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PERSPECTIVE

Review of current technologies used in municipal solid waste-to-energy facilities in Canada

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Abstract The increasing amounts of municipal solid waste produced accompanied with the rising need for energy has caused a growth in the popularity of waste-to-energy (WTE) facilities as waste and energy solutions for many regions in Canada. The recent commercially viable WTE facilities across Canada show that the main technologies used in Canada are incineration, gasification, and plasma gasification. The aim of this study is to present these WTE technologies through the examination of case studies taken from the existing facilities across Canada. Background information on case studies, information on the WTE process, and a comparison highlighting the differences between the facilities are discussed.

Keywords Municipal solid waste · Waste-to-energy process · Incineration · Gasification · Plasma gasification

Introduction

Municipal solid waste (MSW) is becoming a major environmental concern as the waste produced by municipalities all over Canada is continually increasing with the population growth. In addition, the growing population's demand for energy is also steadily rising, hastening the depletion of energy reserves and increasing the need for alternative sources of energy. Waste-to-energy (WTE) facilities serve the dual purpose of both reducing the amount of MSW sent to landfills while also producing electricity. In general, MSW composition on a wet weight basis mainly consists of a large organic fraction (40–60 %), ash and fine earth (30–40 %), paper (3–6 %) and plastic, glass and metals (<1 %). The C to N ratio ranges between 20 and 30, and the lower calorific value ranges between 800 and 1,000 kcal/kg (Sharholy et al. 2008).

According to the Environmental Protection Agency (EPA), WTE processes are those processes that recover energy from non-recyclable wastes and such processes are considered to be part of waste management hierarchy. The products of WTE processes can take any forms including heat, electricity, or fuel coming from gasification, anaerobic digestion, combustion, pyrolysis, or landfill gas recovery. The aim of converting non-recyclable waste materials into heat and electricity is not only to produce a renewable energy source but also to reduce carbon emissions (Environmental Protection Agency (EPA) 2014). In the literature (i.e., Nixon et al. (2013), different variations of WTE technologies are described, compared and evaluated with respect to energy produced/mass of MSW processed.

Internationally, a great number of facilities using WTE technologies are being deployed, most notably in countries such as USA, UK, Germany, and the Netherlands (Wood et al. 2013). Similarly, Canada has also seen many plans and proposals in implementing WTE technologies as a solution to problems in dealing with MSW and energy consumption.

Waste-to-energy facilities offer multiple functions such as diverting MSW from landfills, replacing fossil fuels for electricity generation, and lowering the carbon footprint. Although incineration is currently widely used WTE technology, there are increasing interests in the development of more advanced WTE technologies to improve

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performance. The emerging technologies convert solid wastes into gaseous fuels such as syngas followed by purification. The clean fuel produced is either used in a high-efficiency combustion engine (e.g., gas turbine) to generate electricity, or it is processed in a catalytic reactor to produce liquid biofuels such as methanol or bio-ethanol. Different technology vendors have specific variations on the process to enhance conversion efficiency and tailor the end-products to site-specific markets. These emerging technology facilities, within the same technology category, can have different characteristics. Implementation of these emerging technologies depends on factors such as waste composition, local waste feedstock supply, market prices for electricity and fuels, and distance to the available markets for products. As most of the emerging technology facilities are still operated as demonstration plants, there is very limited information available concerning the performance on energy, environmental, and cost of these widely diversified facilities.

A review of different WTE technologies such as those used in Canada, for understanding how the emerging technologies perform differently from incineration, is particularly important for filling this critical information gap. Thus, the objective this study is to present recent WTE technologies used in Canada through examination of case studies. The case studies (Table 1) are comprised of currently existing facilities across Canada and each case study will have an overview of the facility and WTE process methods used for further understanding of how these technologies are implemented.

Incineration facilities

The first technology, incineration, is the oldest WTE technology, and involves the combination of combustion of MSW, heat recovery methods, and flue gas cleaning to create electricity while causing minimal harm to the environment. The combustion process during incineration is done at temperatures above 850 °C and releases combustion gases while leaving behind bottom ash which is removed and dealt with appropriately (Wood et al. 2013). Numerous methods of heat recovery are used to increase the efficiency of incineration, with the main source of electricity coming from the heat recovered from the combustion gases, usually through the use of a boiler to create steam. Flue gas cleaning is perhaps the most important part of the incineration process, as all stack gases released from facilities must adhere to the in-stack emission limits placed by the provincial government. Restrictive stack gas parameters include particulate matter, oxides of nitrogen (NO_x), acid gases (i.e., SO_4, HCl), heavy metals (i.e., Hg, Pb), and dioxins and furans (Wood et al. 2013).

Metro Vancouver waste-to-energy facility (WTEF)

Metro Vancouver's WTEF opened in 1988 and is maintained and operated by Covanta Energy Corporation's Covanta Burnaby Renewable Energy Division. The WTEF typically processes almost 300,000 tons of waste per year to create 180,000 MW·h of energy. Of the 1 million tons of steam produced, around 20 % of steam is sold to neighboring facilities (Metro Vancouver 2012).

The process begins with the unloading of waste into a refuse bunker (Fig. 1). The waste is mixed and is transported via an overhead crane into feed chutes. The feed chutes transport the waste into the incinerator where the waste is burned at temperatures over 1,000 °C. Residue created from incombustible materials is called bottom ash and accounts for roughly 17 % of the waste fed into the process. Bottom ash is treated with phosphoric acid in order to stabilize metals

Table 1 Facility information

Company	Facility	Location	Technology	Product produced	Start date
Covanta Energy Corp.	Metro Vancouver WTEF	Burnaby, BC	Incineration	Steam	1988
U-PAK Group of Companies	Emerald Energy from Waste Inc.	Brampton, ON	Incineration	None	1992
Plasco Energy Group Inc.	Plasco Trail Road Demonstration Facility[a]	Ottawa, ON	Plasma gasification	Syngas	2008
Navitus Plasma Inc.	Dufferin Eco-Energy Park EFW Facility	East Luther-Grand Valley, ON	Plasma gasification	None	2011[b]
Nexterra Systems Corp.	UBC Bioenergy Research & Demonstration Facility[a]	Vancouver, BC	Gasification	Steam	2012
Enerkem	Enerkem Alberta Biofuels LP	Edmonton, AB	Gasification	Biomethanol	2014

[a] Commercial demonstration facility

[b] Date of project proposal

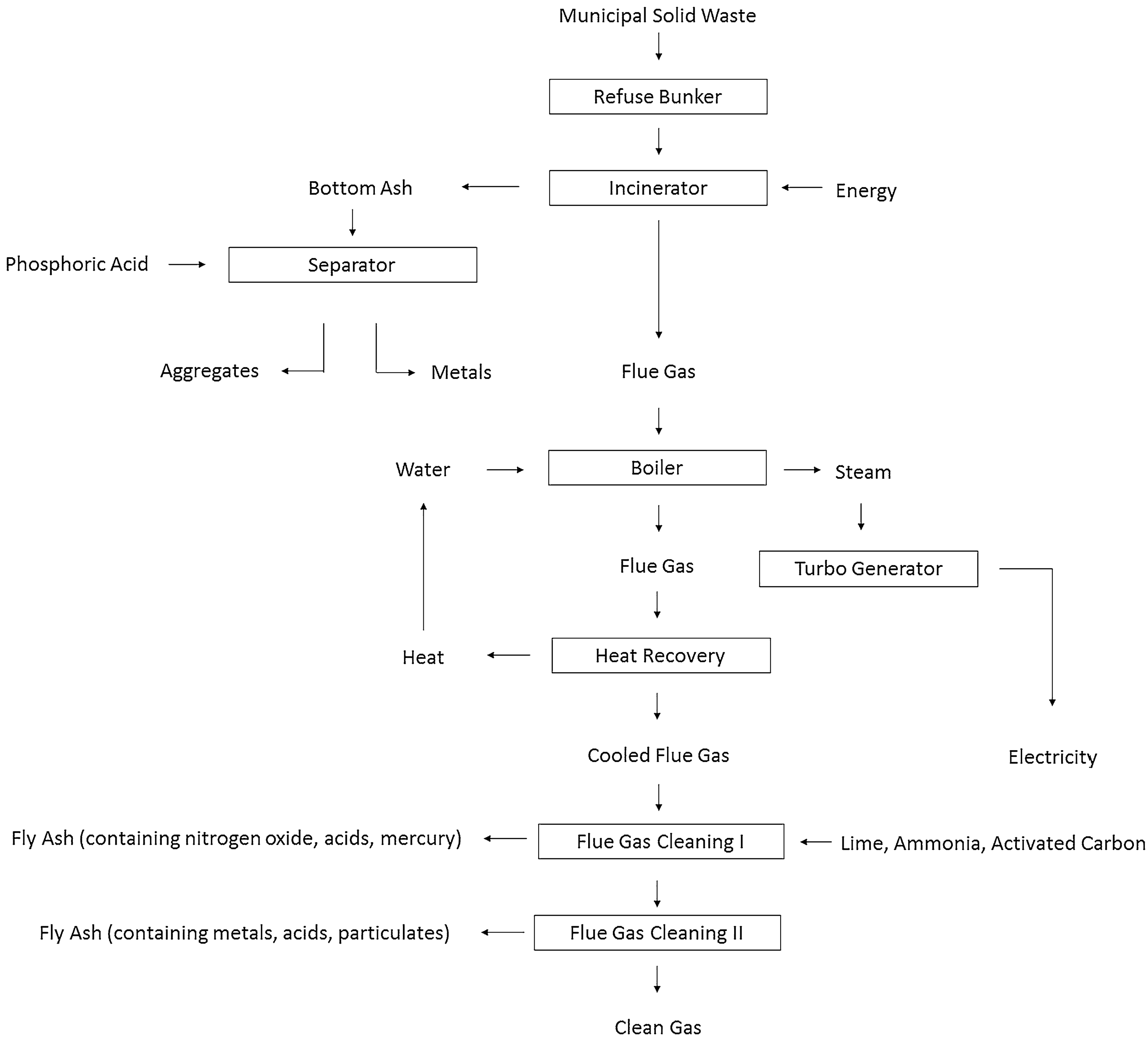


Fig. 1 Metro Vancouver Waste-to-Energy Process

before their removal and the remaining ash is used as aggregate material. The heat and gases released from the incinerator move to a boiler where water is converted into steam and the gases are cooled. The steam created from the boiler turns a turbo generator to produce electricity. The gases coming out from the boiler are further cooled and the recovered heat is used to heat incoming boiler water. The gases then enter the flue gas cleaning system. In the first section of the flue gas cleaning system, lime, ammonia, and activated carbon are injected to clean the flue gas of acid gas, nitrogen oxides and mercury. The flue gas then travels through a series of fabric bag filters to remove any remaining acids, metals, and particulate matters. The cleaned flue gas is then discharged through the stack.

Emerald Energy from Waste Inc.

Opened in 1992 as part of a public-partnership between Algonquin Power and the Region of Peel, the facility located in Brampton averages 150,000 tons of waste processed every year to create a maximum of 27,000 MW·h of electricity. The facility was purchased by U-PAK Group of Companies in 2014 and the facility was renamed from Algonquin Power Energy from Waste Inc. to Emerald Energy from Waste Inc. (U-PAK Group of Companies, 2014).

The incineration process begins with the collection of waste that is unloaded into a storage area before being transported to the combustor (Fig. 2). A transfer ram

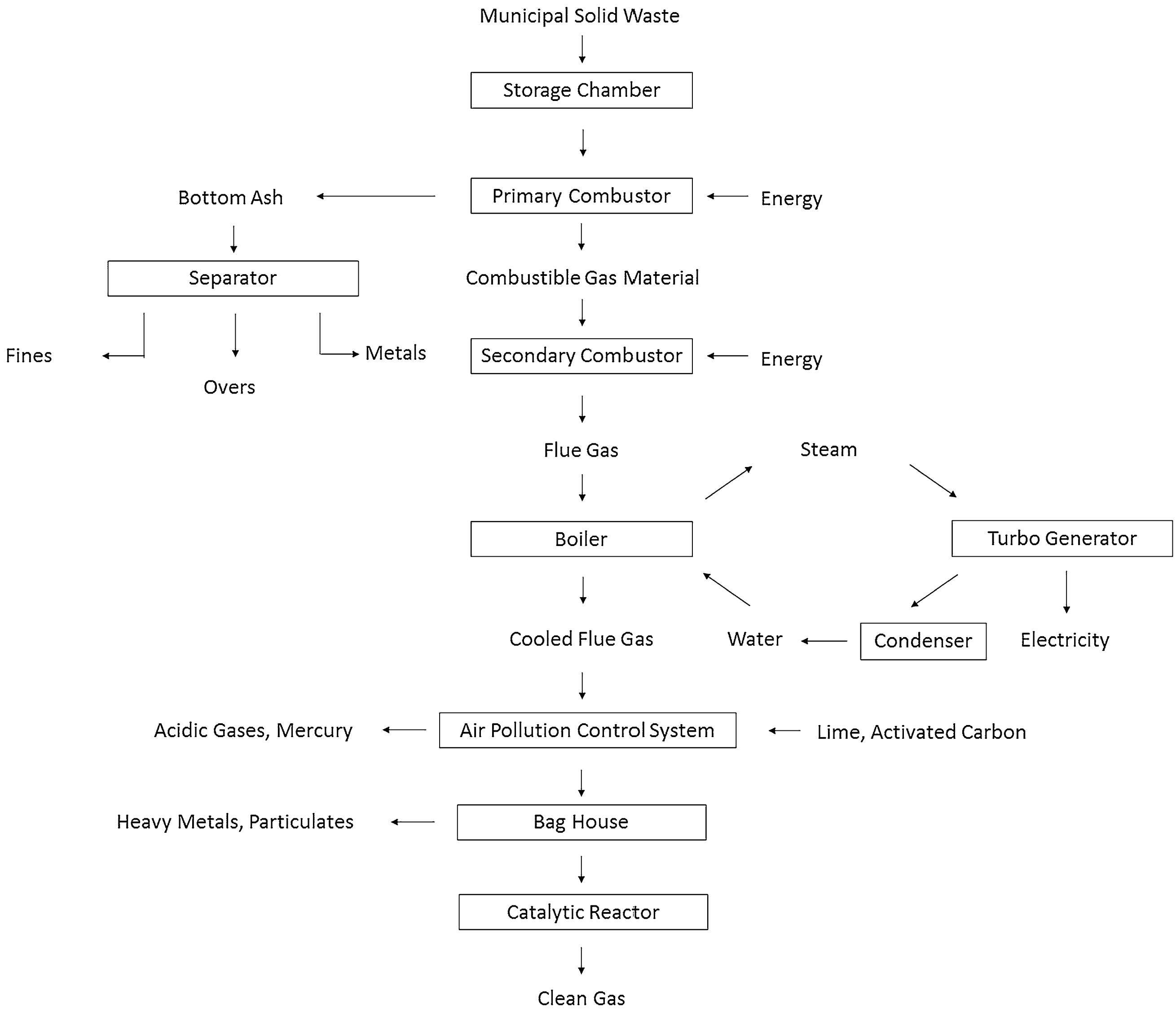


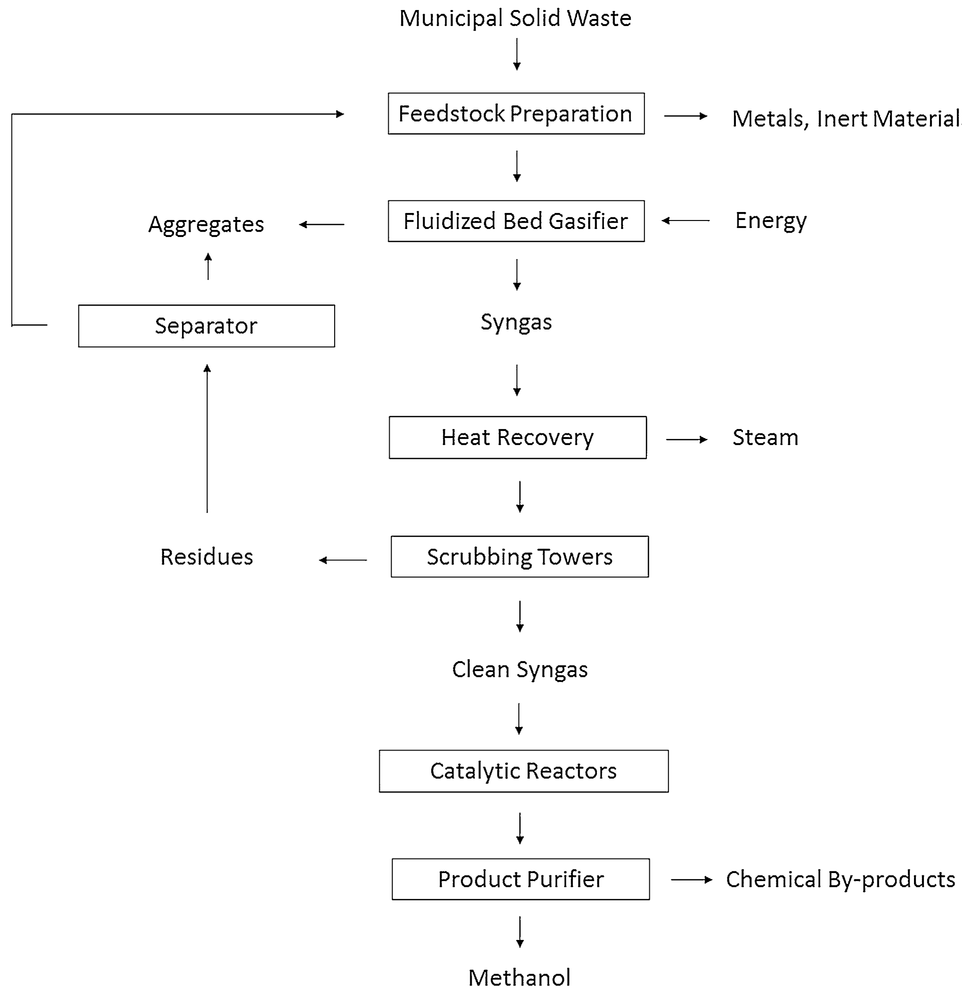
Fig. 2 Emerald Energy from Waste Inc. waste-to-energy process

moves the waste from the storage area into the thermal combustor. The waste is burned in the primary combustor for 6 h in an air-starved environment. Transfer rams mix the garbage to ensure thorough combustion of waste. Ash leftover from the primary combustor is removed and is sorted into ferrous material (6 %), "overs" (22 %), and "fines" (72 %). Overs consist of materials larger than 1 inch, while fines consist materials smaller than 1 inch. The fines can be used as cover in landfills or aggregate material (Dodds 2010). Combustible gas material is moved to the secondary chamber for further combustion. Combustion in the secondary chamber is done at minimum temperatures of 1,000 °C (Dodds 2010). Flue gas generated during the combustion process is transported to a heat recovery boiler where the heat from the flue gas is used to create steam. The steam produced turns a turbine which generates electricity and the cooled flue gas continues to the Air Pollution Control (APC) system. In the APC system, hydrated lime and powdered activated carbon are added to the flue gas to adsorb acidic gases, mercury, and dioxins. The flue gas then travels to the baghouse, a chamber which uses a vacuum alongside of filters to remove particulates in the flue gas. The flue gas then continues to a selective catalytic reactor which is located at the base of the stack. The reactor reduces oxides of nitrogen and dioxins. The clean leftover flue gas then leaves through the stack.

Gasification facilities

For gasification, the MSW is heated up to temperatures usually around 900 °C in environments where the amount

Fig. 3 Enerkem process



of air and oxygen is controlled in order to gasify the waste. The gasification process is a partial oxidation reaction of the MSW, thus creating the syngas instead of combustion gases as seen with incineration. The syngas created from gasification generally has the heat recovered, is cleaned and then utilized depending on what is desired. Similar to incineration, gasification also creates bottom ash which needs to be removed and properly treated.

Enerkem Alberta Biofuels LP

Officially inaugurated as of June 4, 2014, the facility is currently following a commissioning plan before beginning operation for commercial purposes. The facility, located in Edmonton, is part of a MSW to biofuels initiative in partnership with the City of Edmonton and Alberta Innovates—Energy and Environment Solutions. At the start of commercial operation, the facility is expected to convert 100,000 tons of waste into 38 million liters of biofuel per year (City of Edmonton 2014). The facility will initially produce biomethanol as the final product, and by the end of 2015, a module to convert biomethanol into ethanol is expected to be added (Enerkem 2010).

The Enerkem Process begins with the preparation of the waste into appropriate feedstock (Fig. 3). The waste is sorted both mechanically and manually to remove inert materials, compostable materials, and metals. The waste is then shredded and dried if needed before transferring to the gasifier. The gasifier used is a fluidized bed gasifier which produces the primary syngas along with a bottom residue of solid matter that can be used as aggregate material. The syngas travels through a heat recovery unit. Then the syngas is cooled and the heat is recycled for other uses. The syngas then enters the scrubbing tower which cleans the syngas of any leftover residue into a clean syngas made up primarily of CO and H_2. The residue is removed and separated into inert material that can be used as aggregate material, and the material that can be gasified is transported back to the gasifier. The clean syngas which enters a catalytic reactor is converted into methanol and other chemical by-products. The product purifier

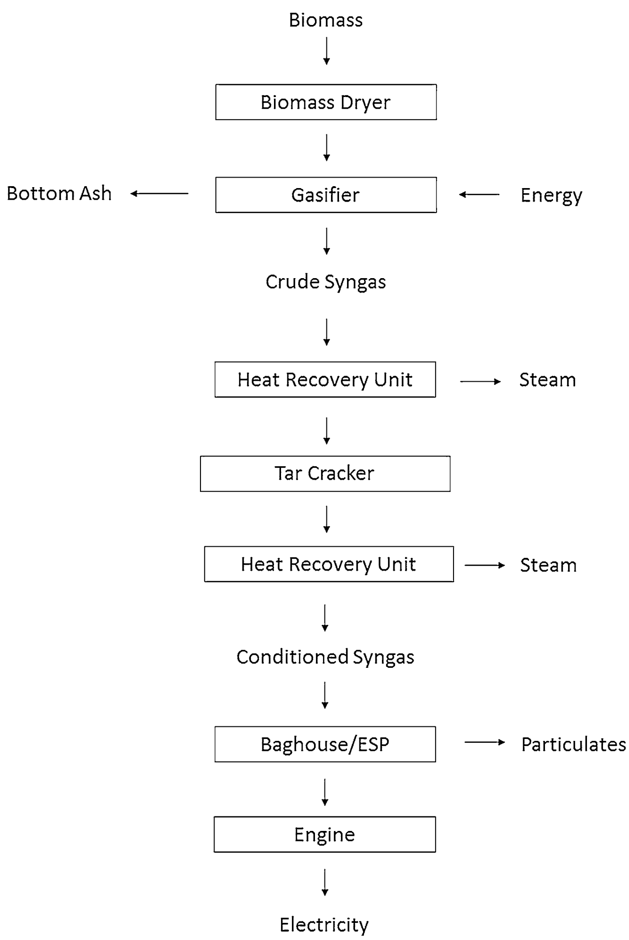


Fig. 4 Nexterra CHP system

separates the methanol from the other by-products leaving methanol that can be used as biofuel. After the implementation of the conversion module to convert methanol into ethanol, both methanol and ethanol will be possible end-products of this process (City of Edmonton 2014).

UBC Bioenergy Research and Demonstration Facility

In 2012, operation of the UBC Bioenergy Research and Demonstration Facility began at University of British Columbia. The facility uses wooden materials and biosolids as feedstock and utilizes energy from renewable waste combined with heat and power (CHP) system, which incorporates both Nexterra's gasification and syngas conditioning technologies and GE's highly efficient combustion engines to produce electricity and heat. This commercial demonstration facility is the first of its kind in North America and converts 12,500 tons of dry wood waste to produce 15,000 MW·h of electricity per year. In addition, the system also creates steam approximately 490 tons of steam per year that is used to heat the university campus (Nexterra 2013).

The process begins with the drying of the wood biomass from anywhere between 50 and 70 % into 20 % moisture level (Fig. 4). The dried biomass is then transported to a storage facility where the biomass is fed into the gasifier via a horizontal auger. Inside the gasifier, the biomass is exposed to controlled amounts of air, steam, and oxygen at temperatures ranging from 815 to 950 °C (Nexterra 2013). Temperatures are constantly regulated to ensure ash does not melt and inhibit ash flow while still being able to properly gasify the biomass. The ash produced in the gasifier is removed using augers into ash hoppers for removal and the syngas is transported to the syngas conditioning system. The syngas flows through a heat recovery unit to cool the syngas while creating steam. The syngas then enters a tar cracker, a unit which uses catalysts to reform the tar in the syngas without affecting the rest of the syngas (Sundac 2007). The conditioned syngas, now free of any tar, once again flows through a heat recovery unit to recover the heat released. The syngas is then filtered using a baghouse or electrostatic precipitator (ESP) to remove any particulates in the syngas. The syngas is finally used to run a specified high-efficiency engine created by GE to produce electricity.

Plasma gasification facilities

Although quite similar to gasification, plasma gasification utilizes plasma created from either plasma electrodes or plasma torches in order to gasify the MSW. Gasification using plasma usually heats the MSW to temperatures well over 1,000 °C, which melts solid residue or otherwise solid residue turns into an inert slag. The slag is removed and generally used as some sort of aggregate material. The syngas produced from plasma gasification is cleaned much like in gasification.

Plasco trail road commercial demonstration facility

In 2008, Plasco Energy Group Inc. began operation of the Plasco Trail Road Commercial Demonstration Facility (PTR) in a joint project with the City of Ottawa. The facility is designed to convert 36,500 tons of MSW per year into energy. The company states that the conversion efficiencies of the facility are above expectations and is delivering syngas that is able to produce 1 MW·h of electricity per ton (Risto 2011). As stated in the Final Assessment Report by Plasco Energy Group, the facility was able to process 1,433 tons of MSW to generate 174 MW·h of electrical power in only 644 h of operation, equivalent to approximately 18,000 tons of MSW and 2,200 MW·h per year, in the last period of assessment (Risto 2011).

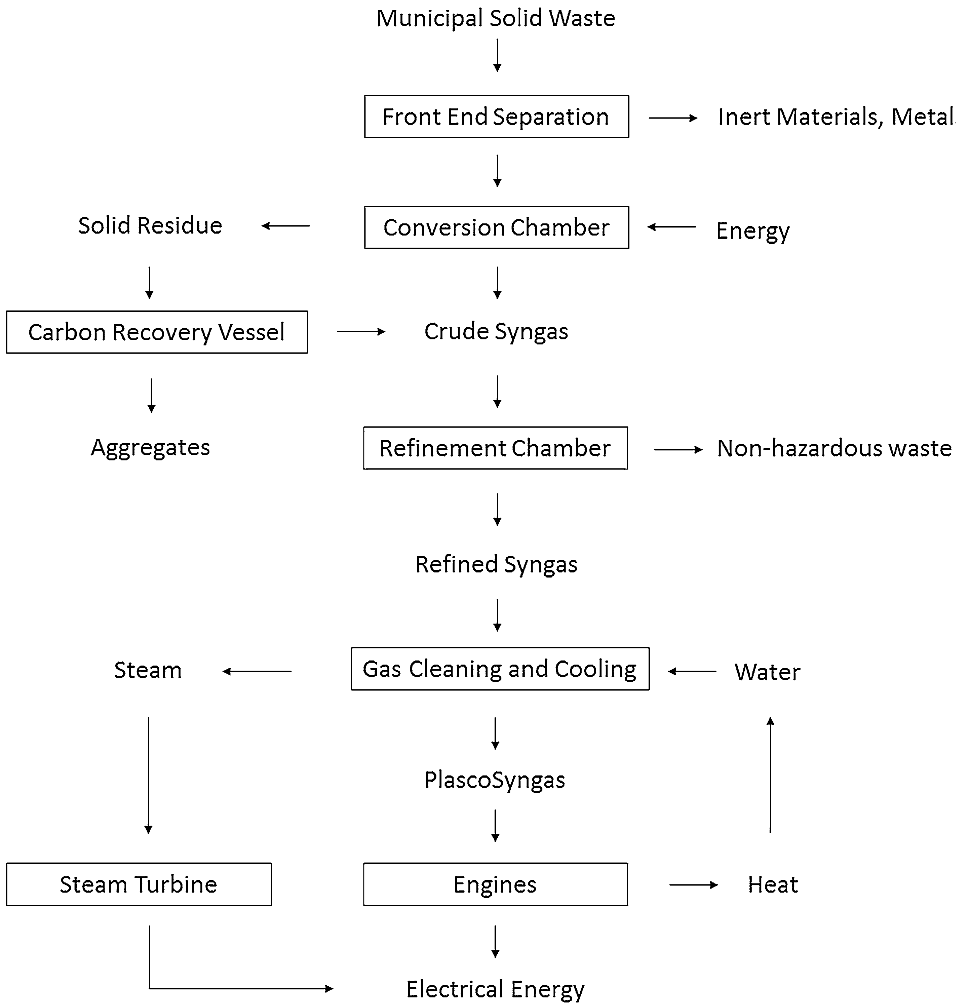


Fig. 5 Plasco waste-to-energy process

The waste conversion process begins with front end separation (Fig. 5). During this stage, any inert materials with no calorific value are removed and the MSW is then shredded and any metals present are removed. The MSW is moved to the conversion chamber where gasification takes place. A crude syngas is created using heat recovered from the downstream process. In order to improve the efficiency of the process by minimizing residual waste and increasing the heating value of the syngas, residue from this step is sent to the carbon recovery vessel where a plasma torch is used to recover the residual carbon from the solid residue. The syngas in the conversion chamber is combined with the syngas from the carbon recovery vessel in the refinement chamber where process air and plasma refine the crude syngas into a cleaner, lighter syngas. Solid particulates resulting from this refinement stage are stabilized through a vitrification process followed by rapid cooling to create an inert, non-hazardous waste product called slag. The refined crude gas then passes through a heat recovery unit and is then cleaned of particulates, metals, and acid components. A clean, synthetic fuel gas, deemed Plasco Syngas, suitable for use in internal combustion engines to generate electricity is the final result of this process (Risto 2011; Tsangaris at al. 2014). Heat recovered during the gasification process and waste heat from the engines can be used to generate additional electricity using a steam turbine.

Dufferin Eco-Energy Park EFW Facility

As part of the Dufferin Eco-Energy Park (DEEP) Project, Navitus Plasma Inc. had planned to integrate an energy-from-waste facility which uses Westinghouse Plasma Corp.'s patented gasification technology. The proposed facility was estimated to process almost 100,000 tons of MSW per year generating approximately 24,500 MW·h (Navitus Plasma Inc. 2011). The project was originally proposed in 2011, however, due to factors such as the lack of waste produced in the region of Dufferin and

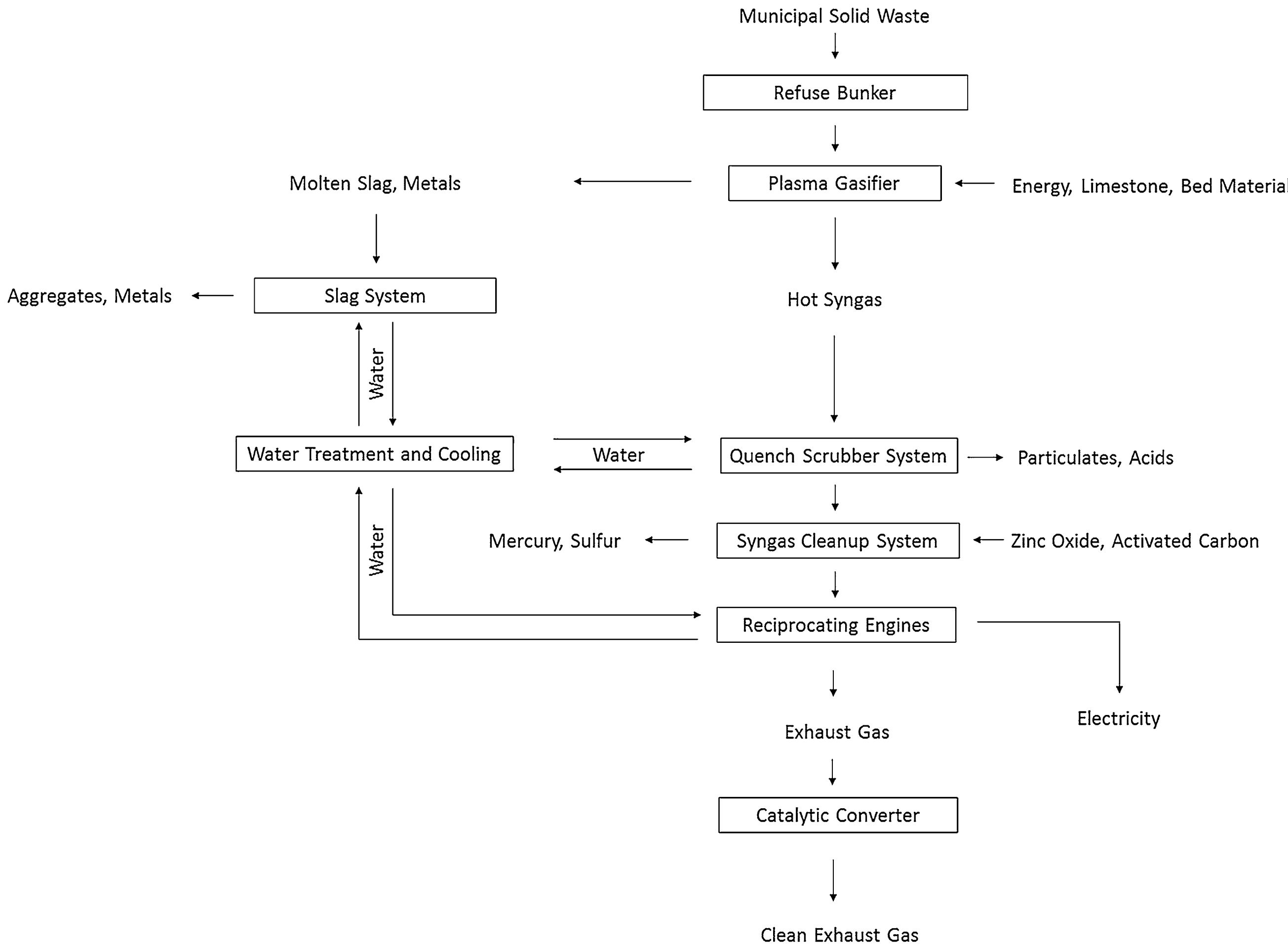


Fig. 6 Dufferin waste-to-energy process

changes in Dufferin's waste collection relationships with other areas, the project was struggled to acquire enough support and was finally abandoned in 2014 (Halliday 2014).

The proposed process begins with the unloading of MSW into bunkers (Fig. 6). A shredding device will reduce the size of waste to a maximum size of 150 mm and the shredded waste is then transported using an enclosed conveyor to the plasma gasifier which uses technology patented by Westinghouse Plasma Corporation (Navitus Plasma Inc 2011). Bed material, which is manufactured on-site through recovered particulate matter, and limestone are also added. The bed material provides spaces for molten slag and metals to pass through for removal and the limestone will act as a fluxant to increase the flow of slag. Air and oxygen are injected from an oxygen plant which separates air into nitrogen and oxygen, while plasma torches produce the heat required to gasify the waste fed into the gasification vessel. The molten slag and metals removed from the gasification chamber flow into a water quench system where the slag and metals are separated and solidified. The metals and aggregate material can then be sold. The hot syngas produced in the gasification vessel then enters a venturi scrubber system which injects water to both cool the syngas as well as for cleaning the syngas of fly ash. A spray tower then utilizes a caustic water wash to further remove any particulates while also neutralizing acids into salts which dissolve into the water and are also washed away. The syngas then enters the syngas cleanup system, which removes sulfur through a packed bed using zinc oxide sorbent and mercury using activated carbon (Navitus Plasma Inc 2011). The cleaned syngas is then sent to a bank of reciprocating engines. The engines are water cooled and the syngas drives the electric generator to produce electricity. Exhaust gas from the engines travel to a catalytic converter which reduces the oxides of nitrogen and other pollutants. The resulting exhaust gases consist of mainly CO_2, water, nitrogen, and oxygen and are released through the stack. The water is used to quench the slag, syngas, and to cool the engines.

Table 2 Facility Production per Year

Company	Facility	Waste processed (tons)	Electricity generated (MW·h)	Product produced	Amount of product for sale/use
Covanta Energy Corp.	Metro Vancouver WTEF	300,000	180,000	Steam	200,000 tons
U-PAK Group of Companies	Emerald Energy from Waste Inc.	150,000	27,000		
Plasco Energy Group Inc.	Plasco Trail Road Demonstration Facility	18,000	2,200	Syngas	n/a[a]
Navitus Plasma Inc.	Dufferin Eco-Energy Park EFW Facility	100,000	24,500		
Nexterra Systems Corp.	UBC Bioenergy Research & Demonstration Facility	12,500	15,000	Steam	490 tons
Enerkem	Enerkem Alberta Biofuels LP	100,000		Biomethanol	38,000 m^3

[a] Information is not available

Conclusions

In conclusion, a review of the three categories of WTE technologies currently used in Canada covering incineration, gasification, and plasmas gasification are discussed. The review includes six case studies with different processes used in the WTEF. From the data presented, one may deduce efficiencies of the process by estimating energy produced/mass of wastes processed however such an assessment will be misleading due to limited availability of the data on the feedstock used in all case studies (Table 1).

It is important to note that the values given in Table 2 can be misleading in determining the efficiencies of each facility. Factors such as the composition of the waste, the amount of waste processed, and the amount of product used toward electricity generation can greatly influence the data in the table when comparing waste processed with the amount of electricity generated. For example, the two facilities in British Columbia, Metro Vancouver WTE Facility, and UBC Bioenergy Research and Demonstration Facility, are likely being fed waste composed of more high cellulose content materials than the average. Because of this fact, the amount of electricity produced per ton of waste will be higher than the amounts produced in other regions (Glaser 2007).

Compared to incineration, beneficial offsets of gasification include clean fuels produced in the back-end of catalytic process and recovery of recyclables such as metals in the up-front sorting process. In looking at the most recent WTE facilities in Canada, it is apparent that the WTE industry is beginning to favor the newer technology of gasification and plasma gasification. While the incineration facilities existing in Canada predate the year 2000, all facilities utilizing gasification and plasma gasification were proposed and deployed only in the past decade. It can also be seen that the WTE industry as a whole is growing in popularity in Canada, with half of the facilities presented proposed after the year 2010.

It is also seen from the case studies that the functionality and practicality of the facilities are highly influenced by the region where they are located. The Enerkem Alberta Biofuels LP is seen to create methanol and later on ethanol, highly likely due to the fact that Alberta hosts many major facilities that are able to efficiently process fuels. The UBC Bioenergy Research & Demonstration Facility is able to use biomass and biosolids as the main feedstock due to heavy lumber industry existing in British Columbia. As well, the DEEP Facility had the proposal discontinued due to a change in the need for such a facility as time passed.

In a study conducted in 2011, it states that WTE processes which focus more on the production of electricity with limited co-generation products results in an ineffective energy utilization of waste (Pavlas et al. 2013). In a comparison study, it was found that facilities focusing on electricity production obtained a 20 % efficiency compared to a 64 % efficiency for facilities concentrating heat production (Pavlas et al. 2013). Thus, facilities in more urban areas are able to utilize steam (heat production) efficiently and produce steam as a product in addition to generating electricity.

Economically, the amount of post processing required to reach environmental restrictions is much higher for incineration than gasification. In cases where electricity is not the primary product in the gasification process, flue gas affecting the environment is less of a concern. In cases where gasification does indeed primarily produce electricity, the amount of flue gas created is lower in comparison to that of incineration. Due to the reduced amount of flue gas produced and the fact that the flue gas itself is cleaner than in incineration, the capital investment required for flue gas post processing is much lower for gasification (Dvořák et al. 2009).

Canada and the World

According to the data collected from government publications and reports, amount of MSW produced globally is projected to nearly double from 3.5 million tons/day to 6 million by 2025 (Hoornweg and Bhada-Tata 2012).

Making up the majority of this amount are the Organization for Economic Co-operation and Development (OECD) region and the East Asia and Pacific (EAP) region. These two regions will see the most needed WTE technologies in finding methods in managing the region's waste, and it is especially important to introduce these technologies to countries in the EAP region as the region is projected to see an increase in MSW by more than 1 million tons/day by 2025 (Hoornweg and Bhada-Tata 2012).

Canada, as one of the countries in the OECD region, can influence its region as it develops WTE technologies to help the industry grow in popularity. As the industry grows in popularity, more research and resources will be spent on improving the technologies and methods. Forms of WTE technologies already exist in many countries in process industries where waste is used to decrease costs of production of cement, alloys, aluminum etc. (Villar et al. 2012). Countries which have these technologies integrated into their industries are not too far from taking the next step in the construction and operation of WTE facilities.

In the past, many concerns regarding stack emissions have been addressed in studies and research, particularly in Europe with the introduction of the new directive to reduce pollution due to waste incineration (Pařízek et al. 2008). This shift toward gasification technologies in Canada may be mirrored in other countries in the near future as the emissions from gasification are much cleaner and require least post processing than incineration. Policymakers of individual countries are also very responsible in allowing for the development of WTE technologies by creating incentives for companies and individual actors who go beyond the minimum environmental requirements (Kim 2002).

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