment Agency
CFBC	Circulating Fluidized Bed Combustion is a combustion system in which the fuel (usually processed waste fuels such as coarse refuse-derived fuel) are burned within a bed of fine inert material fluidized by a high velocity air stream. The off-gas and entrained solids are separated in a high efficiency cyclone and the solids are returned to the bed.
CHP	Combined Heat and Power produces electricity and heat in the same process.
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
Co-disposal	Co-disposal is the practice of mixing wastes of different origins in the same landfill or other disposal facility.
Criteria	Criteria, Standards and Guidelines are used often interchangeably and sometimes incorrectly in BC. Criteria and Guidelines are target levels established by good practice and determined to be protective of the environment. Standards are limits established by regulation. It should be noted that in the 1990s the Ministry referred to stack emission standards as “criteria”. These are now currently referred to as “guidelines”.
DEFRA	Department for Environmental and Rural Affairs (UK)
DOC	Dissolved Organic Carbon is organic material, from the decomposition of plant and animal material, dissolved in water.
EC	European Commission is the executive body of the European Union. The body is responsible for proposing legislation, implementing decisions and upholding the Union’s treaties and general operation of the Union.
EFW	Energy from Waste, also known as waste to energy (WTE), is the conversion of waste into a useable form of energy, e.g., heat or electricity. A common conversion process is waste combustion.

ELVs	Emission Limit Values, equivalent to permit limits
EMA	<i>Environmental Management Act</i> is an authorization framework intended to protect human health and the quality of water, land and air in British Columbia. EMA enables the use of administrative penalties, informational orders and economic instruments to assist in achieving compliance.
ESP	Electrostatic Precipitator is a particulate collection device that uses the force of an induced electrostatic charge to remove particles from a flowing gas.
EU	European Union is a political and economic union of 27 member states.
FGT	Flue Gas Treatment
FBC	Fluidized Bed Combustion is a combustion system in which a fine inert material, such as sand, is maintained in a fluid condition by air blowing upwards through it. Used in combination with processed waste fuels, such as coarse refuse-derived fuel.
Fly Ash	Finely divided particles of ash which are normally entrained in the combustion gases. Fly ash is recovered from the gas stream by a combination of precipitators and cyclones.
GEM	Graveson Energy Management
GHG	Greenhouse Gases
GVRD	Greater Vancouver Regional District
HAP	Hazardous Air Pollutants
HF	Hydrogen Fluoride
HWR	Hazardous Waste Regulation enacted under the BC EMA for managing hazardous waste.
IAWG	International Ash Working Group
IEA	International Energy Agency an intergovernmental organization which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens.
IPPC	Integrated Pollution Prevention and Control
ISWA	International Solid Waste Association

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ISWRM	Integrated Solid Waste and Resource Management
LAP	Landelijk Afvalbeheer Plan
Mass-Burn Incineration	The incineration of waste in a grate combustion system
Monofill	Landfill site practice whereby only one type of waste material (e.g., MSW bottom ash) is placed in landfill.
MSW	Municipal Solid Waste is waste which is collected for treatment and disposal by a local authority. MSW generally comprise waste from households, civic amenity sites, street-sweepings, local authority collected commercial waste, and some non-hazardous industrial waste.
MW	Megawatts (10^6 W) is a unit of power equal to one million watts
NCV	Net Calorific Value
NO _x	Mono-nitrogen oxides (NO and NO ₂). These oxides are produced during combustion.
NPRI	National Pollutant Release Inventory is Canada's legislated publicly accessible inventory of pollutant releases (to air, water and land), disposals and transfers for recycling.
PAH	Polycyclic aromatic hydrocarbons consist of fused aromatic rings and do not contain heteroatoms or carry substituents.
PCB	Polychlorinated biphenyls consist of 1 to 10 chlorine atoms attached to biphenyl, which is a molecule composed of two benzene rings.
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
PM _{0.1}	Particulate Matter consisting of airborne particles with a mass median diameter less than 0.1 micrometers. Includes as a sub-set nanoparticles (<10 nm or 0.001 micrometers)
PM _{2.5}	Particulate Matter consisting of airborne particles with a mass median diameter less than 2.5 micrometers.
PM ₁₀	Particulate Matter consisting of airborne particles with a mass median diameter less than 10 micrometers

Pozzolan	A silica-rich or silica and alumina-rich material which in itself possesses little or no cementaceous value, but which will, in finely divided form and in the presence of moisture, react chemically with calcium hydroxide to form compounds possessing cementaceous properties.
RDF	Refuse Derived Fuel is a fuel product recovered from the combustible fraction of household waste.
REOI	Request for Expressions of Interest
Rm ³	Referenced cubic metre, representing a standard volume of gaseous emission at the reference conditions specified in a jurisdiction
SCR	Selective Catalytic Reduction is a method used to reduce NO _x to N ₂ and H ₂ O through the injection of ammonia into the flue gas stream which then reacts with NO _x within a catalyst bed.
SNCR	Selective Non-Catalytic Reduction is a method to lessen nitrogen oxide emissions in conventional power plants that burn biomass, waste and coal, through the injection of ammonia into hot flue gases at a suitable temperature range to support the chemical reaction to convert NO _x to N ₂ and H ₂ O.
SO _x	Oxides of Sulphur
SRF	Solid Recovered Fuel (interchangeable with RDF) being a fuel product recovered from the combustible fraction of household waste.
SSO	Source Separated Organics
SWMP	Solid Waste Management Plan, prepared for each Regional District in BC, and including the authorization to operate a municipal solid waste landfill
Syngas	The name given to a gas mixture synthesized from waste materials that contains varying amounts of carbon monoxide and hydrogen (but may contain smaller amounts of other gases)
TCDD	2,3,7,8-Tetrachoro dibenzo-p-dioxin
TEQ basis	2,3,7,8-Tetrachoro dibenzo-p-dioxin toxic equivalent, based on the 1989 International toxic equivalency factors
TOC	Total Organic Carbon, is the amount of carbon within organic molecules (carbon chains or rings that also contain hydrogen) versus inorganic molecules (e.g., carbon monoxide, carbon dioxide, carbonates). In regards to air emissions a portion of TOC would be comprised of VOCs (see below).

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TWG	Thematic Working Group
TWh	Terawatt hours (10^{12} Watt hours)
UK	United Kingdom
US EPA	United States Environmental Protection Agency founded to protect human health and to safeguard the natural environment including air, water, and land.
VOC	Volatile Organic Compounds are organic substances of concern (carbon chains or rings that also contain hydrogen) that have high enough vapour pressures under normal conditions to significantly vapourize and enter the atmosphere (i.e., with a vapour pressure greater than 2mm of mercury (0.27 kPa) at 250°C or a boiling range of between 60 and 250°C) excluding methane.
WAG	Welsh Assembly Government
WFD	Waste Framework Directive
WHRG	Waste Heat Recovery Generator
WID	Waste Incineration Directive
WTE	Waste to Energy, also known as Energy from Waste (EFW) is the conversion of waste into a useable form of energy, e.g., heat or electricity. A common conversion process is waste combustion.

1 INTRODUCTION

The province of British Columbia is committed to sustainable environmental management including leading the world in air quality. In fact, one of the province's five Great Goals for a Golden Decade^[1] is to “*lead the world in sustainable environmental management, with the best air and water quality, and the best fisheries management, bar none*”. Through airshed management planning, industrial emission standards, and a host of local air initiatives progress is being made toward this goal for air quality.

The province has also made significant climate change commitments. The 2007 *Greenhouse Gas Reduction Targets Act* (GGRTA) sets legislative targets for immediate action toward reducing greenhouse gas emissions. The act sets a GHG emissions reduction target of 33% for 2020 and 80% for 2050, with low interim targets leading up to 2020. The province has taken a number of proactive steps toward reducing GHGs from all sectors including introducing a carbon tax and developing the framework for a cap and trade system for large emitters. These are outlined in the BC Climate Action Plan.^[2]

The BC Bioenergy Strategy^[3] supports the shift from carbon-intensive fossil fuels to biomass fuels as a practical approach to a low-carbon future. The growth in community energy projects and the establishment of municipal landfill methane gas capture systems are both initiatives that demonstrate the commitment to bioenergy in BC today. MSW represents up to 3% of the province's available biomass resources, recognizing that a portion of the municipal solid waste stream is biomass. Various measures can be used to manage the biomass portion of the MSW stream such as recycling, composting and anaerobic digestion. However, experience in other jurisdictions indicates that even with such programs, a portion of MSW would continue to be comprised of biomass.

Waste to energy facilities, which produce heat and power through thermal treatment of MSW, could be used to recover energy from MSW including the biomass fraction. Carbon pricing (established through carbon tax and/or a cap and trade program) may make a Waste to Energy project more financially favourable if the project reduces emissions compared to a business-as-usual scenario in the process of producing power. However, the province has yet to determine how GHG emissions reduction policy will apply to municipal landfills and Waste to Energy operations.

The Waste Discharge Regulation, under the BC *Environmental Management Act*, includes a definition for “municipal waste incineration or burning industry” as an activity that would be allowable in the province with appropriate waste discharge authorizations in place.^[4] To date, the Metro Vancouver Burnaby incinerator is the only sizeable WTE facility in BC. The emission limits for this facility are

¹ British Columbia Strategic Plan 2010/2011 – 2012/2013. Website: http://www.bcbudget.gov.bc.ca/2010/stplan/2010_Strategic_Plan.pdf

² BC Climate Action Plan. Website: <http://www.livesmartbc.ca/government/plan.html>

³ BC Bioenergy Strategy, BC Ministry of Energy, Mines and Petroleum Resources, 2007

⁴ BC *Environmental Management Act*. Waste Discharge Regulation. Website: http://www.bclaws.ca/Recon/document/freeside/--%20e%20--/environmental%20management%20act%20sbc%202003%20c.%2053/05_regulations/50_320_2004.xml

contained in the 1995 Greater Vancouver Regional District Solid Waste Management Plan (SWMP).^[5] Emission criteria for municipal solid waste incinerators were produced by the province in 1991 to be used as a basis for setting SWMP or permit limits for these facilities. The emission limits for the Burnaby incinerator contained in the GVRD SWMP are consistent with these criteria.

This report provides a technical review of the leading municipal solid waste thermal treatment practices currently in use globally and a summary of the associated emission criteria and standards for those technologies. The report also reviews the management of residuals from waste to energy facilities. Finally, the report provides a set of conclusions and recommendations for the province to consider in the development of current guidelines for WTE facilities.

1.1 Project Outline

Waste to Energy, or WTE, typically involves the conversion of solid waste to energy resulting in the generation of electricity from the recovered heat, and/or the generation of hot water or steam to be used for community-based industrial, commercial or residential heating applications. WTE technology has been adopted in many jurisdictions globally and has merit for consideration in BC.

The BC Ministry of Environment (BCMOE) Environmental Protection Division has adopted an interim policy “Determining Best Achievable Technology Standards” that provides guidance on the setting of emissions criteria, standards or regulations. The intent of the policy is to promote the use of best achievable technologies (BAT) in new and existing facilities, and to set criteria and/or permit limits in accordance with BAT.

There are seven steps to determine BAT to be considered in the setting of standards and criteria for the province and for facilities. These steps include:

1. Identification of all potential technologies or options
2. Eliminating technically infeasible options
3. Consideration of the reliability of each option
4. Ranking of technically feasible options by control effectiveness
5. Consider the cost effectiveness of each option
6. Selection of the appropriate BAT for the specific application
7. Determining the appropriate waste discharge criteria or standard.

This report is intended to provide background information on items 1 through 6, and has been structured as follows:

- **Section 2** examines the thermal treatment technologies currently in use globally, and examines emerging technologies that may gain increasing market share in the future.

⁵ 1995 Greater Vancouver Regional District Solid Waste Management Plan. Website:
<http://www.metrovancouver.org/about/publications/Publications/SolidWasteManagementPlan1995.pdf>

- **Section 3** provides an overview of the potential discharges from WTE facilities, including air emission constituents and liquid and solids wastes.
- **Section 4** discusses air emission controls.
- **Section 5** discusses the expected emission rates from WTE facilities, including a summary of actual emissions from facilities operating worldwide.
- **Section 6** discusses the use of Refuse Derived Fuel (RDF), potential emissions from RDF applications and identifies a proposed regulatory approach for RDF.
- **Section 7** discusses the efficiencies and costs of thermal treatment based on available information. It also discusses the use of energy efficiency equations for differentiating between energy recovery and disposal systems under a waste management hierarchy.
- **Section 8** provides an overview of air emission monitoring systems, including continuous emission monitoring, stack sampling and ambient air quality monitoring.
- **Section 9** discusses the regulatory environment governing the WTE sector and how revisions to emissions criteria, standards and permit limits are set in BC according to Best Achievable Technology policy. International, national and regional aspects of emissions management are reviewed, with comparisons of the various objectives, criteria and standards in place across these jurisdictions. A compilation table of various emission limits has been provided to highlight the BC situation relative to other jurisdictions. This section concludes with proposed amendments to the existing BC 1991 Emission Criteria for Municipal Solid Waste Incineration.
- **Section 10** discusses residuals management, including fly ash, bottom ash, pollution control system residuals and gasification process residuals, from various global jurisdictions including the BC experience. Beneficial reuse of ash and safe disposal are discussed. For the BC situation, there is also discussion on the setting of financial security relative to environmental risk for facilities receiving fly ash.
- **Section 11** contains the recommendations to be considered by BCMOE in the setting of amended criteria and standards for the WTE sector in BC.

1.2 Project Authors

1.2.1 Stantec Consulting Ltd.

Stantec was founded in 1954 providing environmental services in Western Canada. Since then it has grown into a full service engineering firm with over 10,000 employees in 150 offices throughout North America. With specific reference to environmental remediation, Stantec has over 1,000 employees completing environmental remediation projects each day.

This capacity allows Stantec to offer our clients enhanced services and greater local presence with global reach. We provide our clients with consistent, safety conscious, high-quality services and personnel they have come to expect and rely on. These services are backed up by experts in their

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field practicing in varied disciplines and geographies bringing the knowledge of many to your project. Stantec's multidisciplinary suite of services in environmental site assessment, remediation, landfill design, landfill monitoring, environmental sciences, sustainability, and geotechnical and materials engineering complement one another, heightening our ability to serve clients throughout the project life cycle from conception to closure.

Principle authors of this report were Janine Ralph and Eric Windhorst of the Stantec, Burlington, ON office and Douglas Whitar, Magdalena Kingsley, Sarah Willie and Kelly Carswell of Stantec, Burnaby, BC. Senior review was completed by David Payne of Stantec, Burlington and Peter D. Reid of Stantec, Calgary, AB.

1.2.2 Ramboll Denmark A/S

Ramboll Group A/S of Denmark, is a consulting company which was founded in 1945. The Ramboll Group has approximately 9,000 employees and is the largest Northern European consulting group. The Ramboll Group specializes in a broad variety of consulting services with WTE as one of the key fields of expertise. Ramboll has worked in the WTE business for more than four decades and has during this period assisted in implementing more than 70 WTE facilities worldwide.

Ramboll is at present involved in more than 30 ongoing WTE projects. The projects are at various stages from project definition through to procurement and supervision during construction, commissioning and follow-up on operation and maintenance which gives an excellent hands-on knowledge of both technology systems and regulatory matters.

Ramboll is member of national and international WTE associations. As active members of the working groups under these associations Ramboll has been directly involved in the discussion with the European Union on regulatory matters.

One of Ramboll's staff is known internationally for his work on the thermal treatment of waste with the European Commission (EC), where for three years he was leader of the EC BAT expert working group of over 100 people. This group was responsible for the production of the official EC guidance on the Best Available Techniques (BAT) for the thermal treatment of wastes, the "BREF" (2006).

Ramboll staff contributing to this report included Bettina Kamuk and Soren Dalager with input from various other staff.

2 THERMAL TREATMENT PRACTICES

This section describes the technology currently available and in use globally for the thermal treatment of MSW. This section also provides information on new and emerging technologies that may not have proven track record, but should be considered in context with existing technologies.

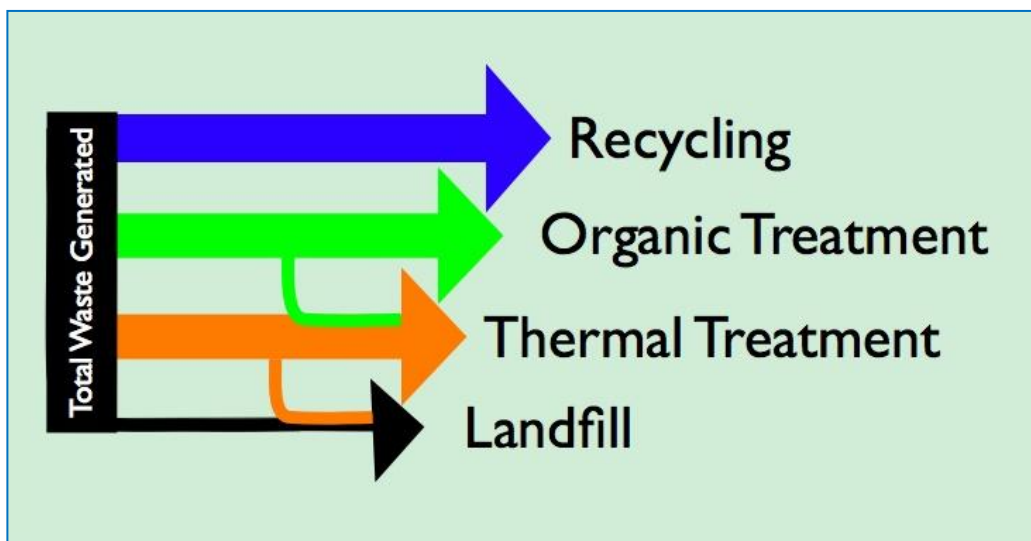
2.1 Overview of Thermal Treatment Processes

The thermal treatment of solid waste is only one part of an integrated waste management system. Thermal treatment can play a number of important roles in an integrated waste management system. Thermal treatment can:

- Reduce the volume of waste, therefore preserving landfill space (thermal treatment does not replace the need for landfills as various residuals still need disposal).
- Allow for the recovery of energy from the solid waste stream.
- Allow for the recovery of minerals and chemicals from the solid waste stream which can then be reused or recycled.
- Destroy a number of contaminants that may be present in the waste stream.
- Often, reduce the need for the “long-hauling” of waste.

In most jurisdictions, thermal treatment of waste is applied to manage the remaining waste stream after source-separated diversion of recyclables and organics. Figure 2-1 presents a schematic diagram illustrating how thermal treatment fits into a conventional waste management system that includes source-separated recycling and organics diversion components.

Figure 2-1: Schematic Overview of the Role of Thermal Treatment in Waste Management



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As noted in Figure 2-1, it is typical in many jurisdictions that WTE is used to manage the majority of post-diversion residual wastes. The diversion of recyclables and organic materials often results in an overall increase in the heat value of the remaining waste stream, rendering it suitable for potential use in WTE applications.

Table 2-1 presents an example of a typical post-recycling residual MSW stream that could be suitable for WTE in BC (Metro Vancouver), and an example of the composition of a typical post-recycling and SSO diversion residual MSW stream in a typical municipal jurisdiction with expanded diversion programs (Durham/York). The estimates for the Durham/York waste stream represent the typical residual waste composition in Ontario for a municipal jurisdiction with a mature source separated recycling and source-separated organic collection and processing system. The portion of the waste stream that is generally comprised of biomass generally does decrease following introduction of SSO programs. However, the remaining garbage should still be expected to have a reasonable proportion of biomass materials.

Table 2-1: Metro Vancouver and Durham/York Residential Post-diversion Waste Category Breakdown Suitable for WTE

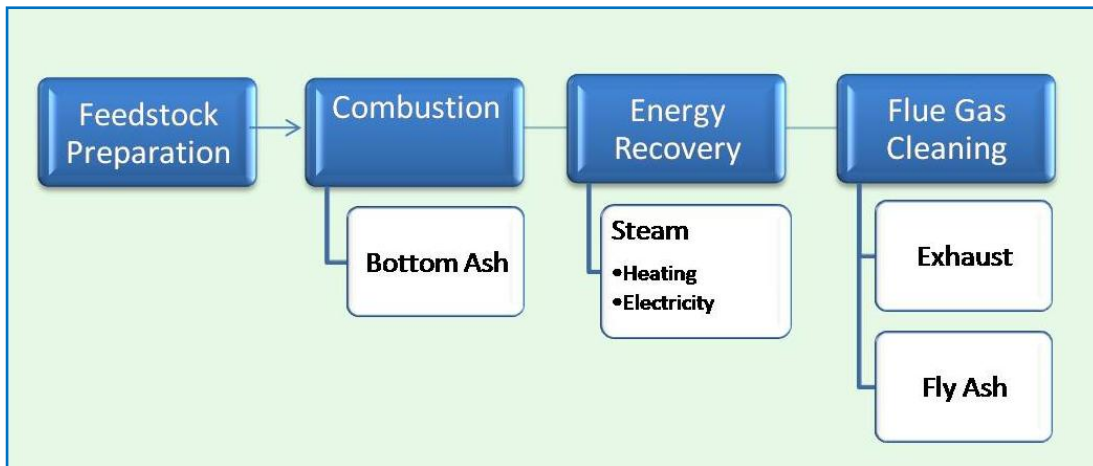
Waste Category	Metro Vancouver Residential Post-diversion (w/o Organics Diversion) (2007) % Composition ^[6]	Durham/York Residential Post-diversion (with Organics Diversion) (2011 Estimates) % Composition ^[7]
Paper	16.7%	18.1%
Plastics	10.2%	12.4%
Metals	1.5%	2.3%
Glass	4.5%	3.9%
HHW	0.4%	0.3%
Organics (food waste, grass, yard waste)	30.2%	13.6%
Animal waste	1.3%	6%
Textiles	1.1%	2.4%
Building renovations	13.3%	4% (includes wood)
Furniture/Bulky goods	3.9%	21.5%
White goods	0.01%	0%
Sanitary products	3.3%	8.7%
Electronics/appliances	2.3%	0.2%
Other	1.8%	6.5%
Wood	9.5%	Not Defined
Approximate % Biomass	60%	50%

⁶ Technology Resource Inc. 2008. SOLID WASTE COMPOSITION STUDY for Metro Vancouver (Greater Vancouver Sewerage and Drainage District)

⁷ Stantec Consulting Limited. Durham/York Environmental Assessment (EA) Study Document as Amended November 27, 2009

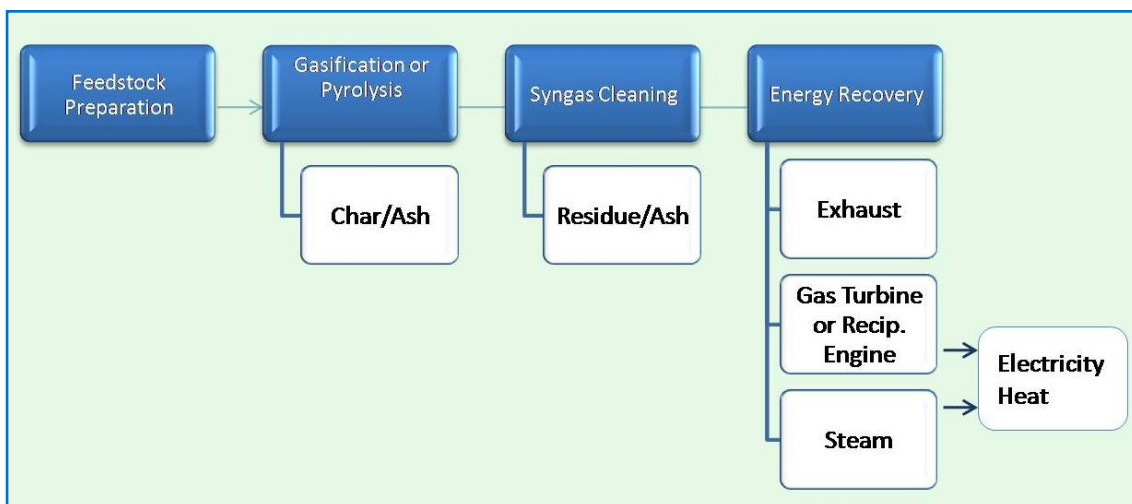
Thermal treatment covers a range of technologies that extract energy from the waste while reducing its volume and rendering the remaining fraction mostly inert. These technologies can be generally grouped into two main categories: conventional combustion and advanced thermal treatment. Conventional combustion technologies include mass burn incineration and fluidized bed incineration among others. Mass burn incineration is the most common type of WTE technology used worldwide. Figure 2-2 provides a simple flow diagram of a conventional WTE approach.

Figure 2-2: Overview of Conventional WTE



Advanced thermal treatment technologies include gasification, pyrolysis and plasma gasification. These technologies tend to be less proven on a commercial scale and involve more complex technological processes. Figure 2-3 provides a simple flow diagram of an advanced thermal treatment WTE approach.

Figure 2-3: Overview of Advanced Thermal Treatment WTE



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Thermal treatment of MSW involves the oxidation of combustible materials found within the waste. Generally speaking, there are three main stages of any thermal treatment process:

- **Drying and degassing** – here, volatile content is released at temperatures generally between 100 and 300°C. The drying and degassing process are only dependent on the supplied heat.
- **Pyrolysis and gasification** – pyrolysis is the further decomposition of organic substances in the absence of added oxygen at approximately 250 – 700°C which results in the production of syngas (a gas mixture consisting primarily of H₂ and CO), tars (high molecular mass hydrocarbons), and char. Gasification is the partial thermal degradation of organic substances in the presence of oxygen but with insufficient oxygen to oxidize the fuel completely (sub-stoichiometric conditions). Gasification occurs at temperatures, typically between 500 – 1,000°C and results in the in the formation of syngas. Overall, this stage results in the conversion of solid organic matter to the gaseous phase.
- **Oxidation** – the combustible gases (i.e., syngas) created in the previous stages are oxidized, depending on the selected thermal treatment method, at temperatures generally between 800 and 1,450°C.

Typically, these individual stages overlap but they may be separated in space and/or time depending on the particular thermal treatment process being considered.^[8]

2.2 Current and Emerging Combustion and Thermal Treatment Practices and Associated Control Technologies

This subsection reports on a literature and market review of current and emerging combustion and thermal practices and their associated emission control technologies. It concisely summarizes the state-of-the-art in thermal treatment. A brief overview of the range of technologies in the marketplace for which there are current operating facilities is provided. Also noted is the stage of development of the technology (i.e., pilot or full-scale) and the availability of supporting technical information.

2.2.1 Current Combustion and Thermal Treatment Technologies

A comprehensive literature review was conducted by Stantec with input from Ramboll, to determine candidate technologies and vendors for the treatment of residual MSW, resulting in the development of a database of over 100 vendors and technologies. The literature review retrieved reports from various government and vendor websites as well as sources held by Stantec. A number of cities and counties (i.e., City of Los Angeles, New York City, City and County of Santa Barbara, Metro Vancouver) have completed in-depth studies and reviews regarding alternative waste treatment approaches. It is important to note that much of the information that was generally available is vendor information provided through “Requests for Expressions of Interest” (REOIs) and other

⁸ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

means and therefore it has not necessarily been verified through a third party and/or verification is not readily available.

Some of the technology information has also been derived from proposals by respondents through Requests for Qualifications (RFQ) processes, Requests for Proposals (RFP) processes and studies for other municipal jurisdictions undertaken by Stantec Staff. Generally, the information derived from official procurement processes has a higher degree of veracity.

The four most prevalent WTE technologies used to treat MSW are described below, namely, conventional combustion, gasification, plasma arc gasification, and pyrolysis. Of the four technologies mentioned, conventional combustion and gasification are the most commonly used methods of converting waste into energy. A subsection on new and emerging technologies is also provided. A database of current technology vendors (current as of March 2010) is provided in Appendix A.

It should be noted that mass burn incineration (conventional combustion) is the most well established and commercially proven thermal treatment technology. There are over 800 mass burn facilities currently in operation worldwide.

2.2.1.1 Conventional Combustion

Conventional combustion is a well-established technology developed over 100 years ago for energy generation from municipal solid waste. The first attempts to dispose of solid waste using a furnace are thought to have taken place in England in the 1870s.^[9] Since that time, vast technology improvements have been made making conventional combustion the most common WTE technology currently being used to treat MSW.

The most common conventional combustion approach is called single-stage combustion or mass burn incineration (sometimes referred to as grate-fired technology). Over 90% of WTE facilities in Europe utilize mass burn incineration technology with the largest facility treating approximately 750,000 tpy.^[10] The following paragraphs discuss the mass burn combustion process. Figure 2-4 provides a conceptual overview of a modern single-stage WTE facility.^[11]

⁹ Waste Online. 2004. History of Waste and Recycling. Accessed February 22, 2010 from <http://www.wasteonline.org.uk/resources/InformationSheets/HistoryofWaste.htm>

¹⁰ Thomas Malkow. 2004. Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal. In Waste Management 24 (2004) 53-79

¹¹ Stantec Consulting Limited. 2009. Durham/York Residual Waste Study Environmental Assessment

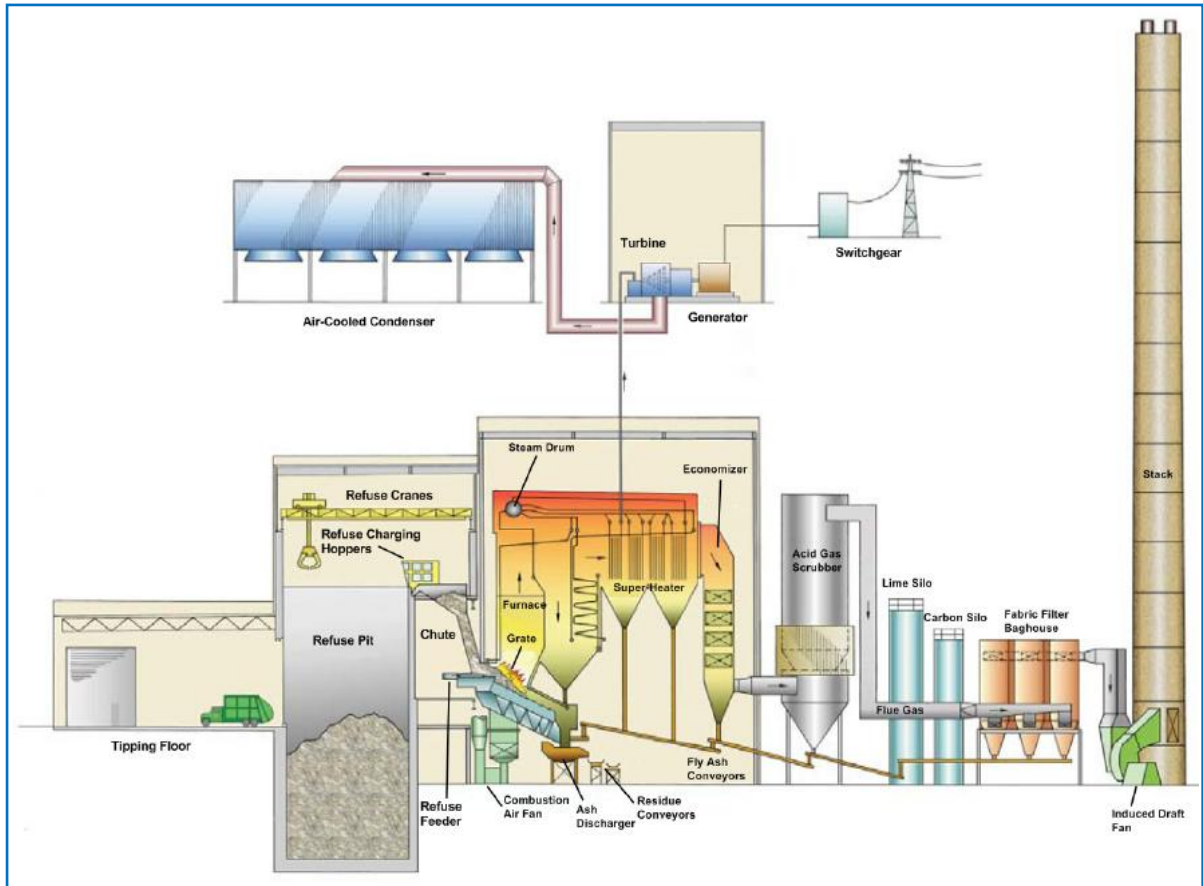
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Figure 2-4: Conceptual Overview of a Modern Single-Stage Mass Burn Incinerator



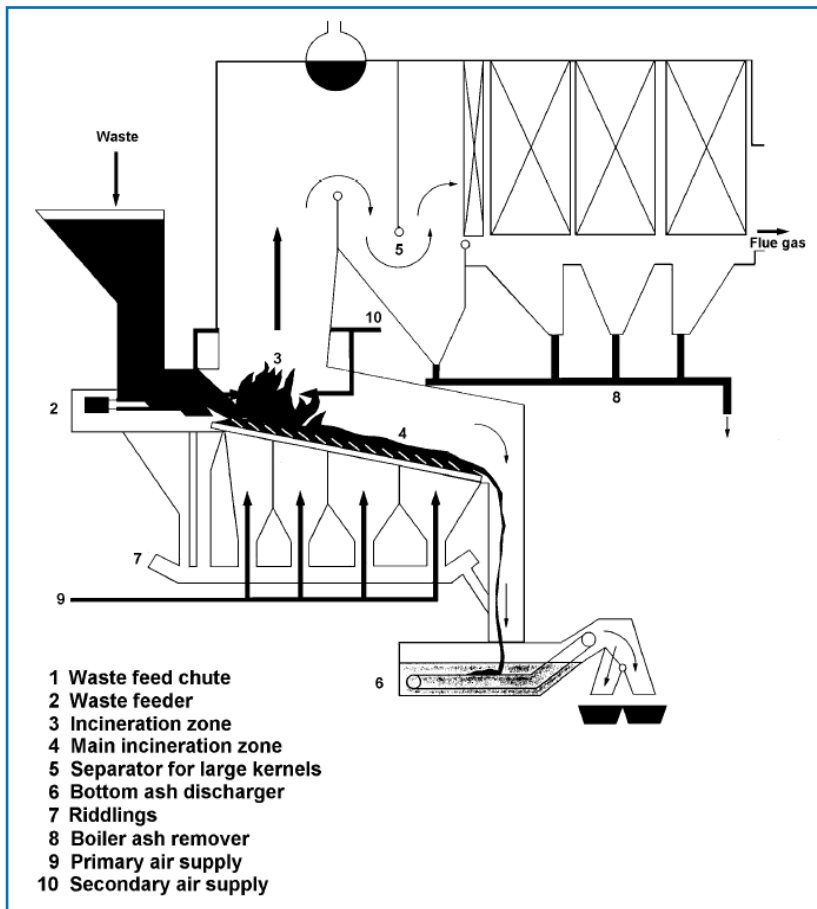
Source: Stantec Consulting Limited. 2009. Durham/York Residual Waste Study Environmental Assessment

At a mass burn facility, minimal pre-processing of MSW is required. Normally, trucks carrying refuse enter a building where they discharge their waste into a pit or bunker. From the pit, the waste is transferred into a hopper by an overhead crane. The crane is also used to remove large and non-combustible materials from the waste stream. The crane transfers the waste into a waste feed hopper which feeds the waste onto a moving grate where combustion begins.

Several stages of combustion occur in mass burn incinerators. The first step reduces the water content of the waste in preparation for burning (drying and degassing). The next step involves primary burning which oxidizes the more readily combustible material while the subsequent burning step oxidizes the fixed carbon. In single-stage combustion, waste is burned in sub-stoichiometric conditions, where sufficient oxygen is not available for complete combustion. The oxygen available is approximately 30 to 80% of the required amount for complete combustion which results in the formation of pyrolysis gases. These gases are combined with excess air and combusted in the upper

portions of the combustion chamber which allows complete oxidation to occur. Figure 2-5 shows an example of an inclined grate incinerator with a heat recovery boiler.^[12]

Figure 2-5: Example of a Grate Incinerator with a Heat Recovery Boiler



Source: German Federal Environment Agency. 2001. Draft of a German Report for the creation of a BREF-document “waste incineration”, Umweltbundesamt

Mass burn technology applications provide long residence times on the grate(s) which in turn results in good ash quality (i.e., less non-combusted carbon). Newer facilities have greatly improved energy efficiency and usually recover and export energy as either steam and/or electricity. Typical mass burn facilities have energy recovery efficiencies of 14% to 27% (assuming that the energy from combustion is being converted into electricity).^[13] Higher energy recovery efficiencies are achieved through the recovery of heat either in conjunction with or in lieu of electricity.

¹² German Federal Environment Agency. 2001. Draft of a German Report for the creation of a BREF-document “waste incineration”

¹³ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

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Mass burn facilities can be scaled in capacity anywhere from approximately 36,500 to 365,000 tpy per operating unit.^{[14],[15]} These facilities generally consist of multiple modules or furnaces and can be expanded through addition of more units and supporting ancillary infrastructure as required. Generally it is preferred to design such facilities with multiple units allowing for individual modules to be shut down for maintenance or if there is inadequate feedstock.^[16] Multiple modules can often be accommodated on a single site with some sharing of infrastructure (e.g., share tip floor, ash management areas, stack).

The capacity of a mass burn incinerator is dependent upon the calorific value of the waste being treated. In Europe, the normal maximum size of a facility is 280,000 tpy, assuming that the waste has a calorific value of 11 MJ/kg. That said, over recent years, the trend in Europe has been to build slightly larger facilities.

Two other conventional combustion approaches are used to manage MSW, but are less common. These two other conventional approaches are modular, two stage combustion and fluidized bed combustion.

Modular, Two Stage Combustion

In modular, two-stage combustion, waste fuel is combusted in a controlled starved air environment in the first chamber. Off-gases are moved into a second chamber where they are combusted in an oxygen rich environment. The heat generated in the second stage is fed into a heat recovery boiler. Ash is generated in the first stage and is managed in a similar manner as that from moving-grate systems (mass burn incineration). Figure 2-6 provides a schematic overview of a two-stage incinerator.^[17] It should be noted that two-stage incinerators are sometimes referred to as a type of gasification technology. However, they are not true gasifiers and are therefore normally classified as a conventional combustion technology.

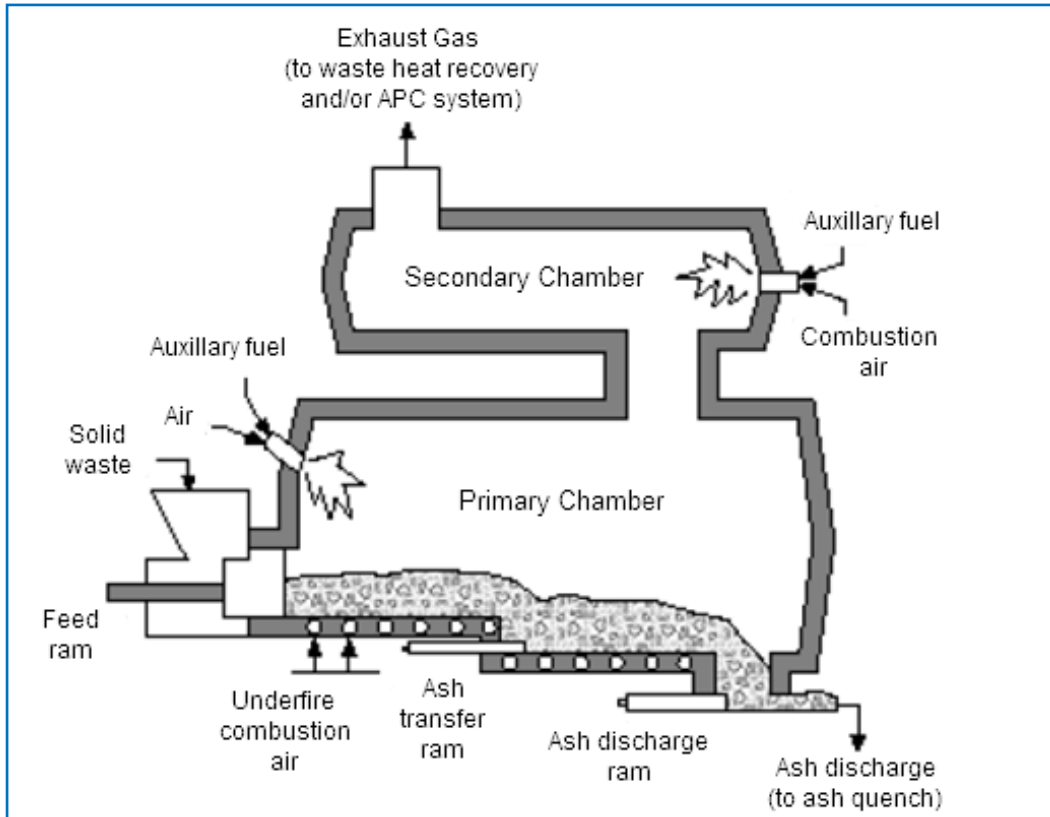
¹⁴ GENIVAR Ontario Inc. in association with Ramboll Danmark A/S, 2007. Municipal Solid Waste Thermal Treatment in Canada

¹⁵ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

¹⁶ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

¹⁷ A.J. Chandler and Associates Ltd. 2006. Review of Dioxins and Furans from Incineration In Support of a Canada-wide Standard Review

Figure 2-6: Schematic Overview of a Two-Stage Incinerator



Source: A.J. Chandler and Associates Ltd. 2006. Review of Dioxins and Furans from Incineration in Support of a Canada-wide Standard Review

Fluidized Bed Combustion

In fluidized bed combustion waste fuel is shredded, sorted and metals are separated in order to generate a more homogenous solid fuel. This fuel is then fed into a combustion chamber, in which there is a bed of inert material (usually sand) on a grate or distribution plate. The inert material is maintained in a fluid condition by air blowing upwards through it. Waste fuel is fed into or above the bed through ports located on the combustion chamber wall.

Drying and combustion of the fuel takes place within the fluidized bed, while combustion gases are retained in a combustion zone above the bed (the freeboard). The heat from combustion is recovered by devices located either in the bed or at the point at which combustion gases exit the chamber (or a combination of both). Surplus ash is removed at the bottom of the chamber and is generally managed in a similar fashion as bottom ash from a moving grate system (mass burn incineration). Figure 2-7 provides a schematic overview of a fluidized bed incinerator.^[18]

¹⁸ A.J. Chandler and Associates Ltd. 2006. Review of Dioxins and Furans from Incineration In Support of a Canada-wide Standard Review

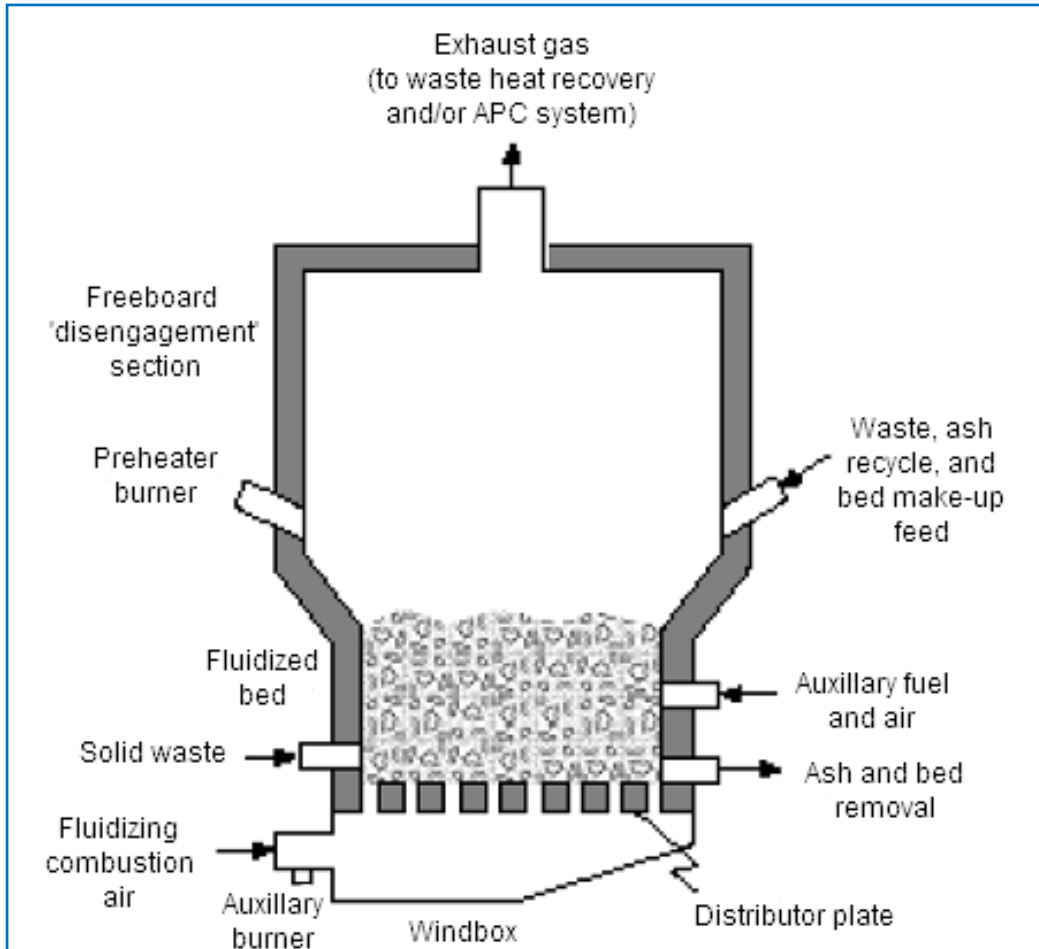
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Figure 2-7: Schematic Overview of a Fluidized Bed Incinerator



Source: A.J. Chandler and Associates Ltd. 2006. Review of Dioxins and Furans from Incineration in Support of a Canada-wide Standard Review

Both two-stage combustion and fluidized bed combustion approaches can be used to manage MSW, however, for fluidized bed applications the waste must be processed into a more homogenous feed. Both processes generally are more complex than single-stage mass burn incineration. For that reason, generally when considering conventional combustion systems in planning processes, single stage combustion systems are usually assumed.

Of the approximately 450 WTE facilities in Europe, 30 of them utilize fluidized bed technology. Most of these use a feed stock mixture of MSW, sewage sludge, industrial waste, pre-sorted organic waste, Refuse Derived Fuel (RDF) or woodchips. Very few facilities are using only MSW as feed stock because of the availability of supplemental fuels. One of the disadvantages of the fluidized bed systems is that a larger portion of fly ash is generated by the fluidized bed process (6% compared to 2% for mass burn systems) due to the particulate present in the fluidized bed itself.

Batch Combustion

In addition to mass burn, two stage and fluidized bed incineration, there are other incinerators referred to as batch waste incinerators that are capable of treating a variety of wastes including MSW. Batch waste incinerators are those that operate in a non-continuous manner (i.e., they are charged with waste prior to the initiation of the burn cycle, and the door remains closed until the ash has cooled inside the primary chamber). Batch waste incinerators tend to treat smaller amounts of waste than other conventional approaches (they are usually sized between 50 and 3,000 kg per batch) and are typically utilized in remote locations where landfill alternatives and/or wildlife concerns associated with landfills are present.

Batch waste incinerators normally utilize dual chamber controlled air technology (alike to two stage combustion but more simple). In batch incinerators, waste (which is normally pre-mixed) is charged into the primary chamber by the operator. The initial heat required to ignite the waste is supplied by a burner which shuts off once combustion becomes self-sustaining. Controlled amounts of underfire air are introduced through holes in the primary chamber and as combustion gases are created they move to the secondary chamber where combustion is completed with the air of additional over-fire air or a secondary burner.

Batch waste incinerators do not typically utilize heat recovery or air pollution control equipment but are still capable of meeting stringent emissions limits (e.g., Ontario Guideline A-7) if they are designed and operated in a proper manner.^[19]

Summary of Conventional Combustion Approaches

Conventional combustion incineration facilities that treat MSW produce unwanted emissions to air during the combustion of waste materials. Over the years, the amount of harmful byproducts produced has been greatly reduced due to the increased sophistication of the combustion and operational controls for such facilities. Emissions that are produced during combustion are reduced using Air Pollution Control (APC) systems which remove unwanted contaminants such as trace metals and various acid gases from the flue gas produced. Generally speaking there are three main types of APC systems used at conventional combustion facilities that treat MSW, namely Dry, Wet-Dry, and Wet systems. The specific aspects of these APC systems are discussed further in Section 4.2.2.

In Canada there are currently seven operational conventional combustion incinerators that treat MSW (greater than 25 tpd). These seven facilities are located in British Columbia (1), Alberta (1), Ontario (1), Quebec (3), and PEI (1).

Of these seven facilities, two are larger mass burn incinerators (L'incinérateur de la Ville de Québec, Quebec and Greater Vancouver Regional District Waste to Energy Facility, British Columbia), one is a smaller mass burn incinerator (MRC des Iles de la Madeleine, Quebec), two are defined as two-stage starved air modular incinerators (PEI Energy Systems EFW Facility, PEI and Algonquin Power Peel Energy-From-Waste Facility, Ontario), and one is defined as a three-stage incinerator (Wainwright Energy from Waste Facility, Alberta).

¹⁹ Environment Canada. 2010. Technical Document for Batch Waste Incineration

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Table 2-2 provides an overview of each of these facilities.^[20]

Table 2-2: Overview of Conventional Combustion Facilities in Canada that Treat MSW

Facility Name	Thermal Treatment Units	Number of Units	Approved/ Licensed Capacity (tpd)	Air Pollution Control System
Metro Vancouver Waste to Energy Facility (1988 start-up)	Mass-burn – Martin grates	3 x 240 tonnes per day	720 (approx. 273,318 tpy)	Selective non-catalytic reduction – NH ₄ injection, spray humidifier, dry lime injection, carbon injection and fabric filter
L'incinérateur de la Ville de Québec	Mass-burn – Von Roll grates	4 x 230 tonnes per day	920 (approx. 293,300 tpy)	Spray humidifier, dry lime injection, powdered activated carbon addition, fabric filter, electrostatic precipitator
L'incinérateur de la Ville de Lévis	Primary combustion chamber with afterburner	1 x 80 tonnes per day	80 (approx. 24,768 tpy)	Spray humidifier, dry lime injection, powdered activated carbon addition, fabric filter
MRC des Iles de la Madeleine	Mass-burn – step grate	1 x 31 tonnes per day	31 (approx. 4,500 tpy)	Spray humidifier, dry lime injection, fabric filter
Algonquin Power Peel Energy-From-Waste Facility, Brampton, ON (1992 start-up)	2-stage modular Consumat units	5 x 91 tonnes per day – 5th line added in 2002	455 (permitted to operate at 118% of rated capacity) (approx. 147,700 tpy)	Spray humidifier, selective catalytic reduction, dry lime injection, powdered activated carbon addition, fabric filter
PEI Energy Systems EFW Facility, Charlottetown PEI	2-stage Starved Air Modular Consumat CS-1600 units	3x 33 tonnes per day	99 (approx. 25,623 tpy)	Spray humidifier, dry lime injection, powdered activated carbon addition, fabric filter
Wainwright Energy From Waste Facility	3-stage Starved Air Modular System	1 x 29 tonnes per day	27 (approx. 3,681 tpy)	Dry lime injection, powdered activated carbon addition, fabric filter

There are also several mass burn incineration facilities currently in the planning or development stages. One such facility is being proposed to be built by the Regions of Durham and York in Ontario. Currently, the facility is in the planning stages and awaiting Environmental Assessment approval from the Ontario Ministry of the Environment. The proposed mass burn incineration facility will be sized initially to treat 140,000 tpy (436 tpd), however the facility design will allow for future expansion up to 400,000 tpy (1290 tpd). The vendor supplying the technology for this proposed facility is Covanta.^[21]

²⁰ GENIVAR Ontario Inc. in association with Ramboll Danmark A/S, 2007. Municipal Solid Waste Thermal Treatment in Canada

²¹ Stantec Consulting Limited. 2009. Durham/York Residual Waste Study Environmental Assessment

Conventional combustion (specifically mass burn) technology is well established, with a number of established vendors that supply some or all components of the technology. Based on a recent review, over 20 vendors worldwide were found to provide some components (grate systems, boilers) or provide services for the overall Design, Build and Operation (DBO) of conventional combustion facilities.

In Europe, the four main suppliers of grates and potentially other components of mass burn incineration technology are:

- Babcock & Wilcox Vølund (Denmark)
- Fisia Babcock Environment GmbH (Germany)
- Martin GmbH (Germany)
- Von Roll Inova (Switzerland).

The same four suppliers are the primary suppliers of grates in North America as well as in Asia. In Asia, Keppel Seghers have also supplied several grate fired plants.

The majority of new WTE facilities are based on mass burn systems and the order books from the four major suppliers of the grate systems show more than 100 new lines are planned in the period from 2000 – 2011. Recent projections developed by the European Confederation of Waste to Energy Plants (CEWEP) show that for Europe, it is projected that over 470 plants (with a combined capacity of 80 million tpy) will be in operation by the end of 2011 and 550 plants (with a combined capacity of 97 million tpy) will be in operation by 2016. Currently, there are 450 conventional combustion facilities (420 mass burn, 30 fluidized bed) in operation in Europe.

Table 2-3 provides a summary of conventional combustion processes, costs, scalability and reliability.

Table 2-3: Conventional Combustion – Summary of Information

Conventional Combustion Summary
Traditional mass burn incineration is a well-established technology developed over 100 years ago for energy generation from municipal solid waste.
There are hundreds of plants in operation, including approximately 450 in Europe (420 mass burn, 30 fluidized bed), 87 in the United States and over 400 in Asia. There are seven conventional combustion facilities in Canada.
Conventional combustion facilities have reasonably good energy efficiency (up to 30% for electricity only and 60% or more for combined heat and power or just heat recovery systems) and usually export their energy as either steam and/or electricity.
The largest facility in Canada is a mass burn facility, processing approximately 300,000 tpy of waste. (Quebec City). There are several mass burn facilities in Europe that treat over 300,000 tpy.
At least 20 companies offer mass burn incineration technology or components of this technology, or services to develop such facilities in North America and elsewhere. There are four primary suppliers of the combustion (grate) systems active in the EU and North America.

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Conventional Combustion Summary	
Other Summary Points	
Median Reported Capital Cost	▪ \$775/annual design tonne +/- 50% (2009\$ CDN)
Median Reported Operating Cost	▪ \$65/tonne +/- 30% (2009\$ CDN)
Feedstock	▪ MSW, biomass ▪ Minimal waste preparation/pre-processing required by technology ▪ Designed to process variable waste streams
Residual to Disposal	▪ 5% (by weight) if the majority of bottom ash can be marketed for other applications ▪ Up to 20 to 25% by weight if there is no market for recovered materials from the ash (0.2 to 0.25 tonnes per input tonne) ▪ Landfill capacity consumption reduced by 90 to 95%
Potential Energy and Revenue Streams	▪ Revenue potential for: electricity, heat (steam and/or hot water), recovered recyclable metals, construction aggregate ▪ Electricity production, 0.5 to 0.6 MWh/annual tonne of MSW for older facilities ^[22] ▪ Electricity production rates of between 0.75 to 0.85 MWh/annual tonne for newer facilities
Scalability	▪ Various sizes of mass burn units; use of multiple units also possible
Reliability	▪ Numerous facilities operating worldwide with proven operational success. ▪ Less complex than other WTE approaches ▪ Scheduled and unscheduled downtime reported as <10%. ^[23]

2.2.1.2 Gasification of MSW

Gasification is the heating of organic waste (MSW) to produce a burnable gas (syngas) which is composed of a mix of primarily H₂ and CO along with smaller amounts of CH₄, N₂, H₂O and CO₂. The syngas produced can then be used off-site or on-site in a second thermal combustion stage to generate heat and/or electricity. Gasifiers are primarily designed to produce usable syngas.

There are three primary types of gasification technologies that can be used to treat waste materials, namely fixed bed, fluidized bed and high temperature gasification. Of the three types of gasification technologies, the high temperature method is the most widely employed on a commercial scale. The waste passes through a degassing duct in which the waste is heated to reduce the water content of the waste (drying and degassing) and is then fed into a gasification chamber/reactor where it is heated under suitable conditions to convert the solid fuel to syngas. Oxygen is injected into the reactor so that temperatures of over 2,000°C are reached. The amount of oxygen required is just

²² Juniper Consultancy Services. 2007. a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

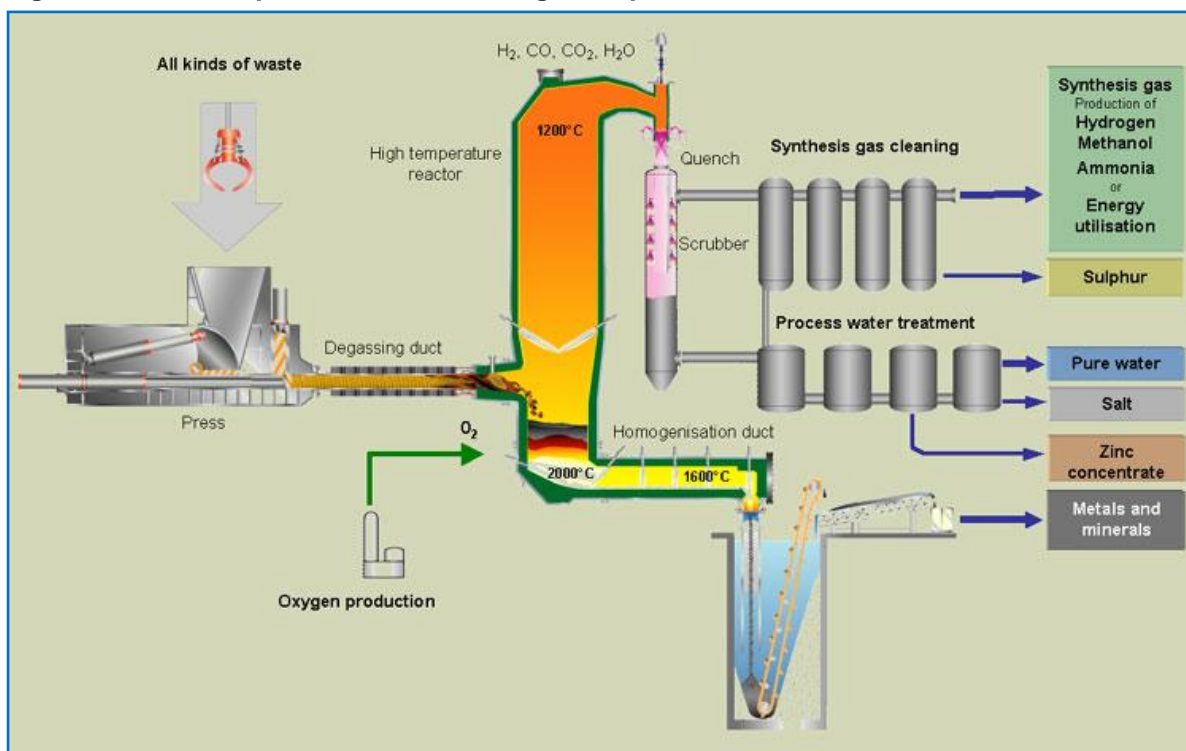
²³ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

enough to maintain the heat that is necessary for the process to proceed. The high temperature causes organic material in the MSW to dissociate into syngas. The syngas is processed to remove water vapour and other trace contaminants, so that it can be used for power generation, heating or as a chemical feedstock.

The Thermoselect technology (which is licensed to JFE Environmental Solutions Corp. of Japan and Interstate Waste Solutions of the United States) is one gasification technology used to treat MSW. As of 2009, there were six plants operating in Japan which utilize the Thermoselect technology to treat MSW.^[24]

Figure 2-8 provides a conceptual overview of a high temperature waste gasification process used to treat MSW, based on the Thermoselect process.

Figure 2-8: Conceptual Overview of a High Temperature Waste Gasifier^[25]



Source: Thermoselect. 2003. Thermoselect – High Temperature Recycling. Accessed February 3, 2010.
<http://www.thermoselect.com/index.cfm?fuseaction=Verfahrensuebersicht&m=2>

²⁴ University of California. 2009. Evaluation of Emissions from Thermal Conversion Technologies Processing Municipal Solid Waste and Biomass

²⁵ Thermoselect. 2003. Thermoselect – High Temperature Recycling. Accessed February 3, 2010
<http://www.thermoselect.com/index.cfm?fuseaction=Verfahrensuebersicht&m=2>

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The following paragraph briefly illustrates the fixed bed updraft high temperature gasification process used by Nippon Steel in Japan. According to Juniper Consultancy Services, the technology utilized by Nippon Steel is the most proven waste gasification technology even though it is not well known outside of Japan.^[26] As of 2009, Nippon Steel was operating 28 facilities that utilized MSW as a feedstock.^[27]

Nippon Steel employs a high temperature gasification system, which they call a “Direct Melting System” (DMS). The process produces a ‘synthetic gas’ (syngas) that is combusted in a steam boiler, driving a steam turbine to produce electricity. The heating process begins by feeding waste into a gasification chamber/reactor. The high temperature causes organic material in the MSW to dissociate into syngas. The syngas is transferred to a combustion chamber which heats a boiler which in turn powers a turbine and produces electricity. The flue gas produced via combustion is then cleaned using a bag filter and an SCR (to reduce NO_x) before it is released into the atmosphere. The Air Pollution Control system is similar to that used for conventional combustion with the exception that no provisions for the control of acid gases have been identified in the information that is available. The ash management system is also similar to that required for conventional combustion. This system does have similarities to modular, two-stage combustion.

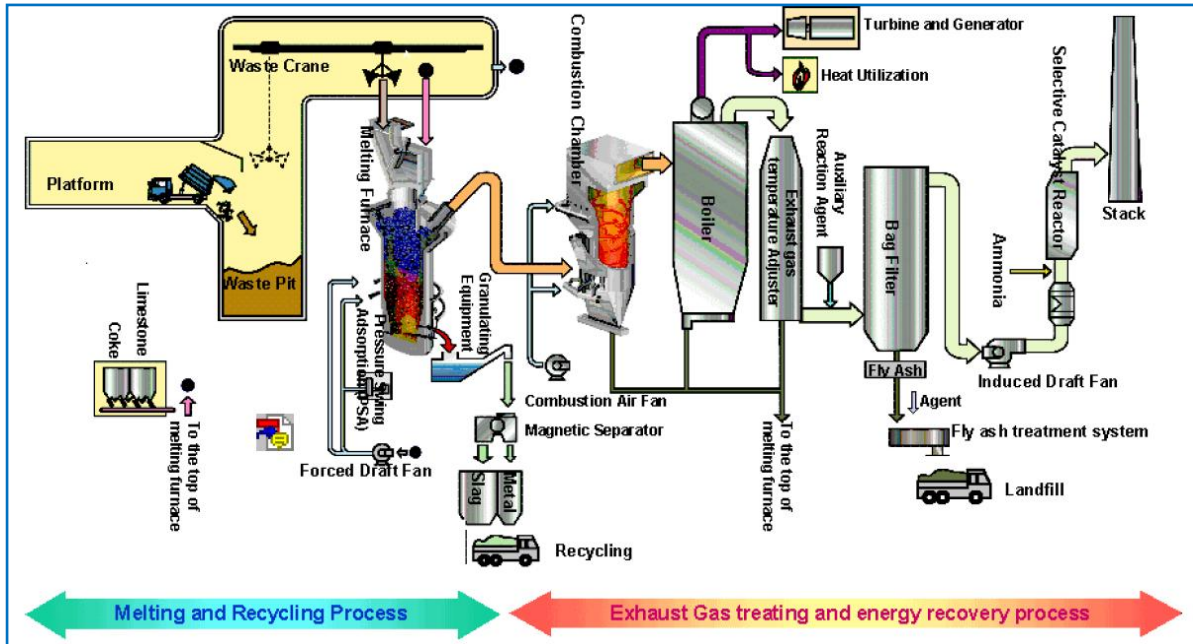
Figure 2-9 provides a conceptual overview of the high temperature waste gasification process employed by Nippon Steel.^[28]

²⁶ Juniper Consultancy Services Inc. 2009. Nippon Steel Gasification Process Review. Accessed February 22, 2010 from http://www.juniper.co.uk/Publications/Nippon_steel.html

²⁷ University of California. 2009. Evaluation of Emissions from Thermal Conversion Technologies Processing Municipal Solid Waste and Biomass

²⁸ Dvirka and Bartilucci Consulting Engineers. 2007. Waste Conversion Technologies: Emergence of a New Option or the Same Old Story? Presented at: Federation of New York Solid Waste Associations Solid Waste and Recycling Conference

Figure 2-9: Conceptual Overview of a High Temperature Waste Gasifier (Nippon Steel)



Source: Dvirka and Bartilucci Consulting Engineers. 2007. Waste Conversion Technologies: Emergence of a New Option or the Same Old Story? Presented at: Federation of New York Solid Waste Associations Solid Waste and Recycling Conference

Ramboll recently visited a gasification facility in China supplied by Kawasaki Steel Thermoselect System (now JFE Engineering after the fusion of Kawasaki, Nippon Steel and JFE).

Information obtained during the facility visit includes the following:

- The plant has been in operation since 2000.
- Designed with two lines, 2 x 15 t/h (actual capacity 250 – 260 tpd or between 159,000 tpy and 171,000 tpy based on actual plant availability).
- APC system includes the cleaning of syngas by water and catalyst before usage at the steel work. Production of sulphur.
- Received waste: 50% industrial waste (80% plastic and 20% wood/paper), 50 % pre-sorted plastic.
- The gate fee (tipping fee) is approximately \$365 US\$/tonne for industrial waste, and \$545 US\$/tonne for plastic.
- Input material is shredded to 5 – 15 cm.
- The facility used MSW feedstock for only the first 6 months, and now uses only more homogenous separated (pre-sorted) industrial waste and plastic as noted above.
- Residues: Bottom ash is cooled by water and vitrified, Iron is removed.
- Energy balance: produces 10 – 11,000 Nm³/h with calorific value 2,000 – 2,200 kcal/Nm³.

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- The facility appears to consume more energy than it produces, with a net energy output of approximately -3%.
- Plant availability: 5,300-5,700 hours/year (approximately 65%). Scheduled and unscheduled downtime was required due to change of refractory, leakages in the gasifier.

JFE indicated in the site tour that they did not intend to build any further gasifiers with the Thermoselect technology in Japan.

Outside of Japan, gasification is only used at a few facilities to treat MSW. This is primarily due to operational issues that arise due to the heterogeneous nature of MSW as the gasification process generally requires a fairly homogenous feedstock. In addition, gasification tends to have much higher range of operating and capital costs in comparison with conventional combustion facilities, given the requirement for waste pre-processing and the added complexity of the technology. Gasification also tends to have higher net costs, given that generally less energy (and thus less revenue) is recovered from the waste stream. ^[29]

In Europe, there are currently no commercially operating gasification facilities that treat MSW as the technology is considered too expensive and unproven. The only larger scale commercial gasifier using MSW as feedstock was a Thermoselect gasification plant that was operated in Karlsruhe, Germany for a few years, but it was shut down in 2004 due to technical and financial difficulties. ^[30] There are several (6 – 7) new gasification facilities operating at a commercial scale in Japan which have been constructed within the past 10 years. The use of gasification in Japan is partly driven by the regulatory environment which favours high temperature treatment (slagging) of the bottom ash/char due to the presence of low levels of dioxins. The Japanese regulatory approach is somewhat different from other jurisdictions as it regulates net dioxin emissions to the environment from all sources (air, waste water, ash). Such an approach has not been applied in other jurisdictions for WTE (e.g., the EU) as other regulatory approaches related to ash and effluent management have been used to minimize health and environmental impacts as discussed in later sections of this report.

Gasification facilities require APC systems to reduce unwanted emissions to air, although the APC approach will vary based on how the syngas is processed as discussed below. Gasification systems and mass burn systems are not directly comparable as the point in the process where combustion takes place differs, as does the APC approach. Although, gasification systems generally appear to have (or report to have) somewhat lower stack emissions than mass burn WTE plants, these results are based on testing from pilot-scale facilities, not actual commercial-scale operations. ^[31] Stack emissions test results from the Japanese facilities discussed above were not available when this report was being completed.

There are two key differences between APC systems for gasification systems and conventional mass burn combustion: first, some gasification approaches focus on cleaning of the syngas prior to

²⁹ Fichtner Consulting Engineers. 2004. The Viability of Advanced Thermal Treatment of MSW in the UK. Published by ESTET, London

³⁰ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

³¹ RPS-MCOS Ltd. 2005. Feasibility Study of Thermal Waste Treatment/Recovery Options in the Limerick/Clare/Kerry Region

combustion, so that emissions control is based on the control of syngas quality; second, based on the composition of the syngas, it may be directly combusted and have some form of more conventional APC system, however these systems may be sized smaller and/or may not require certain APC components that would normally be necessary for a conventional approach. Table 2-4 provides a summary of gasification processes, costs, scalability and reliability.

It should be noted that the available costing information for gasification technologies is generally provided through informal processes and not on the basis of any contractual commitments to the parties involved. Therefore, it is not clear that reported capital costs address all capital and construction cost elements, nor is it clear that reported operating costs address all real costs associated with such facilities. The cost for each facility will vary on a site-by-site basis.

Table 2-4: Gasification – Summary of Information

Gasification Summary	
Gasification combusts fuel to create syngas.	
The technology has been in use for over a century, but only recently has MSW been used as a feedstock.	
At least 42 companies offer gasification technologies or components of this technology that are capable (or claim to be capable) of treating mixed MSW in North America and elsewhere.	
The earliest example of this technology being used for MSW was in 1991 in Taiwan.	
Other Summary Points	
Median Reported Capital Cost	<ul style="list-style-type: none"> ▪ \$850/annual design tonne +/- 40% (2009\$ CDN)
Median Reported Operating Cost	<ul style="list-style-type: none"> ▪ \$65/tonne +/- 45% (2009\$ CDN) (this reported cost by vendors seems well below the range of expected operating costs based on performance of gasification in the EU and Japan)
Feedstock	<ul style="list-style-type: none"> ▪ Automobile shredder residue (ASR), biomass, black liquor, coal, hospital waste, MSW, organic waste streams, plastics, PVC, refinery residues, sludge, tires ▪ Waste preparation/pre-processing required by technology ▪ Difficulties in accepting variable (heterogeneous) waste streams
Residual to Disposal	<ul style="list-style-type: none"> ▪ <1 % if bottom ash can be marketed for other applications ▪ 10 to 20% if it is not marketable (0.1 to 0.2 tonnes of residue per 1 tonne of input waste)^[32] ▪ Landfill capacity consumption reduced by 90 to 95%
Potential Energy and Revenue Streams	<ul style="list-style-type: none"> ▪ Revenue potential for: electricity, syngas, aggregate recovered from ash ▪ Electricity production, 0.4 to 0.8 MWh/annual tonne of MSW^[33]
Scalability	<ul style="list-style-type: none"> ▪ Usually built with a fixed capacity; modular ▪ Individual modules range in size from approximately 40,000 to 100,000 tpy^[34]

³² Juniper, 2007 a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

³³ Juniper, 2007 a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

³⁴ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

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Gasification Summary

Reliability	<ul style="list-style-type: none">▪ At least seven plants in operation in Japan at a large scale with over two years of operating experience^[35].▪ Limited data available in other jurisdictions to assess operational success with MSW feedstock in regards to technical reliability▪ Complex operation▪ Scheduled and unscheduled downtime reported as approximately 20%^[36], However other reports indicate potential for up to 45% downtime.
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2.2.1.3 Plasma Arc Gasification

Plasma arc gasification uses an electric current that passes through a gas (air) to create plasma which gasifies waste into simple molecules. Plasma is a collection of free-moving electrons and ions that is formed by applying a large voltage across a gas volume at reduced or atmospheric pressure. The high voltage and a low gas pressure, causes electrons in the gas molecules to break away and flow towards the positive side of the applied voltage. When losing one or more electrons, the gas molecules become positively charged ions that transport an electric current and generate heat.

When plasma gas passes over waste, it causes rapid decomposition of the waste into syngas. The extreme heat causes the inorganic portion of the waste to become a liquefied slag. The slag is cooled and forms a vitrified solid upon exiting the reaction chamber. This substance is a potentially inert glassy solid. The syngas is generally combusted in a second stage in order to produce heat and electricity for use by local markets. In some cases, alternative use of the syngas as an input to industrial processes has been proposed.

Currently, plasma arc gasification is not commercially proven to treat MSW. The primary reason appears to be the high capital and operational costs for such facilities. The wear on the plasma chamber is very high and to keep the process operating redundant plasma chambers are needed.

Plasma technology for MSW management has been discussed in Europe since the late 1980s but full scale facilities for MSW have not yet been implemented. At some Japanese facilities, a back-end plasma component has been added to vitrify the bottom ash produced from conventional mass burn combustion facilities. Ramboll recently visited the plant in Shinminto, Japan, where MSW combustion is undertaken by a traditional grate fired WTE facility with a back-end ash melter. The downstream ash melter is operated by JFE and consists of two, 36 tonne per day units. Melting of the ash is undertaken by a plasma arc, operating at approximately 2,000 degrees centigrade. The melted ash is water quenched. The total amount of vitrified residues represents 50% by weight of the incoming ash. Approximately 1/3 of the material is used for construction purposes and the other 2/3 is used as landfill cover. The process consumes significant energy, generally producing net energy of only

³⁵ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

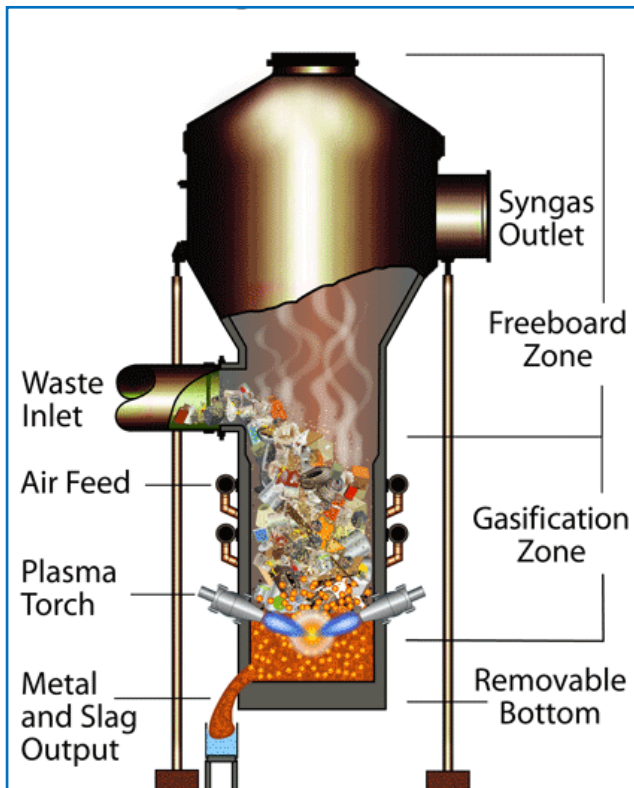
³⁶ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

100 kW per tonne of incoming ash, due to the limited fraction of remaining carbon left in the ash which limits the production of any syngas and thus limits energy production. Note: most ash management processes are net consumers of energy. Plasma chambers in operation in Japan experience a three-month cycle where the chamber has to be taken out of operation for repair every three months mainly to change the refractory lining.

There are no large scale commercial plants in operation in North America or Europe but there are a number of plasma arc systems that are being tested or proposed to treat MSW. Two technologies which are currently being tested in Canada are the Alter NRG process and the Plasco process. Both are discussed further below.

In the Alter NRG process, a plasma torch heats the feedstock to high temperatures in the presence of controlled amounts of steam, air and oxygen. The waste reacts with these constituents to produce syngas and slag. Figure 2-10 provides a conceptual overview of the Alter NRG plasma gasification process.^[37]

Figure 2-10: Conceptual Overview of Alter NRG Plasma Gasification Unit



Source: Westinghouse Plasma Corporation. 2007. Westinghouse Plasma Corp. – Technology and Solutions – PGVR. Accessed February 3, 2010. http://www.westinghouse-plasma.com/technology_solutions/pgvr.php

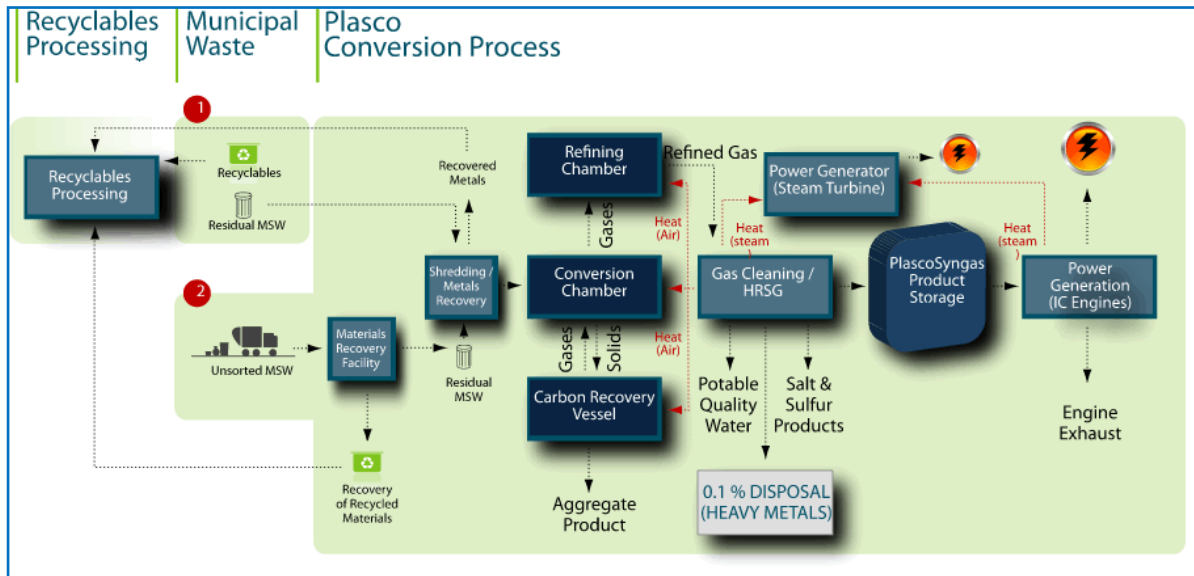
³⁷ Westinghouse Plasma Corporation. 2007. Westinghouse Plasma Corp. – Technology and Solutions – PGVR. Accessed February 3, 2010. http://www.westinghouse-plasma.com/technology_solutions/pgvr.php

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Plasco Energy Corp. (Plasco) has also developed a plasma arc gasification technology capable of treating MSW. Figure 2-11 presents a conceptual overview of the Plasco process.^[38]

Figure 2-11: Conceptual Overview of the Plasco Process



NOTE:

HRSG stands for heat recovery steam generator

Source: Plasco Energy Group. Accessed February 22, 2010

http://www.plascoenergygroup.com/images/Plasco_conversion_process_big.gif

In April 2006 Plasco entered into an agreement with the City of Ottawa to develop a demonstration facility on City-owned property next to the City's Trail Road Landfill. Construction began in June 2007, and the first waste was received at the facility in January 2008. The plant is permitted to process 85 tonnes per day of solid waste provided by the City using Plasco's conversion technology, and Plasco claims that the process would produce 1,150 kWh of power per tonne of waste when fully operational.

In the first year of operations (2008), the plant processed approximately 2,000 tonnes of MSW (6% of the permitted annual quantity of MSW), operating for 890 hours^[39] or approximately 37 days (10% plant availability). Commissioning has indicated the need for improvements to the front end of the plant, including pre-processing of the curbside MSW to ensure that the waste received is suitable for the conversion chamber. The 2009 operating report for the Ottawa plant was not available as of the end of March 2010. The demonstration plant is currently permitted to operate until January 21, 2011. Final documentation for the demonstration plant will include stack test emissions results that are not yet available.

³⁸ Plasco Energy Group. Accessed February 22, 2010. http://www.plascoenergygroup.com/images/Plasco_conversion_process_big.gif

³⁹ Plasco Energy Group. 2010. *Environmental Performance*. Accessed February 10, 2010
http://www.plascoenergygroup.com/?Environmental_Performance

In the Plasco process, the syngas produced in the primary conversion chamber is refined and cleaned. No emissions to air are generated during the creation of Syngas from MSW. The emissions to air from the process are associated with the combustion of the Syngas in gas engines to produce electricity. These emissions must meet requirements in the operating permit that are more stringent than those set out in Ontario guidelines for PM, Organic matter, HCl, NO_x, mercury, cadmium, lead and dioxins/furans.

Table 2-5 provides a summary of the plasma arc gasification process, costs, scalability and reliability.

Table 2-5: Plasma Arc Gasification – Summary of Information

Plasma Arc Gasification Summary	
Plasma gasification uses an electric current that passes through a gas to create plasma.	
Plasma arc is not a new technology; it has industrial applications and has been used for treating hazardous waste.	
The earliest facility found to use plasma arc gasification was a test facility which operated from 1987 – 1988.	
The largest facility currently operating in the world is located in Japan (Eco-Valley Utashinai Plant) and processes over 90,000 tpy of MSW and automobile shredder residue (ASR).	
24 companies supplying Plasma Arc gasification technologies and/or services have been identified that indicate use of MSW as a portion of their feedstock.	
Other Summary Points	
Median Reported Capital Cost	<ul style="list-style-type: none"> \$1,300/annual design tonne +/- 40% (2009\$ CDN)
Median Reported Operating Cost	<ul style="list-style-type: none"> \$120/tonne +/- 50% (2009\$ CDN)
Feedstock	<ul style="list-style-type: none"> MSW, ASR, hazardous waste, hospital waste, organic waste streams, shipboard waste, tires Waste preparation/pre-processing required by technology Difficulties in accepting variable waste streams
Residual to Disposal	<ul style="list-style-type: none"> Estimated at >1 to 10% (0.1 tonne of residue per 1 tonne of input waste), varying due to the nature of the waste and efficiency of the conversion process.^[40] Inert Slag, APC residue Landfill capacity consumption reduced by up to 99%
Potential Energy and Revenue Streams	<ul style="list-style-type: none"> Revenue potential for: electricity, syngas, aggregate substitute Electricity production, 0.3 to 0.6 MWh/annual tonne of MSW^[41] NOTE: Plasma arc facilities tend to consume more energy to operate than other types of facilities
Scalability	<ul style="list-style-type: none"> Modular facilities; multiple modules can be accommodated on a single site with some sharing of infrastructure.

⁴⁰ Juniper, 2007 a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

⁴¹ Juniper, 2007 a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

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Plasma Arc Gasification Summary

Reliability	<ul style="list-style-type: none">▪ Limited data available to assess operational success with MSW feedstock in regards to technical reliability▪ Eco-Valley Utashinai Plant, Japan processes over 90,000 tpy of material but feedstock is not 100% MSW▪ Only two plants (Japan) with 2 or more years of operations▪ Canadian facility (Plasco in Ottawa) has not been in regular (24/7) operation as of early 2010▪ Complex Operation, scheduled and unscheduled downtime, unknown^[42].
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2.2.1.4 Pyrolysis

The concept of pyrolysis of MSW gained popularity in the 1960s as it was assumed that since MSW is typically about 60% organic matter, it would be well suited to pyrolytic treatment. By the mid-1970s studies in Europe and the United States concerning the pyrolysis of MSW were completed, some of these studies involved the construction and operation of demonstration plants. By the late 1970s, however, both technical and economic difficulties surrounding the pyrolysis of MSW arose which resulted in the lowering of interest and expectations for the technology. Since that time, the pyrolysis of MSW has been investigated but continues to face technical limitations.

Pyrolysis is the thermal decomposition of feedstock at a range of temperatures in the absence of oxygen. The end product is a mixture of solids (char), liquids (oxygenated oils), and syngas (consisting of CO₂, CO, CH₄, H₂). The pyrolytic oils and syngas can be used directly as boiler fuel or refined for higher quality uses such as engine fuels, chemicals, adhesives, and other products. The solid residue is a combination of non-combustible inorganic materials and carbon.

Pyrolysis requires thermal energy that is usually applied indirectly by thermal conduction through the walls of a containment reactor since air or oxygen is not intentionally introduced or used in the reaction. The transfer of heat from the reactor walls occurs by filling the reactor with inert gas which also provides a transport medium for the removal of gaseous products.

The composition of the pyrolytic product can be modified by the temperature, speed of process, and rate of heat transfer. Liquid products (pyrolytic oils) are produced by lower pyrolysis temperatures while syngas is produced by higher pyrolysis temperatures. The syngas produced can be combusted in a separate reaction chamber to produce thermal energy which can then be used to produce steam for electricity production.

A full scale (100,000 tpy) facility began operating in 1997 in Fürth, Germany. Modifications to the facility were made between 1997 and 1998 but in August, 1998 the plant was closed following an explosion resulting from a waste 'plug' causing over pressurization of the reaction chamber. At

⁴² AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

present there are no large scale pyrolysis facilities are in operation in Europe. However, a smaller facility has been in operation in Burgau in the Eastern part of Europe.

There were a total of six pyrolysis plants in operation in Japan as of the end of 2007 based on the information available as of March 2010. Information on the current (2010) status of these facilities was not available as of the date that this report was prepared. A new facility was being built in Hamamatsu (2007/2008) using this technology, which is intended to process approximately 450 tpd. Ramboll recently visited a similar pyrolysis facility located at the Toyohashi Waste Treatment Recovery and Resource Center, Toyohashi Japan. Information obtained during the facility visit includes the following:

- The facility consists of two 200-tpd units that process MSW (or approximately 120,000 tpy based on availability).
- The facility was commissioned in 2002.
- The recovery and resource center also has a grate-fired mass burn facility to process MSW.
- The overall capital cost for the pyrolysis plant was approximately \$165 million USD (1998\$).
- The facility is similar to the plant in Fürth with modifications.
- The process involves low temperature pyrolysis (400°C) followed by a high temperature secondary combustion/residual vitrification stage.
- Aluminum and iron are removed after the pyrolysis drum.
- The APC train includes: quenching, baghouse for PM removal, SCR for NO_x, and flue gas recirculation.
- Incoming waste is shredded to 15x15 cm and has an average heat value of 9.2 MJ/kg.
- Residues: bottom ash 12.4%, with recovery of iron and aluminum.
- Energy production: yearly production 41 GWh electricity, with 90% used for internal consumption and pre-treatment. Only 4.46 GWh is sold.
- Heat produced is used to heat a public swimming pool.
- Availability: approximately 6,900 hours per year for line 1 and 7,400 hours per year for line 2 or over 80%. Scheduled and unscheduled downtime is required to repair the refractory lining of the reactor.
- Overall, the operators find the grate fired plant more reliable and flexible with higher availability in comparison with the pyrolysis plant.

Due to the pre-treatment of waste and the fuel burned in the high temperature chamber, the electrical output from the pyrolysis process is almost balanced with the internal energy consumption.

Pyrolysis generally takes place at lower temperatures than used for gasification which results in less volatilization of carbon and certain other pollutants, such as heavy metals and dioxin precursors. The relatively low temperatures allow for better metal recovery before the residual pyrolysis products enter the high temperature chamber where they are vitrified.

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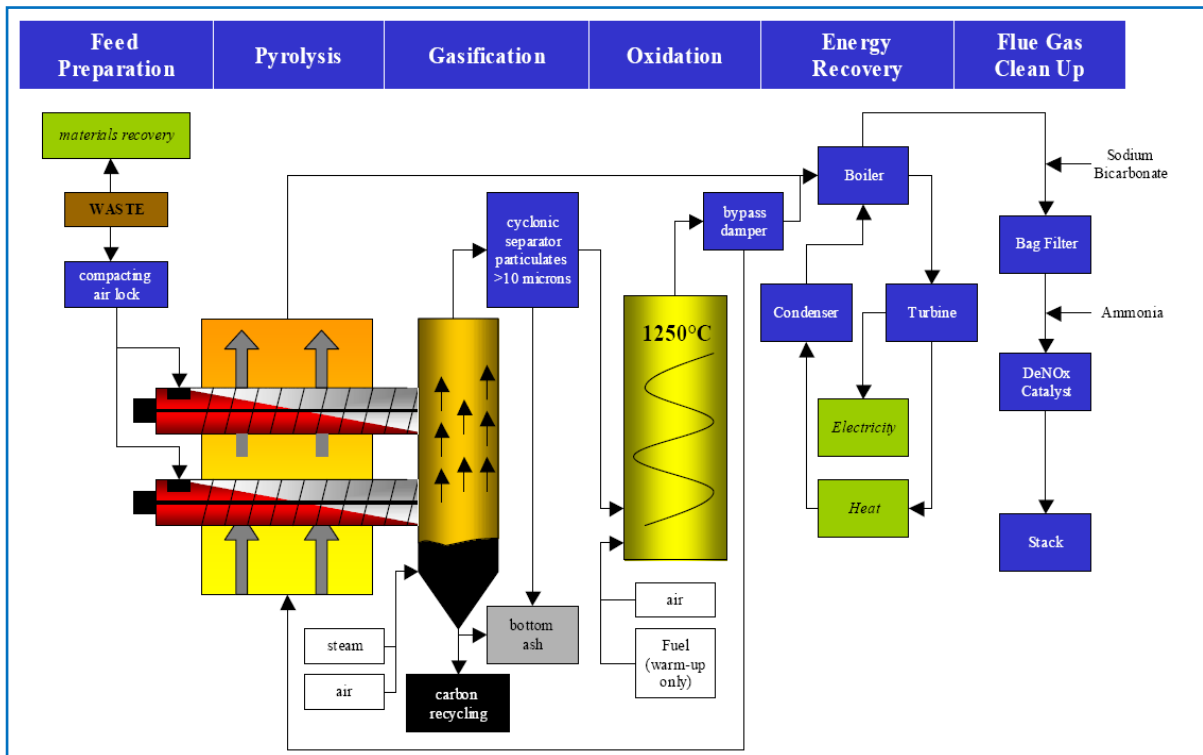
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Issues identified in relation to the pyrolysis process include:

- Low energy outputs
- The requirement for a properly sealed reaction chamber for safe operation. The pyrolysis process is highly sensitive to the presence of air. Accidental incursions of air can result in process upsets and increase the risk of explosive reactions.
- The requirement for pre-treatment of the MSW.

The following figure (Figure 2-12) presents a schematic overview of the Compact Power pyrolysis technology as developed by Compact Power Ltd. In the Compact Power process, sorted MSW is conveyed by a screw through the heated tubes for pyrolysis, followed by gas combustion in a cyclone where energy is captured to produce steam and then electricity. It should be noted that the Compact Power technology utilizes a gasification step following pyrolysis – this does not necessarily occur in all pyrolysis based WTE facilities.^[43]

Figure 2-12: Schematic Overview of the Compact Power Pyrolysis Process



Source: Thomas Malkow. 2004. Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal. In Waste Management 24 (2004) 53-79

⁴³ Thomas Malkow. 2004. Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal. In Waste Management 24 (2004) 53-79

Table 2-6 provides a general summary of pyrolysis process, costs, scalability and reliability. This cost data is less reliable than the costs presented in this report for other technologies since:

- It is unclear if the reported capital costs address all capital and construction cost elements.
- It is not clear that reported operating costs address all costs associated with such facilities.
- It was also noted that the values were consistently reported to be lower than other similar WTE technologies, but without supporting rationale for these differences.

Table 2-6: Pyrolysis – Summary of Information

Pyrolysis Summary	
Pyrolysis is the thermal decomposition of feedstock at high temperatures in the absence of oxygen.	
The longest operating pyrolysis facility is located in Burgau, Germany and has been operating since 1987.	
The largest facility (located in Japan) processes approximately 150,000 tpy of SRF.	
Over 20 companies market pyrolysis technologies or approaches for treating MSW.	
Other Summary Points	
Median Reported Capital Cost	<ul style="list-style-type: none"> ▪ No reliable data
Median Reported Operating Cost	<ul style="list-style-type: none"> ▪ No reliable data
Feedstock	<ul style="list-style-type: none"> ▪ Biomass, automotive shredder residue, coal, hospital waste, MSW, plastics, polyvinyl chloride, sludge, tires, wastewater ▪ Waste preparation/pre-processing required by technology ▪ Difficulties in accepting variable waste streams
Residual to Disposal	<ul style="list-style-type: none"> ▪ If treated, residues reduced to 0.1 to 0.3 tonnes per input tonne ▪ >30%, if residue not treated ▪ Landfill capacity consumption reduced by up to 90%
Potential Energy and Revenue Streams	<ul style="list-style-type: none"> ▪ Revenue potential for: electricity, syngas, pyrolysis oil ▪ Electricity production, 0.5 to 0.8 MWh/annual tonne of MSW^[44]

The flue gas from the combustion of the pyrolysis gas must be treated in an APC system of one of the types presented in Section 2.2.4.2 of this report. No fundamental differences have been identified to-date between flue gas from conventional grate fired plants and pyrolysis plants.

2.2.2 Emerging Combustion and Thermal Treatment Technologies

There is a great deal of flux in the thermal treatment marketplace, with regard to new and emerging technologies. However, many of the emerging technologies have yet to be proven and the financial capacity of many of the new technology vendors is limited.

With more proven technologies such as mass burn, the evolution of technology has focused on improving combustion and emissions performance through design adjustments, such as new grate

⁴⁴ Juniper, 2007 a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

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design and improved combustion air management systems. Significant achievements associated with more conventional technologies include low-NO_x burners, improved efficiency, heat exchangers, waste heat recovery systems, and newly developed equipment for wet scrubbing and activated carbon absorption.

The following is a selected list of some emerging combustion and thermal treatment technologies. While there are other emerging technologies, the following represents technologies that are in development (preliminary development, test facilities or commercial scale proposals) in North America. The information has been made available from technology vendors and generally is yet to be verified by any independent parties.

2.2.2.1 Gasplasma

The gasplasma process is used by Advanced Plasma Power, a United Kingdom-based company. They currently have one small-scale, demonstration plant in operation. The gasplasma process uses waste feedstock to produce clean hydrogen-rich syngas and Plasmarok™, a vitrified recyclate, which reportedly can be used as a building replacement or replacement aggregate.

The gasplasma process is designed for post-diversion materials (i.e., those materials that cannot be recycled or composted). Although it can operate with a variety of feedstock, it operates most efficiently when treating a prepared SRF. Advanced Plasma Power utilizes three different technologies in their process: fluidized bed gasification, plasma arc treatment and a power island. The gasifier operates at a temperature of approximately 900°C. At this temperature, the material is thermally broken down into syngas. The plasma arc treatment “cracks” the dirty syngas coming out of the gasifier. The cracking process breaks the molecular structure of the syngas and reforms it into a simpler structure, thereby producing a hydrogen-rich fuel gas. The hydrogen-rich fuel gas is cooled and further cleaned before being fed into the gas engines at the power island. It is claimed that the electrical generating efficiency reaches 35 – 40%.

The fluidized bed gasifier used in the gasplasma process produces char and ash (approximately 10 – 15% of the feedstock), this material is recovered in Plasmarok™. Plasmarok™ is stated as being an environmentally stable material that can be re-used as a building aggregate (in the UK). The vendor claims Plasmarok™ significantly reduces the amount of residue requiring landfilling; from 60,000 tonnes of SRF, 450 tonnes of activated carbon from the gas scrubbers requires landfilling (over 99% reduction).^[45]

2.2.2.2 Thermal Cracking Technology (Fast Pyrolysis)

Graveson Energy Management (GEM) uses traditional petrochemical industry technology to convert MSW into clean synthetic gas. A GEM facility employing thermal cracking technology has been operating in Romsey, England since 1998. It can process up to 1,680 tonnes per day of RDF that has

⁴⁵ Advanced Plasma Power. 2010. *What is Gasplasma – The Process*. Accessed February 10, 2010
<http://www.advancedplasmapower.com/index.php?action=PublicTheProcessDisplay>

been ground to less than 2 mm particle size and dried to 5% moisture. Thermal cracking is also described as “fast pyrolysis” as it involves rapid heating of the waste fuel in the absence of oxygen.

In thermal cracking, prepared waste material is fed into the oxygen-free chamber. The chamber has stainless steel walls that are heated to 850°C. The waste material is instantly heated and thermally cracks to syngas in a matter of seconds. Syngas entering the Gas Filtration system is further filtered to remove finer particles and is cooled rapidly from 1,500°C to less than 400°C to prevent the formation of dioxins and furans. A small portion of the clean syngas is used to heat the GEM Converter, which reduces the need for fossil fuels. The remainder of the syngas can be used in boilers, engines, or turbines for generation into energy. Mineral solids are produced as a residual, typically in the amount of 8 – 10% for domestic waste.^[46]

2.2.2.3 Thermal Oxidation

Zeros Technology Holdings uses an Energy Recycling Oxidation System that can reportedly dispose of all classifications of waste. Zeros claims no emissions are produced in the process and other effluents can be sold as products or reintroduced into the system, however to our knowledge, these claims have not been supported by independent verification. The system is closed and uses pure oxygen for the oxidation process, as opposed to ambient air. The oxidation process used by this technology was originally developed for oil spill remediation. Several projects are in various stages of development, however there is currently no Zeros facility in operation.

Zeros combines six different technologies in their process: rotary kiln; gasification (Oxy-Fuel Technology); Rankine Cycle Technology; Fischer-Tropsch Fuels Technology; Gas Capture Technology; and Clean Water Technology. The gasification-oxidation process is a two stage process using limited oxygen and high temperature. The system gasifies the fuel source to produce primarily Carbon Monoxide and Hydrogen. This synthetic gas forms the building blocks for the transformation to liquid fuels such as diesel using the Fischer-Tropsch technology.^[47]

2.2.2.4 Waste-to-Fuels

Approaches to transform waste into fuels are generally based on the concept that rather than using the syngas produced through gasification as a direct energy source, the syngas can be used as a feedstock to generate various liquid fuels that could then be used off-site.

Enerkem intends to construct the world’s first facility intended to produce biofuels from MSW. Construction of the Edmonton facility is set to begin in April 2010 and operations are currently planned to begin in mid-2011.^[48] Enerkem indicates Alberta will reduce its carbon dioxide footprint by more than six million tons over a 25 year period, while producing 36 million liters of ethanol annually through the use of this facility.

⁴⁶ GEM Canada Waste to Energy Corp. 2009. *Process Description and Gas Production*. Accessed February 10, 2010. <http://www.gemcanadawaste.com/53257.html>

⁴⁷ Zeroes Technology. 2008. Accessed May 10, 2010 <http://www.zerosinfo.com/technology.php>

⁴⁸ Enerkem. 2010. Edmonton Biofuels Project Status and Schedule. http://www.edmontonbiofuels.ca/status.htm?yams_lang=en

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Enerkem converts urban biomass, agricultural residues and/or forest residues into biofuels by means of a four step process:

1. Pre-treatment of the feedstock which involves drying, sorting and shredding of the materials.
2. Feedstock is fed into the gasifier. The bubbling fluidized bed gasifier converts the residues into synthetic gas and operates at a temperature of approximately 700°C.
3. Synthetic gas cleaning and conditioning, which includes the cyclonic removal of inerts, secondary carbon/tar conversion, heat recovery units, and reinjection of tar/fines into the reactor.
4. Conversion of syngas into biofuels.

Enerkem intends to produce approximately 360 litres of ethanol from 1 tonne of waste (dry base).^[49]

Changing World Technologies employs a Thermal Conversion Process which converts waste into oil. They state: "The Thermal Conversion Process, or TCP, mimics the earth's natural geothermal process by using water, heat and pressure to transform organic and inorganic wastes into oils, gases, carbons, metals and ash. Even heavy metals are transformed into harmless oxides". Changing World Technologies does not have a commercial facility at this time; however they do have a test centre in Philadelphia, PA.^[50]

2.2.3 Summary of Major Thermal Treatment Technologies

Table 2-7 presents an overview of the four major types of WTE technologies used worldwide and a number of their key characteristics.

Table 2-7: Overview of the Four Major Types of WTE Technologies Used Worldwide

Characteristic	Conventional Combustion			Gasification	Plasma Gasification	Pyrolysis
	Mass Burn	Fluidized Bed	Two-Stage			
Applicable to unprocessed MSW, with variable composition	YES	NO	YES	NO	NO	NO
Commercially Proven System, with relatively simple operation and high degree of reliability	YES	YES	YES	Commercially proven to limited degree, more complex than combustion and less reliable, very costly	NO	NO
Reasonably Reliable set of Performance Data	YES	NO	YES	Limited data. Operational problems have been documented.	Limited data. Operational problems have been documented.	Limited data. Operational problems have been documented.

⁴⁹ Enerkem. 2010. *Technology Overview*. Accessed February 10, 2010
<http://www.enerkem.com/index.php?module=CMS&id=6&newlang=eng>

⁵⁰ Changing World Technologies. 2010. *What Solutions Does CWT Offer? What is Thermal Conversion Process (TCP)?*. Accessed February 10, 2010. <http://www.changingworldtech.com/what/index.asp>

3 POTENTIAL DISCHARGES FROM THERMAL TREATMENT

3.1 Air Emissions

3.1.1 Overview of Potential Emission Constituents

The following table (Table 3-1) illustrates the main sources of air emissions from WTE facilities.^{[51] [52]}

Table 3-1: Main Sources of Key Substances of Concern Released from WTE Facilities

Substances	Comments and Main Sources
Particulate matter (including PM ₁₀ , PM _{2.5} and ultrafine (nanoparticles))	Present in flue gas as fine ash from the incineration process entrained in the flue gas. There can also be fugitive releases of dust from waste storage areas and ash management if good operational controls are not in effect.
CO	Present in flue gas as a result of incomplete combustion of waste. e.g., if spontaneously evaporating or rapid-burning substances are present, or when combustion gas mixing with the supplied oxygen is poor.
NO _x	Present in flue gas as both thermal and fuel NO _x . Fuel NO _x originates from the conversion of nitrogen contained in the waste while thermal NO _x results from the conversion of atmospheric nitrogen from the combustion air. In WTE the proportion of thermal NO _x is often much greater than fuel NO _x .
SO ₂	Present in flue gas where sulphur is present in the waste stream. Common sources of sulphur in the waste stream are: waste paper, drywall (or gypsum plaster) and sewage sludge.
N ₂ O	Principally arises from SNCR. Modern MSW incinerators have low combustion-originated N ₂ O but, depending on the reagent, emissions can result from SNCR, especially when urea is used as the reducing agent.
Methane (CH ₄)	Normally not generated at all as long as combustion is carried out under oxidative conditions. May arise from the waste bunker if waste is stored for a long time resulting in anaerobic digestion taking place.
Metals (Heavy metals and compounds other than Hg and Cd) Sb, As, Pb, Cr, Cu, Mn, Ni, V, Sn,	Predominantly found in flue gas as particulate matter usually as metal oxides and chlorides. A portion can also be found in bottom ash, fly ash and sorbent. The proportion of each metal found in the particulate entrained in the flue gas versus that found in the bottom ash, is usually reflective of the volatility of the metal.

⁵¹ Environment Agency, Pollution Inventory Reporting: Environmental Permitting (England and Wales) Regulations 2007, Regulation 60(2), December 2009

⁵² European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

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Substances	Comments and Main Sources
Cd	Predominantly found in flue gas in gaseous form or bound to entrained PM. Common sources of cadmium in WTE facilities are electronic devices (including capacitors), batteries, some paints and cadmium-stabilized plastic. Other sources include hazardous wastes including effluent treatment sludges and drummed waste from metal plating works. It should be noted that BC is actively removing sources of cadmium from the waste stream with the electronic product stewardship program, and battery recycling see http://rcbc.bc.ca/education/retailer-take-back
Hg	Predominantly found in flue gas in gaseous form or bound to entrained PM. Originates from MSW containing batteries, thermometers, dental amalgam, fluorescent tubes, and mercury switches. High quantities of fish/seafood in the waste stream can also lead to mercury emissions. Also found in bottom ash, fly ash and sorbents. There are programs in place to remove mercury from the waste stream such as: Canada Wide Standards for Dental Amalgam Waste, and fluorescent light recycling product stewardship in BC.
VOCs (often presented as TOC)	Predominantly found in flue gas from incineration of organic waste. There is also some potential for fugitive releases from waste storage areas.
PAHs	Principally found in flue gas as products of incomplete combustion. Also found in bottom ash, fly ash and sorbents.
Dioxin like PCBs	Predominantly found in flue gas from most municipal waste streams and some industrial wastes. Low levels of PCBs are found in most municipal waste streams. Higher concentrations in some hazardous waste streams. Also found in bottom ash and APC Residue.
Dioxins and furans	Predominantly found in flue gas, as a result of re-combination reaction of carbon, oxygen and chlorine (de novo synthesis). May also be found in low levels in the incoming waste stream. Also found in boiler ash, bottom ash, fly ash and sorbents.
Ammonia	Predominantly found in flue gas where SNCR is used to control NO _x . May be present as a result of overdosing or poor control of reagents.
HCl	Predominantly found in flue gas from wastes containing chlorinated organic compounds or chlorides. In municipal waste approximately 50% of the chlorides come from PVC plastic (used for household sewerage pipes).
HF	Predominantly found in flue gas. Originates from fluorinated plastic or fluorinated textiles in MSW and a variety of fluorinated compounds found in household hazardous waste.

Like other combustion processes, WTE facilities can release small quantities of a broad spectrum of compounds into the atmosphere. Only a small fraction of these are considered to be air pollutants and are considered substances of concern. Typical substances of concern that are emitted from WTE facilities and often subject to regulatory limits include:

- Total Particulate Matter (including PM₁₀, PM_{2.5} and ultrafine (nanoparticles))
- Products of incomplete combustion: CO and Organic compounds (TOC, VOCs, organic matter)
- Acidic substances: SO_x, NO_x, HCl and HF
- Heavy metals: Hg, Cd, Tl, Pb, As, Ni, Co, Cr, Cu, V, Mn, Sb
- Organics: dioxins and furans.

Common or Criteria Air Contaminants (CACs) typically found in the atmosphere are PM, SO_x, NO_x, VOCs and CO. BC MOE Ambient Air Quality Objectives for these CACs are summarized in Section 8.1.2.3. Background information pertaining to each of the emitted WTE air pollutants of concern is provided below.

Particulate Matter

Particulate matter (PM) consists of solid and/or liquid particles that are suspended in the air column. PM is typically grouped into the following categories based on their aerodynamic diameter (in micrometers (µm)):

- Total Particulate Matter (TPM), consisting of all size fractions
- Coarse PM, less than 10 µm (PM₁₀)
- Fine PM, less than 2.5 µm (PM_{2.5})
- Ultrafine PM, less than 0.1 µm (PM_{0.1}).

In human physiology, coarse particles (those between 2.5 and 10 µm in diameter) are efficiently trapped and removed. They are either filtered out by the hair in the nose or by impacting on and sticking to moist surfaces in the upper respiratory tract. Coarse particles are mainly fine crustal elements. Coarse particles fall out of the atmosphere relatively quickly due to gravity and removal by precipitation.

Fine particles (those less than 2.5 µm in diameter) are able to penetrate deeper into the respiratory tract. Because of this property, fine particles are believed to be responsible for most adverse health effects associated with particulate matter exposure. Fine particles include very fine crustal elements and secondary particles that are essentially ultrafine particles that have formed into larger particles by a variety of physical and chemical processes (e.g., nucleation, condensation, coagulation). Fine particles persist in the atmosphere for long periods and travel long distances because they are relatively stable and their size makes them less susceptible to gravitational settling.

Canadian and American regulatory agencies have air quality objectives for PM₁₀ and more recently PM_{2.5} based upon concentrations in air (in micrograms per cubic metre (µg/m³)).

Ultrafine particles (PM_{0.1}) range in size from 0.1 to less than 0.01 µm in diameter (100 to <10 nanometre (nm)). Ultrafine particles are relatively short lived (minutes to hours) owing to the rapidity of the physical and chemical processes noted above.^{[53] [54]} Some authors use the term 'ultrafine particles' and 'nanoparticles' interchangeably to denote all particles in the nanometer size range. Some advocate the bifurcation of "ultrafine particles" as those between 100 to 10 nm in diameter, and "nanoparticles" as those less than 10 nm. Because of quantum effects, particles smaller than 10 nm in diameter behave differently than their bulk counterparts, and they are different morphologically

⁵³ AWMA, 2005a Nanoparticles and the Environment: Critical Review. Pratim Biswas and Chang-Yu Wu. JAWMA, v55, June 2005 pp 708 – 746

⁵⁴ AWMA, 2005b Nanoparticles and the Environment: Critical Review Discussion. Judith C. Chow, *et al.* JAWMA, v55, October 2005 pp 1411 – 1417

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and chemically compared to ultrafine particles^[55]. Research into the fate and behavior of particles of this size is ongoing. In this report, the designation PM_{0.1} will include ultrafine particles and nanoparticles unless otherwise designated.

The primary sources of PM_{0.1} include the condensation of hot vapours during high temperature combustion processes (i.e., diesel fumes, coal burning, welding, automobiles, wood fires), cooking of foods, biological processes, and secondary formations (i.e., from the nucleation of atmospheric species to form larger particles).^{[56] [57]}

Particles in the PM_{0.1} size range are ubiquitous in the atmosphere, and are at the heart of essential chemical and physical processes such as the sulphur and nitrogen cycle, and cloud formation. A growing body of literature is devoted to the measurement and study of the effects of PM_{0.1}.^[58] Since simple filtration is ineffective at capturing such small particles, measurements focus on particle sizing and particle number (count) by inertial impaction, electrical, and light scattering means.

In addition to size and concentration, the toxicity of nanoparticles is correlated with chemical composition. Smaller particles have proportionally greater surface area per mass and can interact more readily with cell surfaces. With the increase in surface area, the physical parameter of the surface Gibbs free energy increases causing the particles to be more chemically reactive with the surrounding tissue.^[59] As a consequence, health effects resulting from nanoparticles are not correlated with the total mass of particles entering the organism. Insoluble and non-soluble PM_{0.1} are of greatest concern because they eventually accumulate and can lead to toxic effects in specific organs (i.e., heart, lungs, reproductive system).^[60]

In addition to chemical composition, other factors such as surface dose, surface coverage, surface charge, shape, porosity, and the age of the particle can contribute to the toxicity of particles in the ultrafine range. However, not enough data is currently available to assess the significance of each of these factors on the toxicity of PM_{0.1}.

The current understanding of adverse health effects of exposure to PM_{0.1} indicates that the effects are as diverse as the types of particles themselves, making it very difficult to identify major trends. A detailed summary of the current state of knowledge of the impact of different types of PM_{0.1} on human health was completed by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) in 2008.

Carbon Monoxide

Carbon monoxide is a colourless, odourless gas. As a product of incomplete combustion, emissions sources include fossil fuel and wood combustion. Motor vehicles, industrial processes, and natural sources (fires) are some common sources.

⁵⁵ AWMA, 2005a Nanoparticles and Environment: Critical Review. Pratim Biswas and Chang-Yu Wu. JAWMA, v55, June 2005 pp 708 – 746

⁵⁶ Health Canada. National Ambient Air Quality Objectives for Particulate Matter – Executive Summary. Part 1: Science Assessment Document

⁵⁷ The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST). Health Effects of Nanoparticles. November, 2008

⁵⁸ AWMA, 2005a Nanoparticles and Environment: Critical Review. Pratim Biswas and Chang-Yu Wu. JAWMA, v55, June 2005 pp 708 – 746

⁵⁹ The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST). Health Effects of Nanoparticles. November, 2008

⁶⁰ The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST). Health Effects of Nanoparticles. November, 2008

Volatile Organic Compounds (VOCs)

Volatile Organic Compounds are organic substances of concern (carbon chains or rings that also contain hydrogen) that have high enough vapour pressures under normal conditions to significantly vapourize and enter the Earth's atmosphere (i.e., with a vapour pressure greater than 2 mm of mercury (0.27 kPa) at 250°C or a boiling range of between 60 and 250°C) excluding methane. Individual jurisdictions have varying definitions for VOCs that may be tailored to the specific regulatory context in which the definition is applied. These gaseous organic substances are products of incomplete combustion. For WTE facilities, generally Total Organic Carbon (TOC) or Total Non-Methane Organic Carbon (TNMOC) which is largely comprised of VOCs, is measured continuously in flue gas as being representative of the mass of VOC emissions. This is necessary as there are a myriad of species of VOCs that may be present in extremely small concentrations within the flue gas and monitoring of individual species is not possible.

Sulphur Dioxide

Sulphur dioxide is a colourless gas with a distinctive pungent sulphur odour. It is produced in combustion processes by the oxidation of sulphur compounds, such as H₂S, in fuel. At high enough concentrations, SO₂ can have negative effects on plants and on animal health, particularly with respect to their respiratory systems. Sulphur dioxide can also be further oxidized and may combine with water to form the sulphuric acid component of acid rain.

Anthropogenic emissions comprise approximately 95% of global atmospheric SO₂. The largest anthropogenic contributor to atmospheric SO₂ is the industrial and utility use of heavy oils and coal. The oxidation of reduced sulphur compounds emitted by ocean surfaces accounts for nearly all of the biogenic emissions. Volcanic activity accounts for much of the remainder.^[61]

Oxides of Nitrogen

Nitrogen oxides are produced in most combustion processes, and almost entirely made up of nitric oxide (NO) and nitrogen dioxide (NO₂). Together, they are often referred to as NO_x. Nitrogen dioxide is an orange to reddish gas that is corrosive and irritating. Most NO₂ in the atmosphere is formed by the oxidation of NO, which is emitted directly by combustion processes, particularly those at high temperature and pressure, such as internal combustion engines.

Nitric oxide is a colourless gas with no apparent direct effects on animal health or vegetation at typical ambient levels. The concentration of NO₂ is the regulated form of NO_x. External combustion processes, such as gas-fired equipment and motor vehicles, are primary sources of anthropogenic NO_x emissions. The levels of NO and NO₂, and the ratio of the two gases, together with the presence of certain volatile organic compounds (VOCs) from motor vehicle emissions, solvent use and natural sources, and sunlight are the most important contributors to the formation of ground-level ozone.

Anthropogenic emissions comprise approximately 93% of global atmospheric emissions of NO_x (NO and NO₂). The largest anthropogenic contributor to atmospheric NO_x is the combustion of fuels

⁶¹ Wayne, R. Chemistry of Atmospheres. Oxford Science Publications, 1991.

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such as natural gas, oil, and coal. Forest fires, lightning, and anaerobic processes in soil account for nearly all biogenic emissions.^[62]

Acid Gases

Acid gases are those gaseous contaminants which contribute towards the formation of acidic substances in the atmosphere. In combustion, acid gases of concern include sulphur dioxide (SO₂), oxides of nitrogen (NO_x), hydrogen chloride (HCl) and hydrogen fluoride (HF).

Heavy Metals

Heavy metals are usually carried on particulate matter and occur naturally or can be emitted through anthropogenic sources (i.e., combustion). The concern for human and ecological health varies with each metal as well as its mobility through various environmental pathways. Some metals (such as mercury) have toxic effects if inhaled, ingested or absorbed through skin. Typical metals emitted as a result of MSW combustion include cadmium, thallium, chromium, arsenic, mercury and lead. Semi-volatile metals include lead or cadmium whereas mercury and thallium are highly volatile and vapourize readily.

Dioxins and Furans

Dioxins and Furans are organic compounds with a chemical structure that contains two benzene rings and up to eight chlorine atoms. They can be created as an undesired by-product of chemical processes such as the manufacture of pesticides, or chlorine bleaching of pulp. Dioxins and Furans can also be produced under certain conditions within combustion processes in which chlorine is present in the fuel burned, or where poor combustion operating conditions can result in de novo synthesis (as discussed below). Normally, a well functioning incinerator facility will destroy dioxins and furans within the combustion zone. The reference dioxin isomer is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). Other isomers are usually expressed in terms of equivalents of TCDD. TCDD is almost insoluble in water, slightly soluble in fats and more soluble in hydrocarbons.

Dioxins and furans may form (referred to as de novo synthesis) in catalytic reactions of carbon or carbon compounds with inorganic chlorine compounds over metal oxides (e.g., copper oxide) during the waste incineration process. These reactions generally take place in the temperature range between 250 – 400°C which occurs as the flue gas cools after leaving the combustion zone of the incinerator. Modern incinerators are designed to ensure that the length of time flue gas spends in that temperature range is minimized so as to reduce the possibility of de novo synthesis of dioxins/furans and to control and destroy dioxin and furan in the emission before discharge.

3.1.2 Point Source Emissions

Point source emissions are those emissions resulting from a single point such as the emissions exhausted via a stack or vent, i.e., a single point source into the atmosphere. Point source emissions are usually the most significant emission source (in terms of annual mass releases) for combustion activities at WTE facilities. APC equipment (e.g., scrubbing units, fabric filters (bag house)) as

⁶² Wayne, R. Chemistry of Atmospheres. Oxford Science Publications, 1991

described further in this report, are incorporated into the exhaust system prior to discharge to atmosphere control the release of pollutants into the atmosphere.^[63] Point source emissions at a WTE facility are those that contain the treated exhaust from the process and typically it is this exhaust stream that is monitored for compliance with regulatory limits.

3.1.3 Fugitive Emissions

Fugitive emissions are those that are not released from a point source such as a stack, but rather from an area-based source. Typically fugitive emissions are uncontrolled, or are controlled on an as-needed basis, such as through the use of dust suppression techniques in dry conditions. Fugitive emissions from WTE facilities, including dust, odour and VOCs, are largely minimized by maintaining the WTE facility under negative pressure, using indoor facility air for combustion. Some examples of areas with potential for fugitive emissions and potential mitigative measures are:

- The loading and unloading of transport containers. To mitigate fugitive emissions from receiving areas these areas are usually fully enclosed, and the air from these areas is drawn into the combustion process, keeping the waste receiving area under negative pressure.
- Storage areas (e.g., bays, stockpiles, etc) for waste and residual materials. As noted above, mitigation includes enclosing these areas and using the air from these locations as sources for combustion air.
- Transferring material between vessels (e.g., movement of materials to and from silos, transfer of volatile liquids such as select liquid fuels). Filters are commonly added on silos for lime and other dusty materials.
- Conveyor systems, which are usually enclosed.
- Pipe work and ductwork systems (e.g., pumps, valves, flanges), which are maintained to prevent accidental losses.
- Abatement equipment by-pass, which must be designed to allow for retention of any accidental emissions.
- Accidental loss of containment from failed plant and equipment.
- Oil and ammonia storage tanks, which require appropriate preventative maintenance and other practices to ensure containment.^[64]

Generally the regulation of potential fugitive emissions from a WTE facility is addressed through the approval of the site specific design and operations plans for the facility and the issuance of the required permits for the facility operation, including specific terms and conditions that reflect the requirements for design and operation.

3.1.4 Factors Affecting Airshed Impacts

The addition of a new emission source within an airshed has the potential to impact ambient air quality. The potential impacts are a function of a number of factors:

⁶³ Environmental Agency. 2009. Pollution Inventory Reporting

⁶⁴ Durham/York Residual Waste Study Environmental Assessment, November 27, 2009, Stantec Consulting Limited

- **Discharge Characteristics.** The increase in mass loading to an airshed of contaminants of concern from a new facility has the potential to degrade ambient air quality. The greater the discharge rate, the greater the potential risk. Air pollution control systems are specifically designed to reduce the discharge of these constituents such that the impact is considered to be acceptable. The temperature and velocity of the discharge also can affect the effect on airshed quality. Generally, hotter and higher velocity discharges will disperse further from the point of discharge, effectively reducing ambient concentrations of the constituents of concern. The chemical reactivity of the constituents in the discharge will also determine the fate and behaviour in the ambient air. Stable compounds and small particulate may remain suspended in the airshed for a long time, whereas unstable compounds or large particulate will experience a shorter residence time in the ambient air.
- **Airshed Characteristics.** The dispersion and physical/chemical reactions of constituents are governed by the characteristics of the airshed. Topography, latitude, temperature, prevailing wind direction and pre-existing emissions all affect the dispersion of a discharge, and therefore affect the fate and behaviour of the constituents in the atmosphere. Some airsheds are affected by a combination of factors. For example, the lower Fraser Valley is a complex airshed, with confining mountains forming a basin around the river valley, prevailing winds that transport the air mass up and down the valley, seasonal 'sea breeze' effects that result in a daily reversal of wind direction, and a photochemical sensitivity to NO_x and volatile hydrocarbon emissions that react with sunlight to form elevated concentrations of low level ozone.

Examination of the permitted and actual emissions from WTE facilities (as shown in Table 5-2) that have been recently designed and are operating in a manner consistent with BACT indicates that the concentrations of the constituents of concern (Criteria Air Contaminants, Hazardous Air Pollutants, among other definitions) are quite low and often at least an order of magnitude less than their regulated limits. In comparison to other existing combustion-based industries, WTE facilities typically have lower discharge concentrations of the constituents of concern. While a new WTE facility will add, on a mass basis, additional constituents into the airshed, the increment will in almost all cases be insignificant in terms of overall ambient air quality and increased risk to human health and the environment. The proponents of a new facility have an obligation to demonstrate that this is the case through detailed meteorological and dispersion modeling studies and by quantitative human health and ecological risk assessment (HHERA) studies. One of the more recent examples of such site specific air modeling and HHERA studies undertaken in Canada for a WTE facility, are the recently completed studies for the Durham York Residual Waste EA Study.^[65]

3.2 Liquid Effluents

In addition to emissions to air, some WTE facilities also generate an effluent discharge. Whether or not an effluent discharge is produced depends on the type of APC system used as well as other design parameters.

⁶⁵ Stantec Consulting Limited. 2009. Durham/York Residual Waste Study Environmental Assessment.

Effluent management is more often required for WTE facilities that include wet scrubbers as a component in the APC train, (i.e., facilities with a wet APC train). Facilities that use other alternatives to control acid gases, as discussed in Section 4, generally are designed as zero effluent discharge facilities, and if they are likely to generate any effluent it would typically include storm water and/or sanitary wastewater which can easily be managed by conventional storm water and wastewater control systems.

Water is used at WTE facilities for various processes and effluent may result from any of the following sources.^{[66] [67]}

- APC process wastewater – normally from wet flue gas treatment (dry and semi-dry systems do not typically give rise to any effluent) although not all wet systems produce effluent that needs to be discharged from the facility (discussed further below).
- Wastewater from collection, treatment and (open-air) storage of bottom ash – not usually discharged but used as water supply for wet de-slaggers.
- Other process wastewater streams – e.g., wastewater from the water/steam cycle resulting from the preparation of boiler feed water and from boiler drainage. In many cases this water can be reused in the incineration and APC treatment process as make-up water and does not result in actual discharge from the facility.
- Sanitary wastewater (e.g., toilets and kitchen).
- Stormwater which originates from precipitation falling on surfaces such as roofs, service roads and parking lots and is usually discharged directly to storm sewers, though may receive passive or active treatment if storm water management is in place. Storm water may also be generated at waste unloading areas if these areas are uncovered. Such storm water would usually be segregated from other sources and treated prior to discharge.
- Used cooling water (e.g., cooling water from condenser cooling).

WTE facilities that utilize dry or semi-dry APC systems are often designed with zero wastewater discharge. This is accomplished via the reuse of wastewater produced by a facility. For example, facilities that utilize semi-dry APC systems can reuse boiler blowdown and reject water from the boiler as scrubber slaking and dilution water. As mentioned previously in this report, semi-dry and dry APC systems are the most common type used in North America.

WTE facilities that utilize wet APC systems can also be designed as zero wastewater discharge facilities but require a wastewater treatment system that allows the effluent resulting from the wet scrubbers to be re-used within the facility. The wastewater resulting from wet flue gas treatment

⁶⁶ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste.

⁶⁷ European Commission. 2006. Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration.

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contains a wide variety of contaminants including heavy metals, inorganic salts (sulphates) and organic compounds (including dioxins/furans).^[68]

There are three main alternatives for the treatment or reuse of wastewater from wet flue gas treatment systems:

- **Physical/chemical treatment** – based on pH-correction and sedimentation. With this system a treated wastewater stream containing some dissolved salts must be discharged if not evaporated using one of the following two evaporation processes listed below.
- **In-line evaporation of process wastewater** – by means of a semi-dry system (e.g., for systems that use wet and semi-dry APC systems). In this case the dissolved salts are incorporated into the residue of the APC system. There is no discharge wastewater other than that evaporated with the flue gases.
- **Separate evaporation of wastewater** – the evaporated water is condensed, but can be discharged (or reused) without special measures.

As noted above the physical/chemical treatment and separate evaporation methods may result in a potential effluent discharge from the facility.

Table 3-2 provides an example of the composition of untreated effluent from MSW incinerators that utilize wet flue gas treatment systems. Typical contaminant concentrations following treatment are also indicated.

Table 3-2: Composition of Effluent from MSW Incinerators that Utilize Wet Flue Gas Treatment Systems

Parameter	Units	Average Before Treatment ^[69]	Typical Effluent Discharge Values from Dutch MSW Incinerators (2002) ^[70]	Range of Effluent Discharge Values from Austrian MSW Incinerators (2001) ^[71]
pH	–	–	–	6.8 – 8.5
TOC	mg/l	73,000	–	4.3 – 25
Sulphate	g/l	4,547	–	<1.2
Chloride	g/l	115,000	–	7 – <20
Fluoride	mg/l	25,000	–	<0.006 – <10
As	mg/l	–	0.01	<0.003 – <0.05
Hg	mg/l	6,200	0.005	<0.001 – <0.01
Pb	mg/l	250	0.1	<0.01 – <0.1
Cu	mg/l	100	0.02	<0.05 – <0.3
Zn	mg/l	690	0.2	<0.05 – <0.5

⁶⁸ European Commission. 2006. Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration.

⁶⁹ Draft of a German Report with Basic Information for a BREF-Documents “Waste Incineration”. 2001. German Federal Environmental Agency

⁷⁰ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

⁷¹ Federal Environment Agency – Austria. 2002. State of the Art for Waste Incineration Plants

Parameter	Units	Average Before Treatment ^[69]	Typical Effluent Discharge Values from Dutch MSW Incinerators (2002) ^[70]	Range of Effluent Discharge Values from Austrian MSW Incinerators (2001) ^[71]
Cr	mg/l	170	0.03	<0.05 – <0.1
Ni	mg/l	240	0.03	<0.05 – <0.5
Cd	mg/l	8	0.05	<0.001 – <0.05
Sn	mg/l	–	0.05	0.06
Mo	mg/l	–	1	–
Tl	mg/l	–	–	<0.01 – 0.02
PCDD/PCDF	ng/l	–	1,000	–

NOTES:

(–) means the value is not provided

Refer to Table 3-3 in Section 3.2.4 for an example of BAT discharge limit values for effluent resulting from MSW incinerators.

The following subsections describe each of the three primary wastewater treatment methods in more detail.

3.2.1 Physical/Chemical Treatment

The following figure (Figure 3-1) illustrates a typical configuration of a physical/chemical treatment unit for scrubber wastewater:

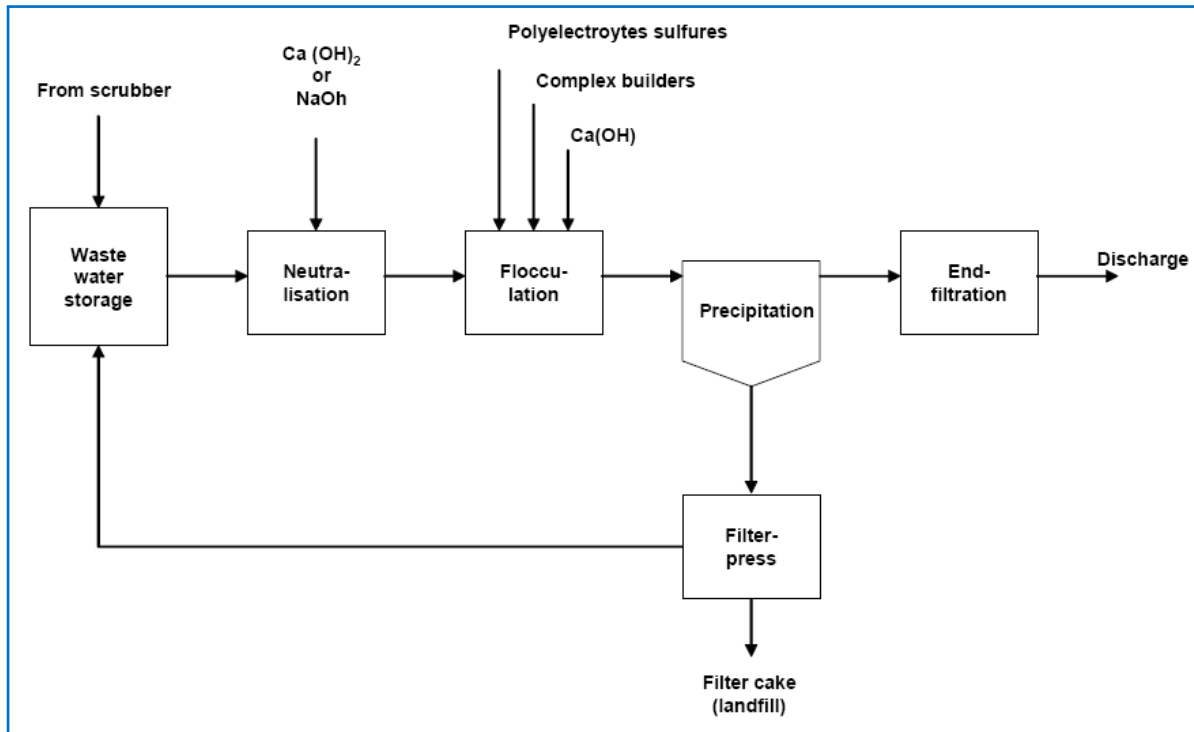
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Figure 3-1: Schematic Illustrating Physical/Chemical Treatment of Wastewater from a Wet APC System^[72]



Source: Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

The process consists of the following steps:

- pH neutralization – normally lime is used resulting in the precipitation of sulphites and sulphates (gypsum)
- Flocculation and precipitation of heavy metals and fluorides – takes place under the influence of flocculation agents (poly-electrolytes) and FeCl_3 ; additional complex builders can be added for the removal of mercury
- Gravitation (precipitation) of the formed sludge – takes place in settling tanks or in lamellar separators
- Dewatering of sludge – normally achieved through dewatering filter presses
- End-filtration of the effluent (polishing) – via sand filters and/or activated carbon filters, removing suspended solids and organics such as dioxins/furans (if activated carbon is used).

⁷² Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste.

In addition to the process steps listed above, facilities may also apply:

- Sulphides for heavy metal removal
- Membrane technologies for removal of salts
- Ammonia stripping (if SNCR is used to control NO_x)
- Separate treatment of wastewater from the first and last steps of the scrubber system (allows for the production of high quality gypsum)
- Anaerobic biological treatment to convert sulphates into elemental sulphur.

3.2.2 In-line Evaporation of Wastewater

With this treatment option, the wastewater is reused in the process line in a spray-dryer. The waste water containing soluble salts is first neutralized and then injected into the flue gas stream. The water evaporates and the remaining salts and other solid pollutants are removed in the dust removal step of the APC train (e.g., bag filter). The neutralization step can be combined with flocculation and the settling of pollutants, resulting in a separate residue (filter cake). In some systems, lime is injected into the spray absorber for gas pre-neutralization.

This method is only employed at facilities that utilize spray-dryers and wet scrubbers. A spray dryer functions in a similar way to a spray adsorber (used in semi-dry APC systems). The main difference between the two is that the spray dryer uses wastewater from the wet scrubber (instead of lime) after the wastewater has been neutralized.

Figure 3-2 presents a schematic overview of in-line evaporation of wastewater.

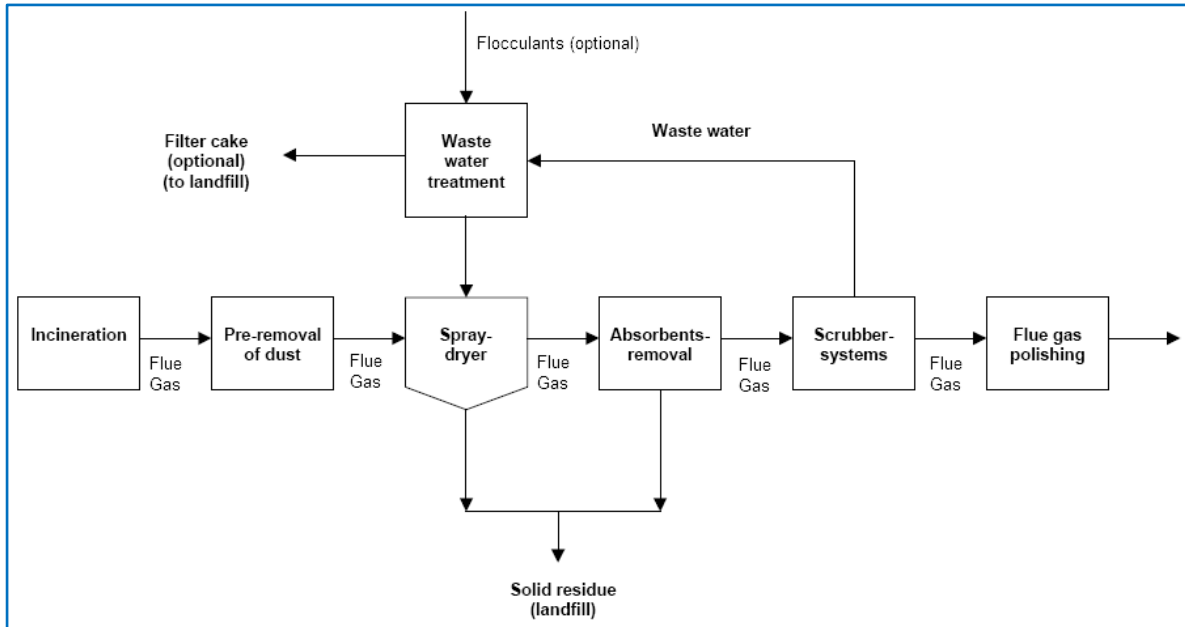
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Figure 3-2: Schematic Illustrating In-line Evaporation of Wastewater^[73]



Source: Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

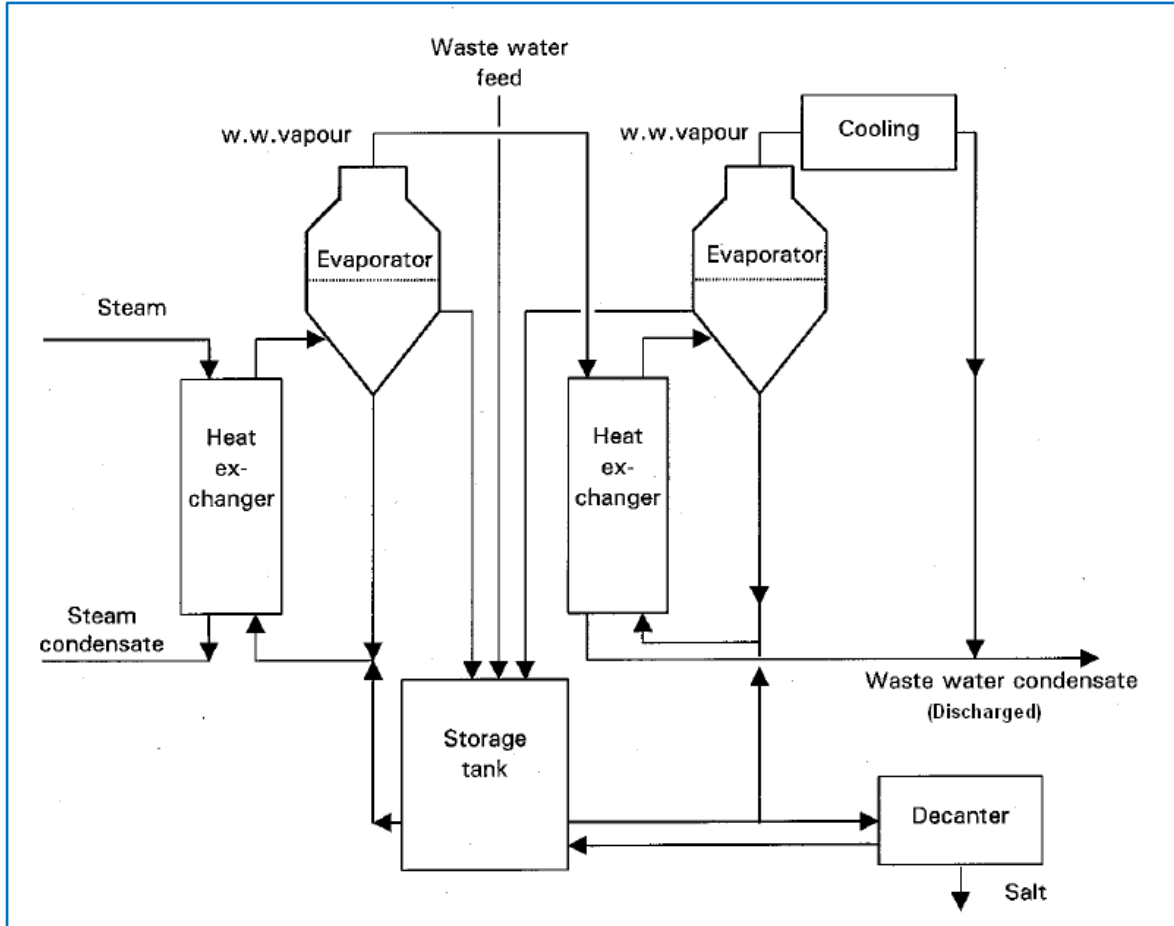
3.2.3 Separate Evaporation of Wastewater

In this process, wastewater is evaporated using a steam heated evaporation system. Wastewater is fed into a storage tank where it is heated (using heat supplied via a heat-exchanger). The heat acts to partially evaporate the liquid out of the storage tank. The un-evaporated liquid flows back to the storage tank while the vapours produced by evaporation eventually cool down resulting in a clean condensate which can be discharged directly from the facility. As evaporation continues the salt concentrations in the liquid rise, resulting in crystallization of the salts which can be separated in a decanter and collected in a container and disposed of in a landfill.

Figure 3-3 displays a two-stage process with two evaporators installed, where the input of heat into the second evaporator is the vapour from the first evaporator (results in less energy demand).

⁷³ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste.

Figure 3-3: Schematic Illustrating Separate Evaporation of Wastewater^[74]



Source: Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

3.2.4 BAT for Effluent Management

As discussed in Section 3.2, effluent management is more often required for WTE facilities that include wet scrubbers as a component in the APC train, (i.e., facilities with a wet APC train).

The following effluent treatment and operational parameters for wet APC systems are considered BAT.^{[75] [76] [77]}

⁷⁴ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

⁷⁵ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on Bat

⁷⁶ Federal Environment Agency – Austria. 2002. State of the Art for Waste Incineration Plants

⁷⁷ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration.

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- The use of onsite physical/chemical treatment of effluent prior to discharge to achieve at the point of discharge from the effluent treatment plant (ETP) effluent concentrations within the range identified in Table 3-3.^[78]
- The separate treatment of the acid and alkaline wastewater streams arising from scrubber stages when there are particular drivers for additional effluent discharge reduction, and/or where HCl and/or gypsum recovery is to be carried out.
- The re-circulation of wet scrubber effluent within the scrubber system so as to reduce scrubber water consumption and in general the re-circulation and re-use of wastewater arising from the site (i.e., using boiler drain water for reuse in the wet scrubber).
- The provision of storage/buffering capacity for effluents to provide for a more stable treatment process.
- The use of sulphides or other mercury binders to reduce mercury in the treated effluent.
- The assessment of dioxin and furan build up in the scrubber and adoption of suitable measures to prevent scrubber breakthrough of these contaminants.
- When SNCR is used the ammonia levels in the effluent may be reduced using ammonia stripping and the recovered ammonia re-circulated for use in the SNCR.

Table 3-3: BAT Associated Operational Emissions Levels for Discharges of Wastewater from Effluent Treatment Plants Receiving APC Scrubber Effluent^[79]

Parameter	BAT Range in mg/L (unless stated)	Sampling and Data Information
Total Suspended Solids	10 – 30 (95%) 10 – 45 (100%)	Based on 'spot daily' or 24 hour flow proportional sample
Chemical Oxygen Demand	50 – 250	Based on 'spot daily' or 24 hour flow proportional sample
pH	6.5 – 11	Continuous measurement
Hg and its compounds	0.001 – 0.03	Based on monthly measurements of a flow proportional representative sample of the discharge over a period of 24 hours with one measurement per year exceeding the values given, or no more than 5% where more than 20 samples are assessed per year.
Cd and its compounds	0.01 – 0.05	
Tl and its compounds	0.01 – 0.05	
As and its compounds	0.01 – 0.15	
Pb and its compounds	0.01 – 0.1	Total Cr levels below 0.2 mg/L provide for control of Chromium VI.
Cr and its compounds	0.01 – 0.5	Sb, Mn, V and Sn are not included in Directive 2000/76. Average of six monthly measurements of a flow proportional representative sample of the discharge over a period of 24 hours.
Cu and its compounds	0.01 – 0.5	
Ni and its compounds	0.01 – 0.5	
Zn and its compounds	0.01 – 1.0	

⁷⁸ European Commission. 2006. Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration.

⁷⁹ European Commission. 2006. Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration.

Parameter	BAT Range in mg/L (unless stated)	Sampling and Data Information
Sb and its compounds	0.05 – 0.85	
Co and its compounds	0.005 – 0.05	
Mn and its compounds	0.02 – 0.2	
V and its compounds	0.03 – 0.5	
Sn and its compounds	0.02 – 0.5	
PCDD/F (TEQ)	0.01 – 0.1 ng TEQ/L	

NOTES:

1. Values are expressed in mass concentrations for unfiltered samples
2. Values relate to the discharge of treated scrubber effluents without dilution
3. BAT ranges are not the same as ELVs
4. pH is an important parameter for wastewater treatment process control
5. Confidence levels decrease as measured concentrations decrease towards lower detection levels

SPLIT VIEWS:

1. BAT 48: One Member State and the Environmental NGO expressed split views regarding the BAT ranges. These split views were based upon their knowledge of the performance of a number of existing installations, and their interpretation of data provided by the thematic working group (TWG) and also of that included in the BREF document. The final outcome of the TWG meeting was the ranges shown in the table above but with the following split views recorded: Hg 0.001 – 0.01 mg/l; Cd 0.001 – 0.05 mg/l; As 0.003 – 0.05 mg/l; Sb 0.005 – 0.1 mg/l; V 0.01 – 0.1 mg/l; PCDD/F <0.01 – 0.1 ng TEQ/l.
2. BAT 48: Based on the same rationale, the Environmental NGO also registered the following split views: Cd 0.001 – 0.02 mg/l; TI 0.001 – 0.03 mg/l; Cr 0.003 – 0.02 mg/l; Cu 0.003 – 0.3 mg/l; Ni 0.003 – 0.2 mg/l; Zn 0.01 – 0.05 mg/l; PCDD/F <0.01 ng TEQ/l.

As discussed previously in Section 3.2, not all WTE facilities that utilize Wet APC systems actually produce effluent discharge. Refer to Section 3.2.2 and 3.2.3 for a full description of these techniques.

3.3 Solid Wastes

Waste incineration leads to weight and volume reduction of wastes. The solid wastes generated by WTE facilities will vary based on the design of the plant, and can consist of: reject wastes (removed prior to combustion), bottom ash, metallic scrap, APC residues, slag (depending on the facility design), filter cake from wastewater treatment, gypsum and loaded activated carbon. These material streams are discussed briefly below.

3.3.1 Reject Waste

The MSW stream commonly includes various materials that should not enter the combustion chamber either as they will not efficiently combust due to their size and composition (e.g., metal appliances) or as they could cause damage within the combustion unit (e.g., propane tank). Depending on the design of the WTE facility, there will be a specified range of materials that will be identified as unacceptable for combustion. Generally, screening and removal of these materials will take place on the floor of the reception building as each load of material is emptied onto the tipping floor/bunker. In addition, operators who manage the loading of the combustion chambers also remove certain materials when they are observed in the loading process. Generally, approximately

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2% of the waste received at a WTE will be rejected and removed for alternate disposal. In addition, depending on the length of the scheduled or unscheduled down-time associated with plant maintenance, it is possible MSW would have to be redirected to alternate disposal.

3.3.2 Bottom Ash

Bottom ash is the mineral material left after the combustion of the waste. Bottom ash is a heterogeneous mixture of slag, metals, ceramics, glass, unburned organic matter and other non-combustible inorganic materials, and consists mainly of silicates, oxides and carbonates. Typically, bottom ash makes up approximately 20 – 25% by weight or 5 to 10% by volume of the original waste.^[80] At most incineration facilities, bottom ash is mechanically collected, cooled and magnetically or electrically screened to recover recyclable metals. The remaining residue is either disposed of at a landfill, or alternatively, it may be used as a construction aggregate substitute.^[81] Further information is presented in Section 9.1.1 and 9.3. In some cases (e.g., gasification) the mineral material left after combustion of the waste is generated as a slag, but is generally managed in a similar fashion as bottom ash.

3.3.3 Recycling of Metals

Most WTE facilities include equipment to remove ferrous metals from the bottom ash. Recovery of non-ferrous metals (primarily aluminum) has also become more common. Depending on the composition of the incoming MSW stream, recovered metals can represent up to 10% of the input tonnage to the WTE facility. Generally, WTE facilities can recover approximately 80% of ferrous and 60% of non-ferrous metals present in the bottom ash. Separated metallic scrap is either delivered to a scrap dealer or returned to the steel industry.

3.3.4 Primary APC Residues

APC residues are the residues resulting from the APC system and other parts of incinerators where flue gas passes (i.e., superheater, economizer). APC residues are usually a mixture of lime, fly ash and carbon and are normally removed from the emission gases in a fabric filter baghouse.

APC residues contain high levels of soluble salts, particularly chlorides, heavy metals such as cadmium, lead, copper and zinc, and trace levels of dioxins and furans. The high levels of soluble, and therefore leachable, chlorides primarily originate from polyvinyl chloride (PVC) found in MSW. Typically, APC residues make up approximately 2 – 4% by weight of the original waste.^[82] Generally APC residues are managed separately from bottom ash as they are often classified as a hazardous waste. Common practice for APC residue management is to stabilize or otherwise treat these

⁸⁰ AECOM Canada Ltd. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling. June, 2009.

⁸¹ AECOM Canada Ltd. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling. June, 2009.

⁸² Algonquin Power Energy from Waste Facility Fact Sheet, <http://www.peelregion.ca/pw/waste/facilities/algonquin-power.htm#ash>

residues and/or to dispose of them at a hazardous waste facility. Methods of managing these residues are discussed in Sections 9.1.2 and 9.3.

3.3.5 Other APC Residues

Other residues generated by APC systems generally consist of used reagent materials (e.g., activated carbon) or residues recovered through effluent treatment. The generation of these other APC residues is dependent on the APC design. In general, the filter cake from wastewater treatment is heavily charged with Hg, Zn and Cd. In most cases it must be managed as a hazardous waste and treated or disposed of at secure hazardous waste facilities. For WTE facilities that use activated carbon in their APC train, it has become more common to combust the loaded activated carbon together with waste.

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Final Report

Section 3: Potential Discharges from Thermal Treatment

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