An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)

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1.0 Introduction

In accordance with growing concern over the treatment of solid waste and the search for renewable energy, Energy From Waste (EFW) practices are becoming more prominent in the field of waste treatment today. Most commonly, and traditionally, EFW involves the incineration of waste and capture of the energy released. This practice decreases both the amount of solid waste that communities must deal with and reliance on non-renewable energy sources. Incineration, however, faces criticism regarding the pollution that it creates, particularly the pollution resulting from exhaust gases that are by-products of the process. Whether incineration is a viable option for the generation of power and the treatment of solid waste may depend on whether the process is environmentally sound or not. Certainly, past experience has made evident a number of issues, but recently developments in the field of air pollution control have made incineration a much more attractive option, environmentally, for waste treatment. It has been said that due to present day emission treatment practices, the emissions from some incinerators can be cleaner than the ambient air (Dodds). These emission treatment developments will be discussed in detail in these pages, as will incinerator emissions, the political scene surrounding incineration, and the technical aspects of incinerators.

Canada, U.S.A., and the European Union, including U.K., France, Germany, and the Netherlands, are among the organizations most heavily involved in waste incineration. Each country has different ideas about what levels of emissions from incinerators are acceptable, and the political climate affecting incineration is different in each area. These regions will be the focus of this report's examination of incineration and its environmental suitability.

Incineration is not the only EFW technology and, as alternative Energy from Waste methods undergo more research and become more accepted, they may take the place of incineration. These new technologies will be briefly described in these pages as well, and their advantages and disadvantages as compared to incineration will be discussed.

2.0 Environmental Regulations Regarding Incineration

The focus of most environmental regulations regarding incinerators is on the gaseous emissions arising from an incinerator. While each region studied has its own standards for air quality, there are also regulations specifically dealing with incinerator emissions. The emissions resulting from the burning of MSW (Municipal Solid Waste) can contain various hazardous substances such as mercury and other toxic metals, particulate matter (PM), hydrogen chloride, chlorine gas, undesirable hydrocarbons (VOCs), and, most notoriously, dioxins and furans (Fed. Reg. V.69, N.26 p.21210). Due to the potential release of these and other substances, incinerator emissions must be monitored and cleaned to ensure that the levels of toxic chemicals being released from their stacks is not of a degree that could cause significant harm.

2.1 Incinerator Emission Regulations in Canada

Canada has not put numerical limits on the levels of pollutants that an incinerator is allowed to emit into federal law. There are federal guidelines, not laws, which give a basis for acceptable levels of emissions from polluting sites (CCME). These guidelines come from The Canadian Council of Ministers of the Environment (CCME) which is a council of all of the provincial Ministers of the environment. Some of the guidelines set by the CCME have been published in papers and have been tabulated here.

Table 2-1: CCME Guidelines for Hazardous Substance Emission from Incinerators (CCME)

Substance	Acceptable Emission Level
Dioxins and Furans	80 pg TEQ/Rm^3 †
Mercury	20 μg/ Rm^3
PM2.5‡	30 μg/ Rm^3 *
Ozone (O_3)	65 ppb*

†For further explanation on g TEQ/Rm^3 see section 3.0 on dioxins and furans and Appendix A on units.
‡Particulate Matter that is airborne and has a diameter of 2.5 microns or less
*This guideline is not yet in place, but slated for implementation in 2010

In the past incineration has been a significant contributor to the total amount of dioxins and furans in Canada. It traditionally contributes 22.5% of the total dioxins and furans release from stacks, creating a total of 44.9 g 1-TEQ/Rm^3 (CCME). Municipal waste incinerators are responsible for 8.4 g/yr of this (CCME). It is due to this record and various other factors that limits on dioxins and furans have been set in place.

Incineration has also been a source of significant levels of mercury in Canadian emissions (CCME). It is estimated that incinerators emit 446 kg/yr of mercury (CCME) making the limitation of mercury from incinerators quite important. Mercury emissions are being reduced now not only as a result of limiting guidelines, but also due to the reduction of mercury content in commercial products (CCME).

Air pollution from incinerators comes in many forms not included in the above table. In addition to the pollutants tabulated above, incinerators are sources of Volatile Organic Compounds (e.g. methane, CFCs); air toxics; particulate matter of varying particle diameters; metals including antimony, cadmium, arsenic, barium, beryllium, titanium, chromium, lead, and manganese; phosphorous; hydrogen chloride; carbon monoxide; and oxides of sulfur and nitrogen (SASK). Algonquin Power, the owner of the Peel Region incinerator in Ontario, has stated that its major concern related to emissions are the particulate matter emissions and nitrogen and sulfur oxides (Dodds).

The CCME does not impose its guidelines on any jurisdiction and actually has no authority to do so (CCME). Each Province or Territory decides on the degree to which it will incorporate the CCME suggested pollution limitations into law (CCME). Provinces and Territories also have environmental legislation that comes from within and not from federal influences as Canadian Provinces and Territories are responsible for their own environmental legislation. The regulations dealing with the pollutants that can come from incineration but are not in Table 2-1 likely have their origins in Provincial legislation. This results in a variation of environmental standards across the country from province to province. Once a province sets its standards and methods of enforcement its greatest tool for keeping track of and minimizing pollution is the “Certificate of Approval” (ON-MOE). The certificate of approval is a requirement for any operation that is likely to cause pollution. In Ontario the certificates apply to facilities that "release emissions into the atmosphere, discharge contaminants to ground and surface water, provide potable water supplies or store, transport, process or dispose of waste" (ON-MOE). Incinerators are involved in both the release of emissions and the processing of waste, making a certificate of approval particularly applicable. The acceptable levels of pollution for a facility, the types of pollution allowed, and site specific considerations are all included in a facility's certificate of approval (ON-MOE). Once the terms of the permit are reached they are enforceable by law and there are penalties for non-compliance (LFEG). Like the regulations, the penalties vary according to province. Recently the Ontario government made a move toward stricter penalties for polluters, with legislation pending that would introduce a fine of $20,000 for an individual and $100,000 for each day of unlawful spills or emissions (ON-MOE). Such legislation would place Ontario's penal system for environmental offenders among the most strict in Canada.

The monitoring of incinerators is an aspect of emission regulation just as important as deciding which pollutants will be monitored and what pollutant levels are acceptable. In Canada the minimum requirement is that an incinerator's stack emissions be tested annually (CCME). If an incinerator's tests are consistently good then the frequency of tests can be diminished (CCME). There is no reason, however, that an incinerator cannot be tested more rigorously and more frequently, or that a province could not create legislation to make stringent testing mandatory. The Algonquin Power EFW incinerator has its stacks continually monitored and the results are reported to the Ontario Ministry of the Environment (Peel). The plant also hires independent consultants to perform stack tests to ensure the reliability of their information (Gee). Every three months the emission results are discussed by the community surrounding the Peel incinerator in public liaison meetings (Peel). In addition to concern over meeting legal requirements, Algonquin Power's desire to retain a high public opinion for the incinerator is a motivation for strict monitoring.

It is difficult to assess Canada's performance in the field of incineration emission control on a national level. Legislation and penalties vary from province to province, creating a different situation for incineration depending on location. The national guidelines set by the CCME are strict in comparison to laws and guidelines set by other countries on similar pollutants, but guidelines do not exist for many of the substances emitted during incineration. There is public pressure on facilities to meet the CCME's guidelines as well as the limits set by the provinces and in some cases this pressure will keep a facility well below dangerous levels of pollution. Facilities, especially incinerators, will often hold public opinion of their operation in high regard and this will keep them in check. Still, without legal requirements, there is no way to ensure that incinerators are being built and operated safely. Most provinces have adequate systems for keeping emissions in check, such as Alberta's continuous emissions monitoring requirements, and are able to provide legal assurances that incinerators are working within set limits (AB-ENV). While the picture for Canadian incinerators does change from province to province, the CCME helps the nation reach a fairly strict consensus on air pollution. Canada treats incineration seriously and is taking reasonable steps to ensure that incinerators cause a reasonably low level of harm to the environment.

2.2 Incinerator Emission Regulations in the United States

The United States Environmental Protection Agency has put clear and relatively strict limits on the acceptable emission levels for many air pollutants. These limits encompass most of the prominent pollutants that are products of incineration and limit their emissions significantly.

Table 2-2: US EPA Rules for Hazardous Substance Emission from Incinerators (Fed. Reg. Vol. 60 #243 and Vol. 63 #164)

Substance	Acceptable Emission Level
Dioxins and Furans	**13 ng/dscm**
PM (Particulate Matter)	**24 mg/dscm**
Lead	**0.44 mg/dscm**
Cadmium	**0.02 mg/dscm**
Mercury	**0.08 mg/dscm**
Sulfur Dioxides	**29ppmv**
Nitrogen Oxides	**180 ppmv**
Hydrogen Chloride	**29 ppmv**

The US EPA also requires a continuous emission monitoring to ensure that these limits are not exceeded. The reporting on these tests is done on an annual basis.

The existence of legislated standards at the federal level is an advantage that the American system has over the Canadian one. It ensures a standard below which no state can fall. Mandatory continuous monitoring is also an advantage over the Canadian system as it will result in data more indicative of the real situation than annual testing. The system set out by the US EPA is clearly defined and appears to be well enforced.

2.3 Incinerator Emission Regulations in the European Union

The European Union has created a standard for incineration emissions that all of its member countries must adhere to and incorporate into law. This is not to say that member countries cannot have stricter standards, but the ones laid out by the EU are a minimum for each country. EU has also set standards for discharged waste water that has been used in emission cleaning. Also, the emission limits are categorized by energy output of the plant and the fuel being burned.

Table 2-3: European Union Limits for Hazardous Substance Emission from EFW Incinerators Burning Solid Fuels(COEC)

All values in mg/Nm^3	**Plant Output**		
Pollutant	**50-100 MWth**	**100-300 MWth**	**>300 MWth**
SO_2	850 or rate of desulfurization >90%	850 to 200 (linear decrease for 100 to 300 MWth) or rate of desulfurization >92%	200 or rate of desulfurization >95%
NO_x	400	300	200
Dust	50	30	30

Table 2-4: European Union Limits for Hazardous Substance Emission from EFW Incinerators Burning Biomass (COEC)

All values in mg/Nm^3	Plant Output		
Pollutant	**50-100 MWth**	**100-300 MWth**	**>300 MWth**
SO_2	200	200	200
NO_x	350	300	300
Dust	50	30	30

Table 2-5: European Union Limits for Hazardous Substance Emission from EFW Incinerators Burning Liquid Fuels (COEC)

All values in mg/Nm^3	Plant Output		
Pollutant	**50-100 MWth**	**100-300 MWth**	**>300 MWth**
SO_2	850	850 to 200 (linear decrease from 100 to 300 MWth)	200
NO_x	400	300	200
Dust	50	30	30

Table 2-6: European Union Limits for Hazardous Substance Emission from EFW Incinerators Burning Solid, Liquid or Biomass Fuels (COEC)

Pollutant	Limit (mg/Nm3 except dioxins/furans in ng/Nm3)
Cd+Tl	0.05
Mercury	0.05
Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V	0.05
Dioxins and Furans	0.1

Table 2-7: European Union Limits for Liquid Effluent Discharge Used in the Cleaning of Gaseous Emissions (COEC)

Pollutant	Emission Limit Value Expressed in Mass Concentration
Total Suspended Solids	20 mg/L
Mercury and its compounds	0.5 mg/L
Tl+Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V	5 mg/L
Dioxins and Furans TEQ*	0.5 ng/L

*TEQ discuss in section 3.0 on Dioxins and Furans

These standards are explicitly stated and are enforced by the member country.

2.4 Incinerator Emission Regulations in the United Kingdom

The United Kingdom, like any European Union member, must have incorporated the EU standards not long after they were put in place. The standards in the UK were not as strict as those outlined by the EU so when the EU directives were incorporated into UK law they superceded the old UK legislation (E-A, UK). Emission levels are left up to the plant operators to report and thus breaches of the standards may easily go unnoticed (Lulofs). More about the compliance of the UK with the EU directives will be discussed in section 3.

2.5 Incinerator Emission Regulations in France

Like the UK, France had legislation in place regarding the gaseous emissions of EFW incinerators before the EU directives had to be incorporated into law, but it was weaker legislation and was replaced by the EU guidelines (Lulofs). French legislation does include areas that the EU directives do not touch on, however. These areas cover solid residue (like slag and ash) and noise pollution (Lulofs).

2.6 Incinerator Emission Regulations in Germany

When the EU directives were required to be incorporated into German law there was little change that needed to be made. Germany already had, and still has a system of emission standards that are stricter than the EU directives (Lulofs). German engineers are at the forefront of both incineration technology and pollution abatement technology as it relates to incinerators (Lulofs). It is thus very easy for Germany to set and meet high standards of emission quality. All incinerators in Germany are required to be equipped with a computer system that automatically records emission levels (Lolofs). The computers send a message to the supervising authority every day detailing the emission characteristics and a special message is sent if any pollutant levels have exceeded the standards (Lulofs). The German system is one of the best reviewed in this paper.

2.7 Incinerator Emission Regulations in the Netherlands

The Netherlands had a system comparable in terms of its strictness to Germany's in the early nineties but still had a hard time incorporating the EU directives into law (Lulofs). While their standards were high (even to the point of placing limits on dioxins and furans prior to the Germans) they were only guidelines, not laws. Once made into law the Netherlands regulations were in fact stricter than the EU guidelines (Lulofs). This provided many incinerator owners with operating issues, but these were, over time, resolved. As in Germany, emissions are monitored and reported via a computer system.

3.0 Dioxins and Furans

One of the most contentious points about incineration is the emission and creation of chlorodibenzodioxins and chlorodibenzofurans, or dioxins and furans, during the waste burning process. Dioxins and furans are bioaccumulative, meaning that once they find their way into the food chain they very rarely leave it. They are extremely persistent and can cause cancer and birth defects. Dioxins and furans come in many forms and, in an attempt to standardize measurements of their effects, a system of toxicity equivalence has been devised. Each variation of dioxin and furan is assigned a toxicity factor which multiplies the mass of the dioxin or furan to give a toxicity equivalent (TEQ) mass. For example, 2 grams of a dioxin with a toxicity equivalence factor of 0.5 would only be 1 g TEQ. (2*0.5 = 1). Similarly 2 grams of a dioxin with a toxicity equivalence of 0.1 would only be .2 g TEQ. (2*0.1=0.2)

Table 3-1: Various Dioxins and Furans and Their TEQ Factors (COEC)

Chemical	TEQ Factor
2,3,7,8-Tetrachlorodibenzodioxin	1
1,2,3,7,8-Pentachlorodibenzodioxin	0.5
1,2,3,4,7,8-Hexachlorodibenzodioxin	0.1
1,2,3,6,7,8-Hexachlorodibenzodioxin	0.1
1,2,3,4,6,7,8-Hexachlorodibenzodioxin	0.1
Octachlorodibenzodioxin	0.001
2,3,7,8-Tetrachlorodibenzofuran	0.1

2,3,4,7,8-Pentachlorodibenzofuran	0.5
1,2,3,7,8-Pentachlorodibenzofuran	0.05
1,2,3,4,7,8-Hexachlorodibenzofuran	0.1
1,2,3,6,7,8-Hexachlorodibenzofuran	0.1
1,2,3,7,8,9-Hexachlorodibenzofuran	0.1
2,3,4,6,7,8-Hexachlorodibenzofuran	0.1
1,2,3,4,6,7,8-Heptachlorodibenzofuran	0.01
1,2,3,4,7,8,9-Heptachlorodibenzofuran	0.01
Octachlorodibenzofuran	0.001

Staunch opponents of incineration will often make statements implying that the creation of previously non-existent toxic chemicals means that incineration should not ever take place (GREEN). While they may have valid arguments, the mainly qualitative claims made by these opponents seem not to take into consideration present day emissions cleaning technology. As well, the elimination of all technologies that are sources of dioxins and furans would be the end of combustion powered motor vehicles and power generators, fireworks, crematoriums, the production of many types of metals, and the burning of wood. The dioxin issue is rarely put in proper context, as will be done here.

A study of the Johnston Island incinerator showed that it was emitting 22.9 pg TEQ/second (Rogers). A diesel truck travelling at an average speed of 40 miles/hour with equal amounts of uphill and downhill driving emits 89 pg TEQ/second (Rogers). Considering that one truck creates 4 times as much dioxins and furans than an incinerator and that the ratio of trucks to incinerators in likely somewhere in the ten thousands, worrying about dioxins and furans from incineration would seem to indicate selective arguments.

Cigarettes are another major source of dioxins and furans. The mainstream (inhaled) smoke from one cigarette contains 1 pg TEQ of dioxins and furans (Rogers). If one were to stay in the same atmospheric conditions that exist at ground level near the Johnston Island incinerator (with a dioxin/furan content of $2.04*10^{-4}$ pg/m^3) for one year one would suffer the same health effects as if one smoked 1.7 to 17 cigarettes a year (Rogers).

However, inhalation only accounts for 2% of human exposure to dioxins and furans (POST). Dioxins and furans, once emitted from a source, settle in soil, crops and grazing land to be taken up by plants and animals (POST). They are also washed off of land into bodies of water where they enter the bodies of fish and other aquatic life forms (POST). In these ways dioxins and furans enter the food chain, the source of the other 98% of human exposure to dioxins (POST). It can be seen from this that it is not the inhalation of dioxins and furans that must be limited, but their introduction to the food chain.

The Johnston Island example is not meant to detract from the serious nature of dioxins and furans. While it may show that risk of exposure is small, the fact remains that dioxins and furans are carcinogenic. They can also be related to reproductive problems and other difficulties (ENERGIE).

There are studies that raise concern about the risks of dioxin exposure in unborn babies. While adults may find the dioxins they inhale in cigarettes and the atmosphere to be negligible, there is some evidence that dioxins, like many other toxic substances, affect babies to a far more pronounced degree than they do adults. Dioxins and furans transmitted to fetuses through the placenta have been linked to developmental impediments that cause birth defects and lowered intelligence in babies (GASCAPE). Dioxins and furans are certainly not to be taken lightly and more information on their effects needs to be gathered.

The impact of the dioxins and furans introduced to the food chain would be acceptable in any of the three following scenarios. The first scenario involves completely preventing with one-hundred percent certainty the introduction of incineration related dioxins and furans to the food chain. The second would be one in which an acceptable level of introducing dioxins and furans to the food chain would be determined and assurances that incineration did not exceed that level would be developed. In the third scenario it would be proven that some level of EFW incineration would result in a lower level of dioxins and furans in the food chain than what would result from competing waste management practices.

The first scenario is unlikely to be realized. While pollution abatement is a rapidly advancing technology it seems unlikely that dioxins and furans could be captured by any type of filter or scrubber down to the last molecule. It is possible that they could be contained with such an efficiency that it might be said that nothing is escaping, but when dioxin emissions are already measured in nanograms it would be a serious undertaking to improve dioxin capture to a greater resolution.

An acceptable level of the introduction of dioxins and furans to the food chain could be, and in present practice is, determined and applied. This level must then be adhered to by EFW incinerators. While governments and incinerator operators find this scenario sufficient in the present, it is unlikely that a “low level of introduction” system would be accepted by all elements of society. The critical issue with this scenario is the bioaccumulative nature of dioxins and furans. Emitting very low levels of dioxins and furans over a very large time span will not result in an equilibrium in which the dioxin content in the food chain will level out, but will lead to an ever increasing amount of dioxins in nature. This is a great source of worry for some and something that will (and does) create difficulties for the “minimal acceptable levels” scenario.

The final scenario is the most realistically acceptable and it is realistic to assume that it can be achieved. While the incineration of waste may create and introduce into the food chain a certain mass of dioxins and furans it is easily imaginable that under certain conditions other means of waste management would create more dioxins and furans. Trucks and other vehicles transporting waste to landfills and recycling plants emit dioxins and furans as do some of the mechanisms that drive landfill organization and recycling processes. Waste management could be arranged such that the total of the dioxins and furans resulting from incineration would be less than the sum of the dioxins and furans resulting from the transporting of waste to recycling centers and landfills. As well, controlling dioxins and furans coming from combustion is much easier to implement if a great proportion of them are coming from one source (e.g. an incinerator) rather than thousands of tiny point sources (e.g. trucks and diesel generators). The claim that incineration should be banned based on its dioxin and furan emissions is worse than useless unless some alternative practice that is less detrimental can be proposed. It is a simple truth that waste must be dealt with in some way and this truth makes the production of dioxins and furans during the waste treatment process a problem of minimization, not elimination. If incineration will result in less dioxins in the food chain than landfilling, recycling or any other known method then, all else being equal, incineration is what should be done. Of course, there are those who would argue for a zero waste society, a kind of utopia where no waste would be created and no dioxins would be created treating waste, but even if that goal is realistic it will not come about instantaneously. We cannot simply decide to wake up tomorrow in a zero waste world. In present society, or even a society treating waste while moving toward a zero waste system, incineration is a tool that can be used in combination with other waste treatment methods to not only minimize the solid volume of waste, not only to generate useful electricity, but to minimize the amount of dioxins and furans entering Earth's food chain.

While dioxins and furans are capable of doing serious damage to human health, animals and plant life, careful study is required for each incinerator, given its abatement equipment, temperature of operation, residence time of waste in the incinerator, and a host of other factors to determine whether dioxins and furans are actually being emitted at a harmful rate. This study must then be placed into an overview of an area's waste treatment system and used such that the system as a whole minimizes the production of dioxins and furans, as well as other environmental hazards. Failure to treat dioxins and furans with the utmost concern could have disastrous effects, but their existence and nature should not preclude the use of EFW incinerators.

4.0 The Political Situation of EFW Incinerators

As important as the scientific and environmental aspects of incineration is the political aspect. Public acceptance for incinerators is particularly relevant, as it would be difficult for elected politicians to allow incinerator operation without public support. Legislation related to incineration and pollutants are also a major factor in the future of EFW incineration. Any of these political factors could ensure the success of EFW incineration or endanger its future.

4.1 The Global Anti-Incineration Movement and Public Worries About EFW

Groups such as Greenpeace, Friends of the Earth, and the Global Anti-Incineration Alliance are very much against incineration and do what they can to prevent systems being constructed. These groups make such statements as(GREEN):

- incinerators are the number one source of dioxins and furans worldwide,

-incinerators create toxic substances that are not in waste to begin with, and

-even state-of-the-art incinerators will pollute

However, statements like these from anti-incineration groups characteristically lack quantitative context. Incinerators may be the number one source of dioxins and furans in the world, but this statistic would take into account incineration going on in areas where no thought is given to pollution control and does not give a clear definition of what an “incinerator” is. Clearly, no one is advocating incineration without pollution control, and anything from a bonfire to an internal combustion engine could be considered an incinerator, which would dramatically increase the amount of dioxins that “incinerators” are producing.

Incinerators do created toxics that would not otherwise exist, but again, sophisticated pollution controls keep these toxics at a level where the benefits of incineration may far outweigh the harm these toxics do. State-of-the-Art incinerators do pollute, but they have environmental benefits as well, which, it could easily be argued, have more of an impact than the pollutants that are their by-products. In fact, research by the NSCA (National Society for Clean Air and Environmental Protection) has suggested that not only will emissions from EFW incinerators be dwarfed by local traffic pollution, but that, if built to modern standards, an incinerator’s health impacts will be undetectable (NSCA). The arguments made by anti-incineration groups seem to be less like legitimate complaints and more like rhetoric used to build support for the anti-incineration movement. Were these arguments to be put into context using quantitative information, there might be more acceptance of incineration.

Irrespective of the validity of the arguments on either side of the incineration debate, the existence and activities of anti-incineration groups create an atmosphere of doubt on the practice of incineration. This doubt causes a wariness in the public regarding incineration and a lack of acceptance which can make for difficulties in the political future of EFW incineration. Politically, public acceptance is the key issue for the incineration of waste and it may be that no amount of scientific data will be sufficient to sway the public to incineration's side.

4.2 The Effects of Incineration on Recycling Practices

Co-existing Recycling and Incineration

In addition to the arguments against incineration on the basis of the pollution it causes, anti-incineration groups and individuals will often make claims concerning the social implications incineration will have in the area of waste management. Most significantly, it is postulated that people will cease to recycle if incineration is sanctioned and practiced. The opponents of incineration are afraid that incineration will be seen as another form of recycling (which it clearly is not), and that many resources that could be recovered will be burned. Another fear is that an incineration industry would be a strong voice sounding against the reduction of waste production. In fact, incineration could easily coexist with recycling. Incineration is offered as an alternative to landfills and similar practices that would not be appropriate for recyclable materials. One British municipal council has found that:

> Experience in a number of other European countries shows that EfW incineration underpins schemes with high recycling rates. EfW gives the opportunity to recover value (energy) from waste which cannot be recycled, provides an opportunity for the recycling of bottom ash (thus contributing to a more sustainable use of aggregates), and provides a treatment option for recyclable waste when markets for recyclables are poor (Tunnard).

A report on the waste management trends in Europe found that:

> Those countries with the highest recycling rates that have successfully countered waste growth through enhanced recycling and composting have benefited from a rapid development of the required infrastructure, complimented by a parallel growth in EfW (Energy from Waste) capacity (Crichton).

The same report collected data presented in the following table.

Table 4-1: Distribution of Waste Treatment by % of Waste (Crichton)

Country	Energy recovery	Recycled	Landfilled	Composted
Denmark	58	29	11	2
Switzerland	45	31	13	11
Netherlands	42	39	12	7
France	39	6	49	6
Sweden	36	26	30	8
Germany	18	38	34	10

Austria	17	34	35	14
Norway	15	22	62	1
UK	8	8	83	1
Italy	7	3	80	10
Spain	6	3	74	17

Shown in Table 4-1 is the correlation between EFW incineration (as most present EFW technology is mass burn incineration) and recycling. Among the 7 countries with the highest EFW incineration percentage are the 6 countries with the highest recycling rate, with France being the anomaly. The 3 countries with the lowest percentage of waste incinerated are among those countries that recycle the least. The data in this table shows that often EFW incineration and recycling go hand in hand and that it is clearly not the case that the implementation of EFW programmes will lead to the elimination or a reduction in efficiency of recycling programmes.

Calorific Value for EFW and Recyclable Material

The calorific value of waste is an issue where the economics of incineration (from the viewpoint of an incinerator operator) may be seen to be politically at odds with the ecology of incineration. The chemical energy readily available to EFW technology within waste is referred to as the "calorific value," and this value has a sizable impact on the economics of EFW. The higher the calorific value of waste being incinerated, the more energy can be generated per unit of energy put into the incineration process. High calorific values increase system efficiencies, and help incinerators continue to operate thereby directly increasing revenues for EFW operators.

There is a side concern here related to the calorific value of waste. The concern is that waste that has recyclables of high calorific values removed from it will not have a calorific value high enough to promote the continuation of the combustion reaction within an incinerator. A report on EFW acceptability in Europe, however, included research that indicated that the calorific value of waste only increases with source separation (ENERGIE). This means that the more homogeneous a waste stream is the better calorific value it has. In sorting recyclable material from non-recyclables the calorific value of both the recyclables and non-recyclables are improved. This is not to say that the amount of energy within the waste is increased by sorting, just that the energy will make itself available for the instigation of further combustion more readily. The concern over recycling decreasing the calorific value of waste is not valid (ENERGIE). Recycling is still an economic concern for incinerator operators, however, for the reasons discussed in the previous paragraph.

Examining the economic aspects of the issue, an incinerator operator would not want to see the end of recycling. Some materials, such as metals, actually decrease the heating value of waste and incinerators would run more efficiently if more of these materials were recycled rather than sent to be incinerated (Dodds). Other recyclable material, however, would increase an incinerator's efficiency. In particular, rubber and plastic material can contribute to a much higher return on energy invested (ENER-G). From a purely economic standpoint, would be better for an incineration operation to burn these recyclable materials.

From an ecological standpoint, incinerating recyclable materials is poor practice. While the incinerator operator will see short term profit, society and the environment will have to provide the resources to replace the recyclable material. The energy gained from the incineration of recyclable material is, in nearly all cases, less than the energy cost associated with manufacturing the same amount of the same material from raw resources (Maubs). The incineration of recyclable material results in a net loss of energy, assuming that the material must be replaced. The pollution caused by the incineration of such material is compounded by the pollution caused in the generation of energy necessary to replace the material, as well as any industrial processes that may be involved. Economic costs are associated with material replacement as well.

If treated as a closed economic system it is better for an incinerator's profits to incinerate recyclable material, but looking at the broad picture of society, incinerating recyclables does not make economic or environmental sense. For this reason, incineration should be used in tandem with strong recycling systems, as occurring in many European countries. Incinerators should be sized to deal only with non-recyclable waste. If recyclables are incinerated, not only will harm be done to society, but credibility will be lent to the arguments of anti-incineration groups, making the political situation for EFW more sensitive than it presently is. The fears of incineration's opponents, that groans will be elicited from the collective voice of incinerator operators when recycling policies are introduced, will be validated and neither society nor the EFW industry will benefit.

One option for incinerators in the case of a shortage of non-recyclable waste available is the replacement of municipal waste with waste biomass. One of the reasons that incinerator operators may not want to see a reduction in the level of waste generated is that any time when an incinerator is not operating at near maximum capacity (which can only be achieved with a steady supply of waste) is a time when potential profit is not being realized. If, however, in times of low waste availability, an alternative source of fuel for incineration is secured, then a lowering of the level of waste being produced may not be seen as such a crisis. With a calorific value very similar to that of MSW, Waste biomass makes an excellent alternative, or supplementary, fuel source.

Table 4-2: Calorific Values of Various Types of Biomass and MSW (JUNIPER)

Biomass or Waste	Calorific Value (MJ/kG)
Wood Residue Chips	6-15
Saw Residue Chips/Sawdust	6-10
Birch Bark	7-11
Straw	6-18
Mixed Green Waste	4
Rice Husks	10-13
Unsorted MSW	7
Sorted MSW	15

As Table 4-2 shows, many types of waste biomass have comparable calorific values to MSW, making biomass an adequate replacement for MSW in the event of a shortage of waste.

Despite the higher calorific values of recyclable material, the incineration of recyclables should not take place and incinerators should be sized to reflect that. The economic effects of eliminating the incineration of recyclable material, however, need not deter EWF entrepreneurs. In the event of a reduction in the amount of non-recyclable waste produced, incinerators can turn to biomass for their fuel.

4.3 The Politics of EFW Incineration in Canada

Incineration does not seem to have a large place in the public consciousness of Canada. It did receive some attention in Toronto's last mayoral race as one candidate made his platform pro-incineration to the dismay of many (Hunziker). In the minds of many Canadians incineration is equated with stench and smoke (Gee) but this equation rarely comes up. While the Peel stack is in plain view of a major highway, most people don't know what it is (Dodds). The people who live near the incinerator and know what it is seem to like it and enjoy the benefits of the electricity it generates (Dodds). Incineration is becoming a more prominent issue in the GTA as the fear of the end of the contract that allows Toronto to ship its garbage to Michigan looms and incineration seems to be one possible solution (Perry). If incineration is touted in the GTA once more, it is likely to face strong opposition, but until then the Peel Region incinerator continues to operate smoothly.

4.4 The Politics of EFW Incineration in The United States

EFW incineration operates on a far larger scale in the United States than it does in Canada. There are 143 municipal waste incinerators in the United States, 98 of which are EFW plants (NSWMA). The US incinerates 14.7% of its garbage, or 33.6 million tonnes/yr (NSWMA). There exists a capacity, nation-wide, to incinerate 95077 tonnes/day and in 2003, 2750 MW of electricity were generated, powering 2.3 million American homes (NSWMA). It would seem as though citizens of the United States have less concern about incineration than the citizens of Canada do.

4.5 The Politics of EFW Incineration in the European Union

With far less area to store solid waste in Europe than in North America, alternatives to landfills had to be considered long ago in Europe. Incineration is more prominent in Europe than in North America and has a much longer tradition. 96% of European incinerators are EFW generating plants (ASSURRE).

Table 4-3: Breakdown of Incineration Capacity in Europe in 1998 (COEC)

Country	Incineration Capacity (kt/yr)	% of MSW Incinerated	# of MSW Incinerators
Austria	340	11	2
Belgium	2240	54	24
Denmark	2310	74	31
Finland	70	2	1
France	11330	42	225
Greece	0	0	0
Germany	12020	36	49

Ireland	0	0	0
Italy	1900	16	28
Luxembourg	170	75	1
Netherlands	3150	35	10
Norway	500	22	18
Portugal	0	0	0
Spain	740	6	14
Sweden	1860	47	21
Switzerland	2840	59	30
UK	3670	8	31
Total	43140		485
Total EU	39800		437

There is a continuing trend toward more EFW incineration in Europe, with a total capacity to burn 50.2 million tonnes per year in 2000 (ASSURRE). This trend is primarily due to landfill restrictions. In 1999 the European Union introduced an act that was intended to reduce the negative effects of landfills on the environment and brought into effect new guidelines for landfill operation (LOW). Waste was classified by this legislation as non-hazardous, hazardous, or inert waste each with its own type of landfill (LOW). A requirement for waste treatment prior to disposal in a landfill and the separation of the waste into these classifications was introduced (LOW). Some types of waste were labeled as waste that could not be accepted into landfills at all (LOW). The new conditions and requirements for waste created new cost associated with landfills and an economic incentive for looking to alternative types of waste treatment. The European Union has made decisions as well to reduce the overall volume of waste being sent to landfills (GAEUEL). To encourage the diversion of waste from landfills to EFW treatment methods Austria, Denmark, Germany, and Sweden have placed bans on the landfilling of combustible waste (ENERGIE).

In Europe 49.6 TWh of energy is recovered from waste incineration, 44.4 TWh of which is recovered in the European Union (ASSURRE). The trend is also toward a smaller number of plants, but much larger plant capacity, leading toward a higher total capacity to incinerate (ASSURRE).

The European Union has implemented incineration related directives, which all member countries must have incorporated into law. These directives limit the pollutants in incinerator emissions significantly and are effective in making incinerators more environmentally acceptable.

4.6 The Politics of EFW Incineration in the United Kingdom

Today there are 7000 incinerators in England and Wales only 12 of which burn municipal waste (E-A UK). The rest burn chemicals, wood, waste oil, clinical waste, sewage sludge, and 3000 of the incinerators are small farm units (E-A UK). With all these incinerators, the national capacity for incineration is 2.8 million tonnes/year, still not enough to fulfill the upcoming EU landfill directive without additional waste diversion (E-A UK).

Table 4-4: Waste Treatment by Region in the UK (E-A UK)

Region	MSW (million tonnes/yr)	Landfill	Recycling and Reuse	Incineration
England	28	82%	10%	8%

&Wales				
Scotland	3	90%	5%	5%
N. Ireland	1	95%	5%	0
Total	32	83%	9%	8%

Figure 4-1: Location of MSW Incinerators in the UK (E-A UK)

Before incorporating the European Union directives on incinerators into law the UK had few incinerator related regulations (Lulofs). The UK incorporated the directives into law in November of 1991, one year later than required (Lulofs). In 1996, however, the UK did implement stricter emissions limits for incinerators (Lulofs), likely due to pressure from groups like Greenpeace and Friends of the Earth, many of which have strong bases in the UK. The government in the UK has always had a more relaxed attitude toward dioxins and furans than the US EPA and many other European countries, but now has a limit of 1 ng TEQ/m^3, a relatively strict limit (Lulofs). Still, there are many breaches of code in the UK. There were 500 reported violations of incinerator emissions standards between January 1, 1996 and November, 1998 which is likely far lower than the actual number of violations as the UK system is one of self-reporting (Lulofs). While there may be standards similar to those in other countries in the UK the country's record would seem to indicate a lax attitude toward incinerator emissions.

There has been some opposition in the public realm to new EFW incinerators in the UK of late (ENERGIE). The opposition seems to have more to do with a resistance to further industrial development in some areas and the sites chosen for new EFW plants than with environmental concerns (ENERGIE).

In 1994 the Energy from Waste Trade Association was formed in the UK (Lulofs). The group exists to present the interests of EFW operators to the government and other organizations.

The UK electricity act requires the suppliers of public electricity to purchase a certain portion of their power from non-fossil fuel sources, and this act is partially responsible for the prominence of incinerators in the UK (Lulofs).

4.7 The Politics of EFW Incineration in France

France incinerates 24% of its waste (E-A UK). France's emission regulations were 30-50% less strict than those of the EU directives when the directives had to be incorporated into law, but they did address a wider variety of pollutants (Lulofs). At the time the EU directives were incorporated (1991) public concern regarding environmental and health effects was near non-existent (Lulofs). It was generally thought that incineration was a clean technology and landfills were problematic (Lulofs). In the late 90s pressure from groups like Greenpeace raised the public awareness of dioxins and furans and a new standard of 0.1 ng TEQ/m^3 was instantiated (Lulofs). Public concern was further heightened when, in 1998, studies revealed cows local to the Lille incineration plant to have heavy dioxin contamination in their milk (Lulofs).

4.8 The Politics of EFW Incineration in Germany

The German TA Luft 1986[1], a piece of legislation governing incinerator emissions, was in place 4 years before the EU directives became mandatory for member countries. It was, in many areas, stricter than the directives of the EU (Lulofs). The German public was very concerned about incinerator emissions, in particular dioxins and furans. There was a standoff involving federal and state ministries of the environment, environmental organizations and citizens groups

[1] Technische Anleitung zur Reirhaltung der Luft or "Technical guideline on the Prevention of Air Pollution."

versus EFW operators, their organizations, and the ministry of Economics. This standoff led to the changing of the TA Luft 1986 into the 17BlmSchV[2], effectively making the guidelines of the TA Luft more enforceable. The German political climate for incineration and EFW is one of encouragement, but strict control on pollutants.

4.9 The Politics of EFW Incineration in the Netherlands

The public in the Netherlands was concerned about dioxins and furans as early as the 1970s. The "Seveso Incident[3]" initiated talks about dioxins in parliament in 1979 (Lulofs). The late 80s and early 90s saw a growing awareness of the environment in the Netherlands and the legislation of Germany was looked to for an example of effective incineration pollution management (Lulofs). It was during this time that the VEABRIN (now the VVAV), an association of Waste Incineration Plants was formed (Lulofs). The VEABRIN protested the strong emissions regulations that were being put in place, but were all but ignored and limitations that were more stringent than those in the EU directives were created.

Many in the Netherlands see EFW incineration as commonplace and wonder about the strong backlash it receives in North America. Indymedia.org posted this comment that was a response from a native of the Netherlands to a Greenpeace anti-incineration protest:

> Being Dutch, from a country with high levels of recycling and EfW I am quite shocked to read about opposition against EfW. Having lived near EfW plants all my life as well as my friends and family I can say that nothing unusual

---

[2] The 17th ordinance of the Federal Emissions Act

[3] The Seveso Incident was an industrial accident in northern Italy. One of the results of the incident was a "toxic cloud" that included 2,3,7,8-tetrachlordibenzoparadioxin. There were health effects among humans and local wildlife.(Seveso)

happens, no higher risks of cancer, birth defects, etc. EfW is highly regarded in The Netherlands, as well as other EU countries, as opposed to landfill. Currently I live out 10 minutes away from SELCHP[4] which doesn't affect anyone in the area I live. Have you thought about those nice emissions from all the road and rail traffic needed to transport recycling materials? (INDY)

This is a clear indication that EfW incineration receives support from at least some sectors of the population in The Netherlands.

5.0 Landfill versus EFW Incineration

As discussed in the previous section, incineration is a widely criticized waste management practice. Many of EFW incineration's detractors may not realize, however, that by saying "no" to incinerators, they are effectively saying "yes" to landfill. Storing waste in landfills is the primary waste management strategy in North America and Europe and it is a strategy with a long tradition. Unless a new, widely spread waste management strategy were invented and applied, or a drastic decrease in the amount of waste generated occurred then the end of incinerators would mean a redirection of all waste intended for incineration to landfills. Such a redirection of waste may not be the most desirable course. Landfills are widely used and have a strong tradition, but this does not mean that they are less harmful than EFW incineration. Like incinerators, landfills have harmful gaseous emissions and environmental impacts. Choosing one waste disposal method over another is not a question of environmentally sound methods versus unsound ones, but a question of which method is the lesser necessary evil.

[4] SELCHP is the South East London Combined Heat and Power incinerator in the UK

5.1 Landfills, EFW Incinerators, and Cancer

Over 9 tenths of cancer cases that can be linked to EFW incinerators are caused by dioxins and furans (Jones). This chemical, emitted (albeit at a controlled rate) and created during the incineration process is carcinogenic. From this, it follows that EFW incineration is a source of cancer causing substances.

Landfills, too, are sources of cancer causing substances. Roughly half of the gas emitted by landfills is methane, while the other half is carbon monoxide (Jones). A small minority of the gas comes in the form of vinyl chloride and benzene (Jones). These two chemicals are 2 of the HAPs (Hazardous Air Pollutants, as defined by the USA's Clean Air Act amendments of 1990) with the highest cancer potency factors in humans (Jones). Incinerators emit benzene a well, but landfills emit it at hundreds of times the rate incinerators do. Like incinerators, landfills have pollution control mechanisms, but they are typically only able to capture 60-85% of the gas emitted (Jones). As well, a study of meteorological trends and gas flow patterns revealed that the number of people exposed to the carcinogenic emissions of landfills is greater than the number of people exposed to the carcinogens emitted by incinerators, assuming similar population densities (Jones).

Incinerators may pose the threat of cancer, but landfills do as well.

Table 5-1: Relative Cancer Risks From Various Activities (Jones)

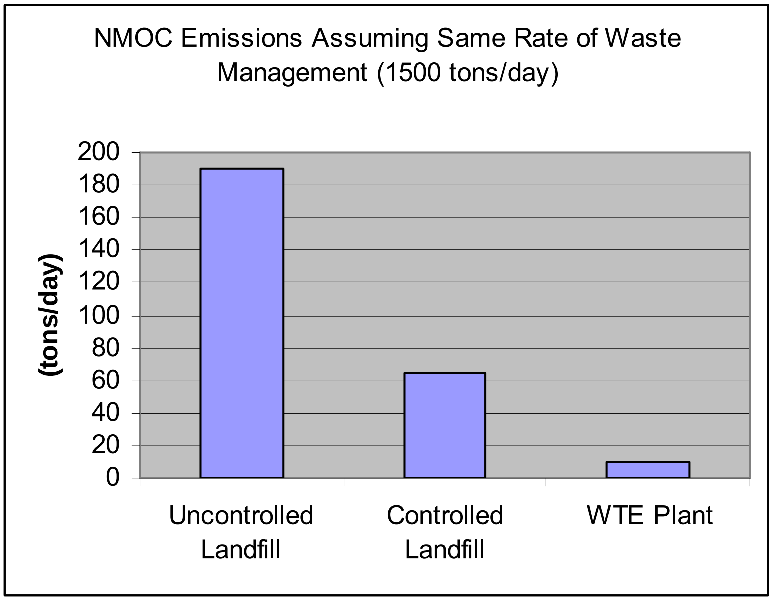
Activity	Chances per Million People
Pesticide Residue on Fresh Foods	4640
Consumption of ½ pound of fish per week from Lake Ontario	720
Acceptable Benzene levels	180
1500 Ton per day landfill fugitive benzene and vinyl chloride emissions, inhalation only	18
1500 Ton per day WTE plant dioxin/furan emissions, all pathways	0.07

Without broaching the subject of the accuracy of research attempting to connect cancer to its cause, it can be seen from Table 5-1 that it is possible that landfills cause more cancer, when dealing with the same amount of waste, as EFW incinerators. It is worth mentioning here, however that the cancer causing agents in landfills break down into less harmful chemicals over time, whereas dioxins and furans do not. The half-life of vinyl chloride in normal soil is two years (still a substantial time) and the half-life of benzene, depending on conditions, can be roughly 13 days or less (BMZ).

Landfills, EFW Incinerators, and Greenhouse Gases

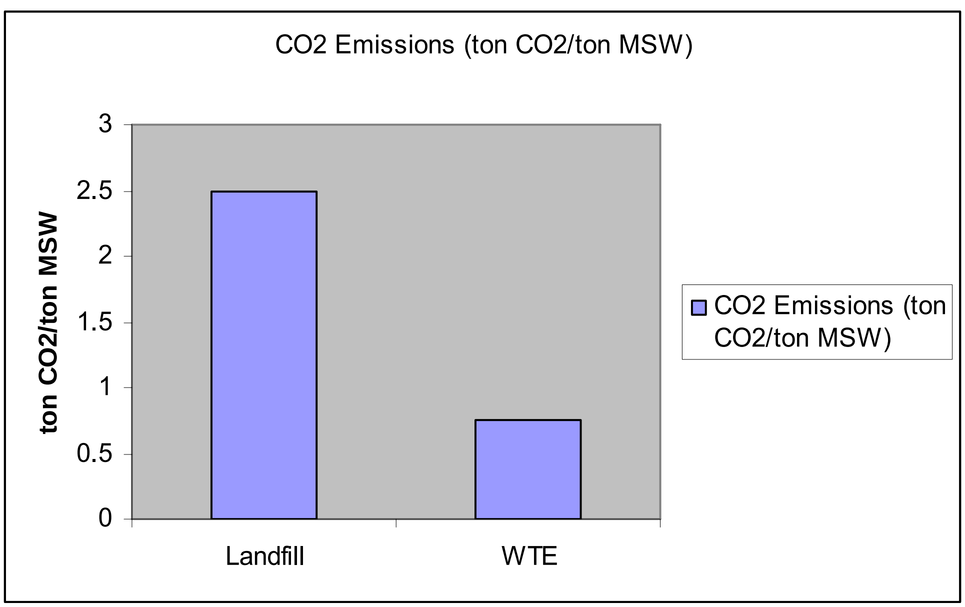
Non-methane hydrocarbon (NMOC) is a substance that contributes to global warming and that is emitted by both incinerators and landfills. The rate at which NMOCs are emitted from EFW incinerators, however, is far less than the rate at which they are emitted from landfills.

Figure 5-1: NMOC Emissions by Waste Management Method (Jones)



The carbon dioxide emissions from landfills are also greater than the emissions of the same substance from incinerators.

Figure 5-2: CO_2 Emissions by Waste Management Method (Jones)



The above data shows that storing waste in a landfill has distinct disadvantages versus EFW incineration.

6.0 Incineration Technology

The basic principle behind generating energy via incineration is the capturing of the heat generated during the combustion of the incinerator's fuel (INTUSER). Most often the heat from the incineration flue gas is transferred through boiler tube walls to water waiting in a boiler (INTUSER). The water is turned to steam and the steam turns turbines to generate electricity (INTUSER). The heat from the used steam can be used in industrial processes and space heating (INTUSER). When the heat from the steam is captured and electricity is generated the process is called "Combined Heat and Power" (CHP) or "co-generation" (INTUSER). Co-generation is a method of ensuring maximal energy efficiency in the incineration process.

The first EFW incinerator began operating in 1874 in Nottingham in the U.K. (INTUSER). Following this, the early 1900's saw a boom in waste incineration, especially in the United States (INTUSER). These early incinerators would have had little or no pollution control and would have released ash, toxic chemicals and noxious gasses into the air along with dust and charred paper (INTUSER). Due to their detrimental health effects these EFW plants faced massive public opposition in America, but their operators continued to burn waste without regard for air quality until 1967 when the US Clean Air Act was passed (INTUSER). Between the passing of the act and the late 1980s 250 EFW incinerators were shut down, most of them on grounds of their unacceptable environmental impact (INTUSER). Recently, due to developments in pollution abatement technologies (discussed in section 7) incinerators have been able to meet and exceed the demands placed on them by environmental legislation and have become a safer means of power generation. The most popular type of incineration has always been “mass burn” incineration, a process in which waste (or another fuel) is placed in the incinerator to undergo traditional combustion en masse (INTUSER). There are many types of mass burn incinerators, each of which can be made far less harmful today then they could have been made as recently as the late 1980s.

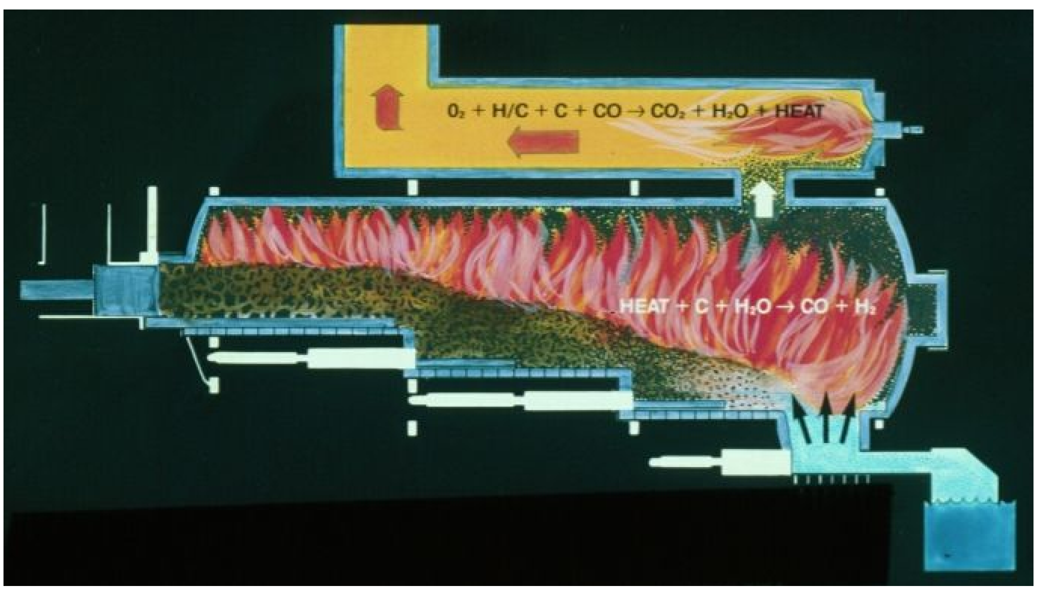
6.1 Water-Wall Incineration

The most popular type of mass burn furnace is the “water-wall” furnace (INTUSER). In the water wall system an overhead crane is used to distribute waste evenly into a hopper and pistons are used to ram the waste from the hopper onto a grate (INTUSER). The grate moves the waste across the combustion chamber where it is exposed to high temperatures and air coming from above and below the grate (INTUSER). The air from below the grate initiates the combustion reaction and is called “underfire air,” while the air from above, the “overfire air” is introduced through nozzles and creates a more uniform distribution of combustion gasses in the chamber while ensuring a more complete combustion of volatile substances (INTUSER). Underfire air also serves to cool the grate (INTUSER). Ash from this process is then moved into a water quench pit and is later taken through other processes for further treatment (INTUSER). The flue gas produced in a water-wall furnace can be used to generate electricity in the standard manner (INTUSER).

6.2 Controlled Air Modular Furnaces

Controlled air modular furnaces were first used in the 1960s and were a vast improvement over the then traditional incinerators in terms of air pollution (INTUSER). This type of furnace limits the air available for combustion by controlling the rate of air intake to the combustion chamber (INTUSER). The temperature of the furnace can easily be controlled by altering the amount of air available for combustion which will slow or accelerate the combustion rate (CONSUTECH). These furnaces are sometimes referred to as “starved air” or “semi-pyrolytic” (INTUSER) and a particular brand of controlled air modular furnace, Consutech’s “Consumat” unit, is the type of furnace used in the Peel Region incinerator (KELLEHER).

Figure 6-1: Consumat Controlled Air Furnace (CONSUTECH)



The Consumat furnace, like other controlled air modular furnaces, consists of a lower and an upper chamber (CONSUTECH). Primary combustion of waste occurs in the lower chamber and the further combustion of hydrocarbons and other chemicals that require oxidation occurs at high temperatures in the upper chamber (CONSUTECH). This type of furnace offers more control over the combustion rate and related variables than a water-wall furnace does and the increased control results in the ability to reduce air pollution produced (INTUSER).

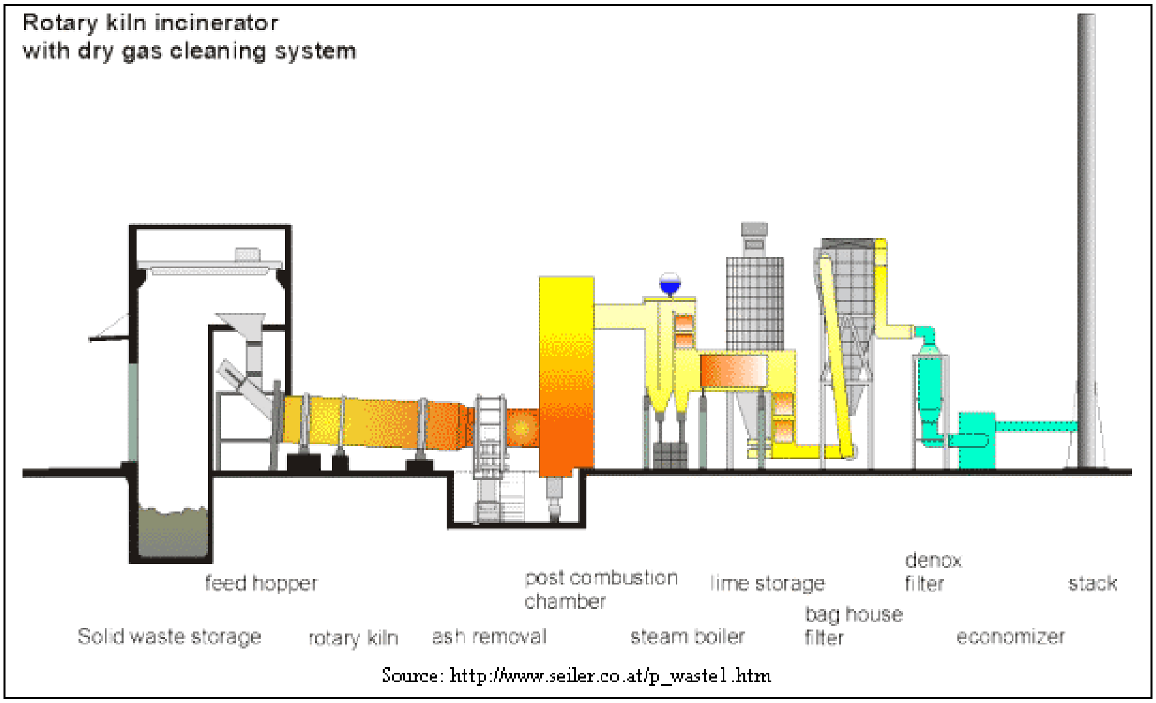
6.3 Liquid Injection Incineration

In a liquid injection incinerator waste is burned while in suspension in either high pressure air or steam streams (INTUSER). While this method can be used to incinerate nearly any pumpable substance, including PCBs, solvents, polymer waste and wastes high in organics it cannot deal with a waste stream that is not relatively uniform (INTUSER). Liquid injection incineration, therefore, is not suitable for the incineration of municipal solid waste.

6.4 Rotary Kilns

In a rotary kiln waste is burned in a rotating cylinder. Rotary kilns can burn waste in any phase (solid, liquid, solid/liquid solution) and can be used to incinerate tars, PCBs, munitions, polyvinyl chloride, and other substances (INTUSER). Rotary kilns are not ideal for EFW applications, however. They are susceptible to thermal shock (large temperature changes over short time spans), they require intensive maintenance, they leak air and require replacement air to be continually added, and produce a large number of particulates (INTUSER). As well, they have a low thermal efficiency and high capital costs (INTUSER).

Figure 6-2: Rotary Kiln Incinerator (INTUSER)

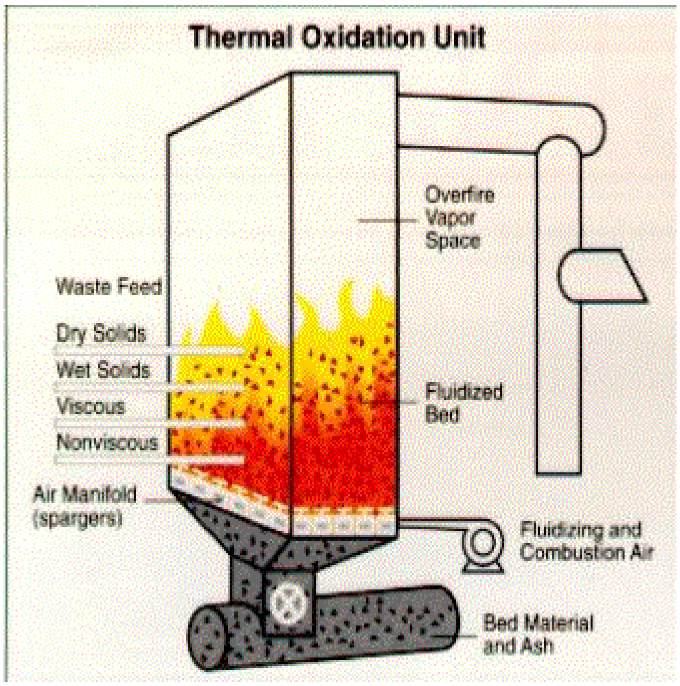


6.5 Multiple Hearth Incinerators

Several grates are used in the multiple hearth incinerator (INTUSER). Waste descends sequentially through the grates into hotter and hotter combustion zones resulting in a high combustion zone residence time for most types of waste (INTUSER). Most forms of combustible industrial wastes, such as sludges and low volatile material are suited for multiple hearth combustion and the high residence time results in the evaporation of most of the moisture in these wastes (INTUSER). A multiple hearth system can use a variety of fuels and is fuel efficient, but unfortunately incurs high maintenance and operating costs (INTUSER). Ash is not acceptable to the multiple hearth system as it tends to fuse ashes into large rock-like structures and, like the rotary kiln, a multiple hearth system is sensitive to thermal shock (INTUSER).

6.6 Fluidized Bed Incinerators

Figure 6-3: Fluidized Bed Incinerator (INTUSER)



FLUIDISED BED INCINERATOR

Source: Southern Cross University (SCU), Australia

A bed of heated inert, sand-like particles is used to transfer heat to the waste that is to be incinerated in a fluidized bed incinerator (INTUSER). The bed rests on a perforated metal plate called a distributor plate and heated air is pumped from the underside of the plate, through the perforations, into the bed (INTUSER). The air bubbles through the particles causing it to act as a fluid, thus the name “fluidized” bed incinerator. Both the waste and the bed are enclosed in the combustion chamber of the incinerator and emissions leave through the top of the enclosure. This type of incinerator offers simple design, minimal No_x production, long product life, high energy efficiency, low capital and maintenance costs, and the ability to combust solid, liquid, and gaseous wastes (INTUSER). A fluidized bed incinerator also traps many of the pollutants that would otherwise be emitted by other types of incinerators reducing the cost of pollution abatement (INTUSER). The operating costs of a bed incinerator are unfortunately high, however, and the throughput capacity is low (INTUSER). As a closed system the fluidized bed also poses difficulties for the removal of residual waste that cannot be combusted (INTUSER).

7.0 Alternative EFW Technology

Incineration is presently the most prominent and proven EFW technology, but it is far from the only method of creating energy from waste. In recent years attempts have been made to create new ways or adapt old ways of generating power from waste materials. These methods are often more efficient and cleaner than incineration. Gasification, pyrolysis and plasma conversion are some of these technologies, and while detractors will say that they are merely fancier forms of incineration they offer benefits over cruder burning processes to the environment and plant operators.

7.1 Gasification

Gasification occurs in a closed tank at extremely high temperature in a limited oxygen environment (US DOE). While incineration often operates in an environment that has a lower oxygen content than the air we breathe it still operates on the principles of the basic combustion reaction:

$$\text{Carbonaceous Material} + O_2 \text{ ======> } CO_2 + H_2O$$

In gasification, carbonaceous material is used as fuel and the oxygen supply is limited, so while the temperature is high enough to cause combustion under normal circumstances, there isn't enough O_2 to create what is normally considered combustion. Instead a more complicated series of reactions occurs, and the majority of the products come in the form of carbon monoxide (CO) and hydrogen gas (H_2) (Kim). These products can then be formed into fuels such as methane and other combustible gases, or can undergo further processing to be made into liquid fuels. Often the reaction rate of gasification can be influenced by pressure, so gasification sometimes occurs under high pressure (DONGEN). The fuels produced by gasification can be used to power fuel cells or combusted to turn turbines and generate electricity, or they can be combusted to produce heat directly.

Gasification is superior to incineration in that it produces less pollution, and it is more efficient. If and when it comes to burning the fuels created by gasification, the risk of creating secondary toxics is less than the risk taken in incineration. Gaseous fuels are more homogeneous than solid waste and will therefore burn more cleanly. The issue of ash and solid residue still exists, and there can be toxic liquid effluent but they can be dealt with in the same fashion as ash or liquid effluent from incineration is. Gasification is also performed in a closed system, as opposed to incineration, which is relatively open to air, so the capturing of exhaust gases is easier and more complete. The energy capture from gasification can be made much more efficient than in incineration, reaching up to 60% (US DOE) as opposed to incineration's 39% (JIE), making gasification the more economical EFW technology.

Table 7-1: Numbers of Gasifier Installation by Country (Bio-Tech Group)

Country	# of Gasification Installations	Country	# of Gasification Installations
Austria	10	Italy	4
Australia	1	Maleisia	7
Belgium	1	Netherlands	2
Canada	1	Poland	1
Costa Rica	1	Portugal	1
Czech Republik	1	Spain	1
Denmark	9	Sweden	7
Finland	14	Switzerland	2
France	2	United Kingdom	9
Germany	20	United States	10

7.2 Pyrolysis

Pyrolysis is similar to gasification in that it is performed in a closed tank with carbonaceous material used as fuel, but where gasification operates in a limited oxygen environment, pyrolysis happens in a virtually oxygen free environment (US DOE). Like gasification, the temperature is high enough to instigate chemical reaction, but the oxygen is not present to facilitate traditional combustion.

The 75% of pyrolysis product is a liquid that comes in the form of bio-oil (US DOE). The bio-oil is denser than the gaseous products of gasification and is therefore easier to transport (US DOE). It can also be used to synthesize petro-chemicals. The remainder of the products exists as waste products and gaseous fuels similar to what is created in gasification. The liquid and gaseous products of pyrolysis can be burned more cleanly than solid waste, so the creation of secondary pollutants is limited. The closed system conditions of pyrolysis offer a situation in which pollutants can more easily be captured than they could be in an incineration process.

Pyrolysis is used in many industries and is more widespread than gasification (USDOE).

7.3 Plasma Converters

A plasma converter uses plasma to create renewable fuels. Like a gasifier or a pyrolyser, a plasma converter uses high levels of energy to change waste into fuel, but the advantage of a plasma converter is that metals and glass need not be sorted out of the waste that is fed to the system (STAR). Metals and glass are actually separated out from the convertible waste during the plasma conversion and ejected via outlets from the plasma vessel for recycle or reuse (STAR). Plasma is a gas, usually air that goes through an ionization process that renders it a good electrical conductor (STAR). Energy is sent through the plasma in the presence of waste, creating lighting like surges of electricity which disassociate the atoms in the waste. If the atoms are of metal they will be ejected from the metals outlet of the plasma converter, if they are silicates or ceramics they will be ejected through the appropriate outlet, and if they are of types that will be used to create fuels they will be sent through various post-plasma treatment stages during which the fuels will be formed (STAR).

7.4 Anaerobic Digestion

Waste, waste biomass in particular, can be subjected to a process called anaerobic digestion. The process involves the digestion of waste by bacteria in an environment that contains little to no oxygen (ENERGIE). The bacteria necessary for this process cannot survive in the presence of oxygen (ENERGIE). The gaseous products that result from anaerobic digestion are mostly methane (from which energy can be derived) and carbon dioxide (ENERGIE). There is also a liquid effluent containing suspended particles left over that, if contaminated can only be used for landfill covering (ENERGIE). If clean feedstock is used the liquid effluent is not contaminated at the end of the process and it can be used as a fertilizer (ENERGIE). Applying this process to MSW would require intense sorting of waste to ensure non-contaminated effluent (ENERGIE).

8.0 Pollution Abatement Technology

Between 1990 and 1997 dioxin emissions in the UK fell by 98% (E-A UK). This trend is indicative of most pollutants in the areas studied in this paper. Until the late 80s there was very little control or concern about the operating of incinerators, excluding a few hard fought battles involving anti-incineration activists. Once concern was raised, however, and emissions limits were created pollution abatement technology for gaseous emissions become commonplace in incinerators. This field of emission control technology is comparatively young and it is still developing. It includes many systems that are used in tandem to scrub emissions down to an acceptably clean substance, and any state-of-the-art incinerator will have some form of pollution abatement technology. It is important to note here that the cleaning of toxic substances out of emissions is not an elimination of toxic substances in nearly all cases (with the exception of afterburning of CO). More often pollution abatement is a concentration of toxics into a more controllable form such as liquid or solid residue. As anti-incineration groups and the laws of thermodynamics will often state, what goes into an incinerator must come out (or accumulate in the incinerator). Matter, including pollutants, cannot (easily) be destroyed, but converting substances into a more manageable state can aid in the effort to prevent them from having detrimental effects on the environment.

8.1 PAC (Powdered Activated Carbon) Adsorbtion

Powdered Activated Carbon is used in the control of mercury emissions (ALSTOM). Carbon rich materials such as bone charcoal or granular charcoal are ground into particles so fine that one gram of these particles can have a combined exposed surface area of 500 square meters (WAN). These particles are then sprayed into an incinerator's emission gas and much of the mercury in the gas is adsorbed (ALSTOM). Adsorption is a process in which fine particles are made to stick together to create larger particles (WAN). When mercury touches the surface of PAC the two substances stick together, and one particle of PAC can pick up multiple mercury molecules (ALSTOM). Once adsorbed, mercury particles which, alone, would have been far to small to filter out of emissions economically. can easily be caught by a conventional filter. PAC Adsorbtion is used in many incinerator operations, including the Algonquin Power incinerator in the Peel Region (PEEL).

8.2 Baghouse Filtering

Baghouse filtering involves a large bag (of a size comparable to a house) made of fabric, often including glass fibre (ALSTOM). The material in the bag allows small particles such as CO_2 and oxygen molecules to pass through, but will not allow most types of particulate matter or adsorbed mercury to cross its boundary. A pressure differential (such as the one that drives a vacuum cleaner, but on a larger scale) drives the emissions through the baghouse and various pollutants are trapped therein. The Peel Incinerator uses a baghouse filter as do most modern incinerators.

8.3 Selective Catalytic Reduction (SCR) Reactors

SCR reactors work in a fashion similar to that of an automobile's catalytic converter and are used to reduce NO_x emissions (ALSTOM). Emissions are passed through the SCR reactor and the NO_x in the system is exposed to anhydrous ammonia (ALSTOM). The anhydrous ammonia and the NO_x react producing nitrogen gas and water, molecules that are naturally present in the atmosphere and reducing the amount of toxic nitrogen oxides in the emissions (ALSTOM). There is an SCR reactor used in the Peel incinerator (PEEL).

8.4 Wet-Spray Humidifiers

A wet-spray humidifier uses nozzles to spray water into emission gas in order to cool them and entrain pollutants in water making emissions easier to deal with downstream. This process is usually an initial air pollution control (APC) measure (BIOSOLID). Water can be sprayed concurrent or countercurrent to the emission flow (BIOSOLID). The Peel incinerator uses a wet-spray humidifier (PEEL).

8.5 Dry Lime Injection

Injecting dry lime into emission gas reduces the gas' acidity. Lime is a basic substance that causes an acid-base reaction with the acidic gasses present in emissions. The products of an acid-base reaction are salt and water. The salt would become part of the incinerator's air pollution control residue and the water would be harmlessly emitted to the atmosphere. The Peel incinerator uses dry lime injection (PEEL).

8.6 Cyclone Separators

A cyclone separator is a vertical tank with the bottom end tapered into a pipeline and a section of the top open. Using centrifugal force the cyclone separates larger particles from smaller ones (BIOSOLID). The cyclone can be used to separate such pollutants as PM10 and other large diameter particles from emissions (BIOSOLID).

8.7 Electro-Static Precipitators

Electrostatic precipitators pass emissions through an electric field, which imparts a charge on dust and particulate matter (KRIG). The emissions continue on past electrodes with charges opposite to those the particles carry. The opposite charges attract each other, and the particles are held on the surface of the electrodes, eliminating them from the final emissions of the incinerator (KRIG). Electro-static precipitators operate in dry or wet conditions, the distinction being that in a wet system the emissions are sprayed with water to aid the particle charging process and in a dry system they are not.

8.8 Afterburners

In order to ensure the complete oxidation of any lingering carbon monoxide (CO), emissions are often drawn into chambers where they are "re-burned" and carbon monoxide is converted into carbon dioxide (BIOSOLID). The chambers come in many positions in relation to the main emissions stream, such as internal, external, side flue, etc., but the operate on the same "re-burning" principle regardless of position (BIOSOLIDS).

8.9 Venturi Scrubbers

Venturi scrubbers can achieve the highest particle collection efficiency of any wet emissions scrubbing system (Beachler). Undesirable gases can also be removed from stack emissions using Venturi scrubbers, but not with the same level of success (Beachler).

There are 3 sections that a gas stream will pass through in any Venturi scrubber. The converging section reduces the cross-sectional area (area perpendicular to gas flow) that the gas has to pass through (Beachler). Flowing gas, in most conditions, will tend to flow at the same volumetric flowrate (same number of cubic meters per second) at any point in the exhaust stream. When the cross-sectional area (area of gas flow passageway perpendicular to the direction of gas flow) decreases the gas velocity will have to increase proportionately to maintain the constant volumetric flow. Increasing the gas velocity is the purpose of the converging section of the Venturi scrubber (Beachler). The second section is the Venturi throat which is a short passageway through which gas passes very quickly (Beachler). The final section is the diverging section which allows the gas a greater cross-section to travel through and returns it to a more manageable velocity (Beachler). Liquid is introduced in either the throat or the entrance to the diverging section (Beachler). The high velocity of the gas shears the liquid into many tiny droplets creating a fog of liquid (Beachler). The existence of the fog makes it quite likely that particles in the exhaust stream will collide with a liquid droplet and this collision often results in the entrainment of the particle in the liquid (Beachler). Gaseous particles are entrained as well, but not as readily as particulate matter is (Beachler). The liquid then moves along with the exhaust gas and must be separated from the emission stream in order to avoid emitting the particles and gasses the Venturi scrubber has worked so hard to entrain (Beachler). Liquid separation is most often done by means of a cyclonic separator, a system which uses centrifugal force to separate particles of higher densities from those with lower densities (Beachler).

One of the drawbacks of a Venturi scrubber is the wear and erosion of the throat housing that is often caused by gases traveling at high velocity (Beachler). This problem can be overcome by regular maintenance and is not too high a price to pay for the efficiency of particle removal that a Venturi scrubber can achieve.

The Peel Region incinerator uses Venturi scrubbers as one of its main pollution abatement mechanisms.

9.0 Case Studies of Incineration Plants

In order to gain an appreciation of the rate at which incinerators deal with waste and produce power one can look to particular incinerators as examples. The following case studies look at the operating statistics for incinerators in Canada and the United States. The following are not the only instances of incineration in these countries but are examples intended to draw a picture of the incineration industry and incineration practices.

9.1 Incinerators in Canada

The Algonquin Power Energy from Waste Facility opened in the Peel region of Ontario in 1992 (PEEL). The facility consists of multiple two-staged “starved air

Consumat[5] units" (units that burn garbage) and powers roughly 6000 homes (KELLEHER). 174,000 tonnes of solid waste are incinerated every year at the Peel Facility (PEEL). The energy from waste at the Peel Facility is converted to electricity and 75% of it is sold to Hydro One (PEEL). The other 15% of the 9 MW (GLOBE) generated is used internationally (PEEL).

In the commercial and industrial sector of South Burnaby, British Columbia is the Burnaby Incinerator, which burns 250,000 tonnes of waste per year (GVRD). Since 1988 this facility has been generating power (GVRD). Unlike most other incinerators, the power generated is not measure in watts, but in kilograms of steam created (GVRD). The heat from the burning waste is directed to large boilers that create 2200 tonnes of steam per day (GVRD). The steam is sold to a paper mill and used to make cardboard (GVRD).

9.2 Incinerators in the USA

The flagship facility of the American Ref-Fuel Company is the Hampstead Resource Recovery Facility in Long Island, New York (REF-FUEL). This facility, having opened in 1989 operates 24 hours a day, six days a week with the capacity to incinerate 2,505 tonnes of waste a day (REF-FUEL). The Hampstead Resource Recovery Facility generates 72 MW (REF-FUEL). American Ref-fuel owns similar waste-to-energy incinerators throughout the North Eastern United States (REF-FUEL) including one in Niagara Falls New York that is a mere 8 minute drive from the border between Ontario and New York (PMC). PMC (Product Management

[5] See Section 5.3 for description of Consumat Unit. See also source "Consutech Systems, LLC."

Corporation), a company based in Ontario, has contracts with Ref-Fuel involving the destruction of some of PMC's wastes in the Niagara Falls plant (PMC).

Covanta Energy's I-95 Energy/Resource Recovery Facility opened in 1990 in Lorton, Virginia (COV). The I-95 is Covanta's largest facility and has the capacity to treat 3,000 tonnes of waste a day (COV). The 79 MW Covanta generates at this plant power 75,000 homes. The power is sold to the Dominion Virginia Power Company (COV).

In Tampa, Florida the Wheelabrator Mckay Bay WTE Facility powers 18,000 homes (WHEEL). It power's 18,000 homes operates 24 hours a day, 7 days a week, and has operated since 1985 (WHEEL). Wheelabrator Mckay sells 22 MW to the Tampa Electricity Company out of this plant and processes 1000 tonnes per day (WHEEL).

10.0 Conclusion

Incineration of any substance, (MSW, hospital waste, biomass, etc.) is widely debated. While it seems to be an effective way of dealing with waste, its reputation leaves something to be desired. Some of the poor public perception of incinerators is due to the poor performance of incinerators that operated without pollution control and the hazards they presented. Current arguments are based on the idea that incinerators are still not safe, but when examined in the light of modern day pollution controls and placed in context, the problems seem negligible. Other antagonists claim that the solid ash resulting from incinerators is evidence that incinerators do not effectively treat waste, but this claim seems unfounded. Waste will go to landfills whether incineration takes place or not, but incineration reduces the volume of that waste, saving space in landfills.

Toxics in incinerator ash are more concentrated than they are in unprocessed waste, but they are still subject to the controls that exist in a landfill, rendering the toxics no less safe than they would be if they were post-incineration or not. It is possible as well to fix ash in concrete to make disposal safer, and in some cases will allow the ash to be used in roads and paths (OGRA).

Dioxins and furans are another part of the toxics in incinerator ash, and they exist in gaseous emissions as well. Dioxins are strongly connected to EFW incineration in particular as not only are the dioxins existing in waste emitted by incinerators, but new dioxins and furans are created during the burning of waste. As more information about the effects of dioxins and furans is gathered they may be revealed as the Achilles' heal of incineration. At present, however, as long as they are not emitted at levels above what is deemed to be acceptable and if incineration is used as part of a strategy to reduce the addition of dioxins to the food chain, incineration remains a viable waste management strategy.

One major argument against incinerators is that they present a false alternative to recycling, an alternative that is not as environmentally friendly or efficient as recycling or reducing waste. Incinerators are not an alternative to recycling. To ensure environmental soundness any and all materials that can be recycled or reused should be taken care of before waste is taken to the incinerator. There is no reason, in principle, why very aggressive recycling cannot take place in tandem with incineration and, in many cases, it does.

Issues related to recycling and the reduction of EFW efficiency due to lower calorific values do not point to the fact that incineration will reduce recycling rates. The incineration of recyclable material is neither ecologically sound, nor can it realistically be demanded by incinerator operators. While some waste streams that have had recyclables removed will result in lower energy production from EFW technology recycling is an area where the short term economic concerns of EFW companies will have to take a back seat to the economic and environmental concerns of the municipalities they serve. Incineration is feasible when it coincides with recycling, not when it competes with it.

A “Zero Waste” situation would be ideal, but according to the National Society for Clean Air and Environmental Protection, it is not feasible (NSCA). Certainly such a situation does not exist now and realistic waste management strategies for today must be developed. EFW incineration can be one of these strategies. EFW incineration is, at best, an effective way to deal with waste and generate energy after all possible recycling has taken place, and at worst, a solution for dealing with waste today while we progress toward the merely theoretical zero waste society.

Gasification, pyrolysis and plasma conversion have been shown, in some cases, to be more efficient and environmentally friendly than incineration (JCSL). With the higher efficiencies comes the economic incentive to gasify,or pyrolyse instead of incinerating, but whether this efficiency can be achieved or not depends on the scale, technology, fuel and other factors (JCSL). At this stage of development it is hard to make generalizations about the economics of incineration versus gasification or pyrolysis. Systems must be analyzed on a case by case basis (JCSL). It has been suggested that gasification and incineration are such different technologies that they should be treated with completely separate rules both economically and environmentally (Maxwell). However, as economic and scientific data are collected and analyzed and as presently immature alternative EFW technologies are developed the waste treatment question may become, “Why incinerate when you can gasify?” Nevertheless, incinerators that are currently operating, in light of the current evidence, seem to be acceptably clean sources of energy and part of a solution to the growing waste management problem.

The greatest problem facing incineration as an energy source is its negative public image. Pollution control, more efficient technologies, and the relative safety of incineration do not bridge the gap between EFW and its acceptance by the public. Unless the majority of a people are convinced that incineration is a safe practice it will be very difficult for their politicians to make significant inroads towards large scale EFW incineration. Thus, for Ontario, an in-depth look at the economic drivers, politics, legislation and other pertinent factors in other progressive jurisdictions is a sound way to start the ball rolling for thermal processing of residual MSW.

Appendix A: Units Used

kg (kilogram)): The base unit of mass in the S.I. (systeme internationale).

g (gram): One one-thousandth of a kilogram.

mg (milligram): $1X10^{-3}$ grams.

µg (microgram): 1X10-6 grams

ng (nanogram): $1x10^{-9}$ grams

pg (picogram): $1X10^{-12}$ grams

g TEQ (Gram Toxicity Equivalent): A mass equal in toxicity to one gram of dioxin or furan with a toxicity equivalence factor of 1.

T (tonnes): Defined as a unit of mass equal to 1000 kilograms and in the Imperial System as a weight of 2,000 pounds.

kt (kilotonnes): 1000 tonnes.

lb (pounds): The base unit of force in the Imperial System of units.

Ton: A unit of mass equaling 907.18 kg

s (second): The base unit of time in the S.I.

m (meter): The base unit of distance in the S.I.

mm (millimeter): One one-hundredth of a meter.

µ (micron): $1X10^{-6}$ meters.

m^3 (cubic meter): A volume of three dimensional space one meter by one meter by one meter.

Rm^3 (reference cubic meter): One cubic meter at 25 °C and 101.3 kPa.

dscm (dry standard cubic meter): One cubic meter at standard conditions.

Nm3 (Normal cubic meter): One cubic meter at standard conditions.

°C (degree celsius): A measurement of temperature in the S.I.

Appendix A: Units Used (con't)

Pa (Pascal): The unit of pressure in the S.I. One Pascal is equal to one Newton divided by one cubic meter.

kPa (kilopascal): One thousand Pascals.

N (Newton): The unit of force in the S.I. One Newton is the force required to accelerate one kilogram of mass by one meter per second squared.

ppb (parts per billion): A measurement of concentration. 1 ppb of a substance indicates that of 1 billion parts of a solution one part will be of the given substance.

ppmv (parts per million by volume): A measurement of concentration in terms of volume.

J (Joule): The base unit of energy in the S.I.

MJ (megaJoule): $1X10^6$ Joules

W (Watt): One Joule per second.

kW (kiloWatt): 1000 Watts

MW (megaWatt): $1X10^6$ Watts.

GW (gigaWatt): $1X10^9$ Watts.

TW (teraWatt): $1X10^{12}$ Watts.

MWth (thermal megaWatt): One megaWatt of thermal energy.

kWh (kiloWatt hour): The energy consumed when one kiloWatt is exerted for one hour.

MWh (megaWatt hour): The energy consumed when one megaWatt is exerted for one hour.

TWh (terawatt hour): The energy consumed when one teraWatt is exerted for one hour.

L (Litre): A measurement of volume in the S.I.

Appendix B: Manufacturers of EFW Technology

Manufacturer	**Country**	**Website**	**Services**	**Major Incinerator Supplier (MIS), Small Incinerator Specialist, (SpI)or "Alternative EFW" Supplier (AE)**
TodaySure Projects	USA	http://www.todaysure.com/	Supplier of EFW incinerators	SpI
HS Thermal Engineering Ltd.	UK	http://www.hstherm al.co.uk/	Design and Manufacture of Combustion and Incineration equipment	MIS
GEM Canada	Canada	http://www.gemcanadawaste.com/4436.html	manufacture of incineration EFW systems	AE
International Waste Industries	USA	http://www.iwi-systems.com/mainpage.html	Design, Manufacture, and Installation of EFW incinerators	MIS
Enercon Systems, Inc.,	USA	http://www.enerconsystems.com/intro.htm	Manufacturer and Supplier of Energy from Waste systems including combustion and pyrolysis systems.	MIS & AE
Enerwaste International Corp.	USA	http://www.enerwaste.com/	Design, installation, and construction of EFW systems	MIS
Energy Products of Idaho	USA	http://www.energyproducts.com/	Manufacturer of combustion EFW systems.	SpI
Barlow Projects Inc.	USA	http://www.barlowprojects.com/150000.htm	Manufacture of EFW incineration facilities	MIS

Manufacturer	**Country**	**Website**	**Services**	**Major Incinerator Supplier (MIS), Small Incinerator Specialist, (Spl)or "Alternative EFW" Supplier (AE)**
Changing World Technologies	USA	http://www.changingworldtech.com/home.html	Manufacture TCP (Thermal Conversion Process) Plants. TCP is similar to pyrolysis	AE
Renewable Environmental Solutions	USA	http://www.res-energy.com/index.asp	Manufacture and operation of TCP (thermal conversion process) plants.	AE
Integrated Environmental Technologies	USA	http://www.inentec.com/	Design, build and market Plasma Enhanced Melters which convert waste to electricity and other useful bi-products	AE
Startech Environmental Corp	USA	http://www.startech.net/plasma.html	Design, manufacture, service of Plasma Converters, converting waste to energy	AE
Nathaniel Energy	USA	http://www.nathanielenergy.com/home_frame.cfm	Design, Manufacture of Thermal Combustors, which are really just gasifiers that combust their gas	MIS
ThermoEnergy Corporation	USA	http://www.thermoenergy.com/whois.htm	Design of EFW reactors and new pollution control methods.	MIS

Manufacturer	Country	Website	Services	Major Incinerator Supplier (MIS), Small Incinerator Specialist, (SpI)or "Alternative EFW" Supplier (AE)
Crochet Equipment Co.	USA	none	Manufacture of thermal combustion EFW equipment	MIS
ECO waste solutions	Canada (burlington)	http://www.ecosolutions.com	Manufacture of "ECO waste oxidizer" thermal combustion involving pyrolysis	SpI
Thermogenics Inc.,	USA	http://www.thermogenics.com/	Designs, builds and installs waste-to-energy systems based on its patented gasification system	AE

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