



# Investigation of Residual Waste Processing Systems

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An investigation and review of residual waste processing systems originally completed by the City of Kingston in 2007 as part of Phase B of the Integrated Waste Management System study

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## 1.0 Introduction and Background

The City of Kingston is currently developing an integrated waste management plan designed to: further conserve resources; reduce environmental impacts and greenhouse gas emissions; and, reduce the overall dependence on landfill disposal. With public consultation included as a key element of each phase of activity, the integrated waste management study will identify a preferred solid waste management system for the City. The recommended system will help the City increase the amount of material it recycles and composts and further reduce the amount of material sent to landfill each year.

The integrated waste management study is being conducted in the following phases:

- Phase A:** Definition of Long-term Waste Management System Objectives (complete)
- Phase B:** Identification of Preferred Long-term Management System Approach (ongoing)
- Phase C:** Identification of Preferred System Technology and Practices
- Phase D:** Development of Preferred System Implementation Strategy

Phase A has been completed. Phase B is nearing completion and a draft report has been issued.

As part of Phase A, the following waste management hierarchy was proposed and has been adopted by Kingston City Council:

1. Prevention / Avoidance (reduce overall waste generation through behavioural or technological change)
2. Enhanced Design for Reduction or Reuse
3. Product Reuse
4. Material Recycling, Composting and Anaerobic Digestion
5. Resource Recovery (recovery of fuels and/or materials for secondary use)
6. Thermal Treatment with Energy Recovery
7. Landfill with Energy Recovery
8. Landfill or Thermal Treatment without Energy Recovery.

The elements of the hierarchy represent waste management programs and actions to be undertaken by the City, listed in descending order of preference and priority.

Among other recommendations relating to the preferred long-term waste management approach for the City, the draft Phase B report includes the following recommendation:

*“The City of Kingston further investigate systems for Residual Waste Processing identified as a component of the preferred System #2 to process the waste that remains after recycling and composting in consideration of the waste management hierarchy.”*

The purpose of this investigational report is to provide an update on the initial investigations completed in 2007 with respect to the above recommendation and reconfirm the suitability of this recommendation.

The residual waste processing technologies identified in the draft Phase B report are categorized as follows:

- Mechanical Treatment;
- Biological Treatment;
- Mechanical/Biological Treatment (MBT);
- Thermal Treatment; and,
- Refuse Derived Fuel (RDF).

The Phase A report presented projections of waste and recycling quantities for the planning period (2006 to 2031). In 2010, the City achieved a 55% diversion rate resulting in the need to only dispose of 18,589 tonnes of post-diversion residual waste. Figure 1 illustrates projections of future quantities of residual waste requiring processing or disposal. The upper solid line represents the current status quo scenario which reflects Kingston’s recent diversion achievements of 55% in 2010 and assumes that the City will maintain that diversion rate into the future.

**Figure 1 – Projections of Residual Waste Requiring Processing or Disposal**



The dashed line represents the City’s target of reaching 65% diversion as defined in the integrated waste management plan. The integrated waste management study identifies numerous opportunities for waste reduction and diversion to assist in moving towards this target.

Residual waste quantities in the range of 20,000 to 25,000 tonnes per year will be assumed as a starting point for consideration of the potential applicability of residual waste processing technologies.

Section 2 of this report presents information related to residual waste processing technologies in fulfillment of the above referenced recommendation of the draft Phase B report. Section 3 summarizes the major findings of this report.



## 2.0 Waste Processing Technologies

Residual, post-diversion, waste can be processed by various means prior to final disposal. The benefits of residual waste processing can include: reduction in volume/weight of waste; recovery of material and/or energy; and, stabilization of waste. The following provides information regarding each of the residual waste processing technologies and reference information regarding the application of these technologies elsewhere.

### 2.1 Mechanical Treatment

Mechanical treatment is a well established technology category that has been used in many different contexts to increase the capture rate of recyclable materials. Mechanical treatment could be considered to process mixed wastes prior to disposal. Mechanical treatment can capture additional recyclables and improve the consistency of the mixture of waste material for biological and thermal processing. It can also be used for the management of respective process residues to capture additional recyclable content (e.g. metal) flowing through the different processes. Essentially, the mechanical treatment process operates like a traditional blue box recycling facility. In a mechanical treatment facility, residual waste is received, the bags are opened up and then materials such as metals and plastics are recovered from the waste.

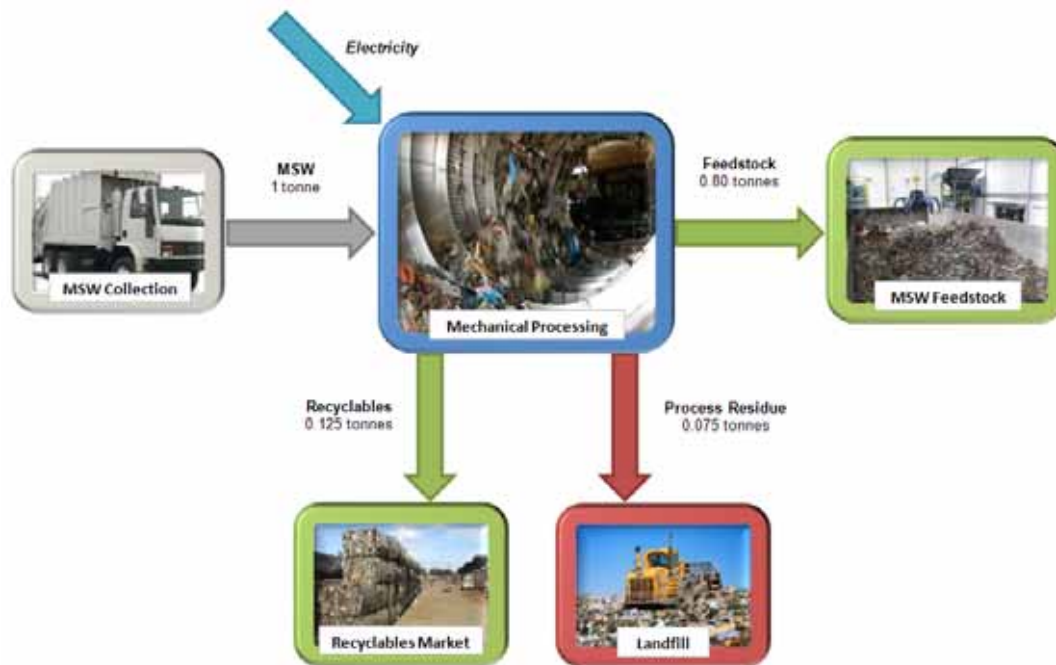
#### 2.1.1 Technology Description

In mechanical separation and recovery processes, the garbage, or municipal solid waste (MSW) stream is first sorted mechanically to produce homogenous waste streams. Mechanical technologies generally remove metals, recyclables and unprocessable material. The mechanical process often includes conveyors, bag breakers, ferrous magnets, grizzlies, eddy current separators, trommel screens, old corrugated cardboard (or OCC) sorting systems, optical sorters and shredders. The segregated material streams produced from mechanical sorting can be recycled or utilized in some of the other treatment technologies described herein.

Many material separation and recovery facilities are in commercial-scale operation throughout North America, and established markets generally exist for most of the recovered materials.

Some examples of conveyor vendors include: Custom Conveyor; United Conveyor; and Pro Baler. Screen Vendors include: CP Manufacturing; Machinex; RRT; and, Van Dyke.

Figure 2 – Schematic Diagram of a Mechanical Processing System



### 2.1.2 Industry Experience and Reference Facilities

There are a number of operating material recovery facilities (or MRFs) operating throughout Canada and the U.S. that utilize mechanical treatment equipment. These facilities are typically used to process Blue Box waste streams or other more homogenous waste streams such as Construction and Demolition materials.

## 2.2 Biological Treatment

Biological treatment involves the use of microorganisms such as bacteria to change the properties of the organic components of the waste stream. Essentially, biological treatment breaks down and stabilizes organic matter such as food waste and waste paper. This approach offers the potential for a relatively stable landfill with reduced odours and other nuisance impacts. Considering the proportion of organics remaining in the residual waste stream, this alternative may be applicable to addressing the purpose of the undertaking. The biological treatment technology typically applied to managing a residual waste stream is typically anaerobic digestion.

### 2.2.1 Technology Descriptions

#### 2.2.1.1 COMPOSTING

Composting is a biochemical process that stabilizes the putrescible fraction of an organic material under controlled conditions. It is a naturally occurring process that breaks down organic material into humus. Composting is typically performed aerobically in a moist environment. The process generates heat, CO<sub>2</sub>, and, in some cases, methane. The process must be managed to keep it within an ideal temperature range to allow bacteria to work most effectively and to sterilize undesirable compounds. Composting technologies can use a building or other structure, or the raw material can be placed in windrows, piles,



or large plastic bags. The process also requires a way to control the moisture content and periodically turn the material. Generally, composting can be performed in-vessel or in the open-air, and is most often applied to the separated organic waste portion of the waste stream only.

Composting has been performed on a commercial-scale on source separated organics (SSO) and most commonly on leaf and yard waste in North America and abroad. Attempts in Europe and North America with composting a mixed MSW stream have had mixed success due to inorganics and other contaminants affecting the application marketability of the compost product. Odours are often a potential issue with both composting and anaerobic digestion processes. The Edmonton Composting Facility, located in Alberta, is one of the largest co-composting facilities in North America; handling up to 200,000 tonnes per year of residential waste and up to 25,000 tonnes per year of dewatered sludge. The Edmonton facility features an in-vessel, mechanical, rotating drum technology that co-composts the waste and biosolids. Based on a recent survey by Biocycle (November 2010), there are eleven operating mixed MSW composting facilities in operation in the U.S. While the facilities listed above have been operating for several years, there were also several large scale facilities in the U.S. that failed for technical and/or financial reasons

### **2.2.1.2 ANAEROBIC DIGESTION**

Anaerobic digestion (or “AD”) is the process of biologically converting the organic fraction of the MSW stream using bacteria in an oxygen-deficient environment to produce a combustible biogas composed primarily of methane (about 60% by volume). It has been extensively used to digest and stabilize sewage sludge and animal manures, and has had recent application treating SSO. The AD process may either be a “wet” process that converts the feedstock into a liquid slurry, or a “dry” process (also referred to as Dry Fermentation) where the feedstock is retained in a stacked pile as a stationary solid. Anaerobic digestion can take place in one or two phases. Typically, anaerobic digestion is a two-phase process in which the first phase blends into the second one without a noticeable interruption. These two phases are known as the “acid phase” and the “methane-producing phase” (methanogenic phase).

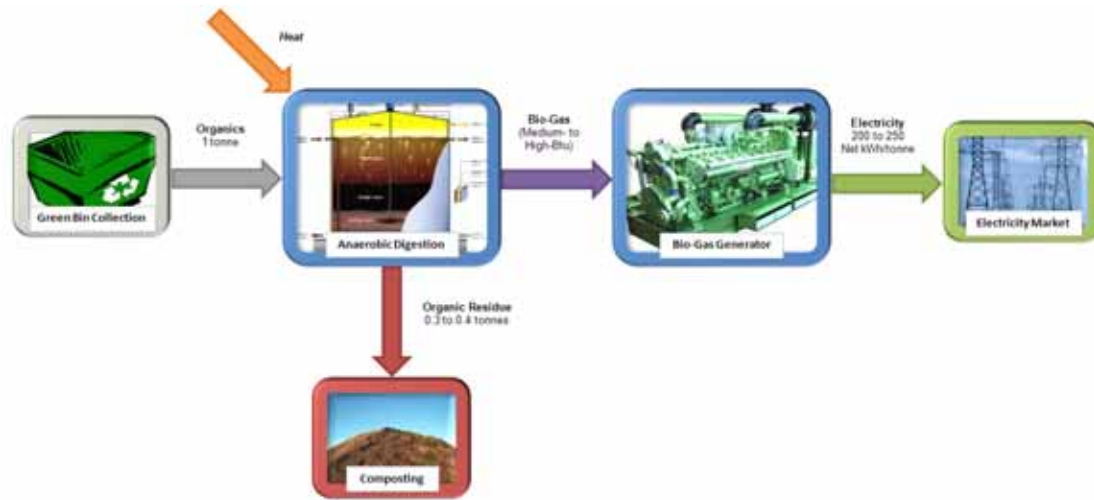
The end products of anaerobic digestion are: biogas, compost and a slurry. The biogas consists primarily of methane (approximately 60% by volume), carbon dioxide (approximately 40%), and trace amounts of hydrogen, hydrogen sulfide, and other gases (typically less than one percent). The resulting low- to mid-energy-content biogas can be utilized in a reciprocating engine or gas turbine to produce electricity, or can be compressed into pipeline quality or a vehicle fuel.

The incoming mixed MSW or SSO will require a pre-treatment process that involves shredding, pulping and separation of the non-compostable fraction of the waste stream. In many cases, this technology can be used in conjunction with composting and mechanical biological treatment (MBT).

AD is widely used on a commercial-scale basis for industrial and agricultural wastes, as well as wastewater sludge. AD technology has been applied on a larger scale in Europe on mixed MSW and SSO. There has been only limited commercial-scale applications in North America, most of them located in Ontario. The City of Toronto has a commercial-scale AD plant for processing SSO at the Dufferin Transfer Station. Another commercial-scale AD facility was located in Newmarket but has been plagued with odour issues and is currently not accepting SSO. There are a number of smaller facilities in the U.S. operating on either mixed MSW, SSO, or in some cases co-digested with biosolids.

An example of vendors that offer AD technologies includes: Arrow Ecology; BTA; Urbaser (Valorga International); Mustang Renewable Power Ventures; Ecocorp; Organic Waste Systems; and, Greenfinch.

**Figure 3 – Schematic Diagram of an Anaerobic Digestion System**



### 2.2.2 Industry Experience and Reference Facilities

There are a number of operating facilities throughout Europe, particularly in Germany and other parts of northern Europe. The list of facilities below is a small sample of the existing commercial scale facilities in North America.

Facility Location	Design Capacity	Technology Type	Start-Up Date
<b>Dufferin, Ontario</b>	25,000 tonnes/year SSO 15,000 tonnes/year MSW	BTA Technology (Germany)	2002

## 2.3 Mechanical/Biological Treatment (MBT)

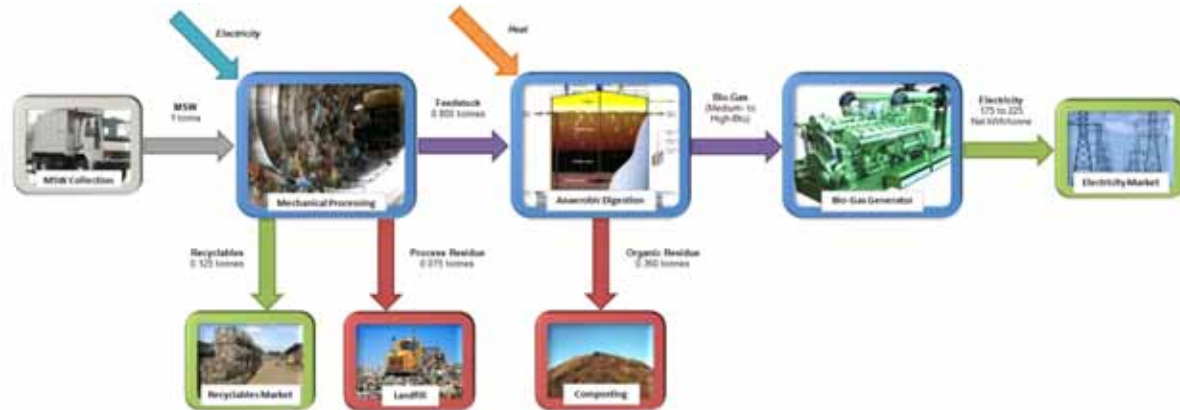
Mechanical Biological Treatment (MBT) systems combine mechanical sorting technologies and biological treatment. MBT is a term that can cover a range of residual waste treatment systems that combine mechanical and biological technologies. Most MBT systems involve mechanical processing to remove metals, glass and plastics from the waste stream that were not captured in the blue box program. This maximizes the diversion of recyclable materials, leaving a primarily organic fraction to be managed as part of the biological treatment process. The goal of the biological processing step is to reduce the volume of waste and to stabilize any biologically active materials. Some MBT systems may propose anaerobic digestion for the biological treatment, capturing the methane produced to provide energy for the plant. The stabilized residue can then be disposed of in landfill.

### 2.3.1 Technology Description

This technology is generally designed to process a fully commingled MSW stream. Processed materials include marketable metals, glass, other recyclables, and a refuse-derived fuel that can be used in another thermal technology process. Limited composting is used to break the MSW down and dry the fuel. The order of mechanical separating, shredding, and composting can vary. MBT is an effective and flexible waste-management method and can be built in various sizes and is often coupled with a

subsequent processing/treatment technology. MBT can alternatively be used to process the waste stream to produce a refuse derived fuel (RDF) that can be used in a thermal treatment process (e.g. combustion, gasification, etc.).

**Figure 4 – Schematic Diagram of a Mechanical/Biological Treatment System**



### 2.3.2 Industry Experience and Reference Facilities

There are a number of operating facilities throughout Europe, as well as a few facilities in Canada. The list of facilities below is a sample of the existing commercial scale facilities in Canada.

Facility Location	Design Capacity	Technology Type	Start-Up Date
Otter Lake, Halifax	120,000 tonnes/year	Various	1999
Edmonton, Alberta	200,000 tonnes/year MSW, 25,000 dry tonnes/year biosolids	Bedminster	2000

## 2.4 Thermal Treatment

Thermal treatment includes approaches such as combustion and gasification where the hydrocarbons in the waste stream are converted to thermal energy, carbon dioxide (CO<sub>2</sub>) and water. Based on recent industry activity in Ontario and facilities operating in other jurisdictions, it is evident that this alternative is reasonably available both from a commercial feasibility perspective and a technical perspective. Aside from the realization of a “zero waste” society, this alternative offers the best potential to minimize the amount of waste destined for landfill. Current thermal technologies can be broadly categorized as follows:

- Conventional Gasification;
- Plasma Arc Gasification
- Pyrolysis; and
- Traditional Combustion (or incineration).



Both gasification, plasma gasification and pyrolysis technologies are considered advanced thermal technologies and are normally followed by thermal oxidation of the synthetic gas. While there are different technological options within each of the three categories, the systems are generally classified within two groups: advanced thermal technologies and conventional combustion.

## **2.4.1 Technology Description**

### **2.4.1.1 CONVENTIONAL GASIFICATION**

Conventional thermal gasification is the process whereby solid organic matter is converted under controlled conditions of partial oxidation into fuel gases and other by-products (i.e. char and tars/oils). In addition to producing fuel gases for purposes of direct conversion into energy, the process can be used to produce chemicals such as methanol and liquid fuels. Appropriate feedstocks for gasification include coal, wood, and potentially the organic materials found in MSW. Partial oxidation is carried out by using less air than required for complete combustion of the fuel (i.e., sub-stoichiometric air), or by indirectly heating the organic matter. Heating temperatures range from 750° to 1,650° C. The gas that is produced is known as synthesis gas, syngas, or producer gas. Syngas consists primarily of carbon monoxide, hydrogen, methane, and other hydrocarbons, as well as CO<sub>2</sub> and N<sub>2</sub> in some gasification processes. The relative concentration of each gas depends upon the composition of the organic matter used and process operating conditions (temperature, pressure, etc.).

There are several types of gasification technologies, including updraft and downdraft (which refers to the direction of air flow in the reactor), bubbling or circulating fluidized bed gasifiers, which have many years of processing history on select feedstocks (e.g. woody biomass).

Gasification of various feedstocks has been demonstrated at different scales over the years. The gasification of coal and different types of wood has been used for many years. Similarly, gasification was used to produce a gaseous fuel for automobiles during World War II. In the 1980s and 1990s, gasification of various types of biomass was, once again, used to power vehicles and some stationary internal combustion engines. However, thermal gasification of MSW in North America has been limited to low processing capacities or at pilot types of operations, and has had limited operational history and success. Thermal gasification of is currently occurring mainly in Japan where the feedstock consist of higher energy or BTU materials which contains mostly industrial waste with smaller amounts of MSW mixed in. In addition, higher costs to operate such plants are economically viable in Japan's economy. Although many gasification unit sizes in Japan are processing between 100 and 250 tonnes/day, smaller modules of this technology can be built for throughputs from 40 tonnes/day and greater.

In general, the gasification process can be controlled and the outputs managed when the characteristics of the feedstock are relatively consistent. On the other hand, any time that the feedstock consists of mixtures of materials with variable characteristics such as MSW, the outputs can vary substantially (e.g., the composition of the gas as well as the ratio of gas to tar changes and thus the gas cleanup and the combustion engine do not perform as expected). In addition, consistent reliable operations are still in question for these facilities using MSW as a sole feedstock. In the absence of sufficient data for commercial-scale performance and operating costs, it is likely that the costs for operation of these plants will be fairly high compared to other MSW solutions.

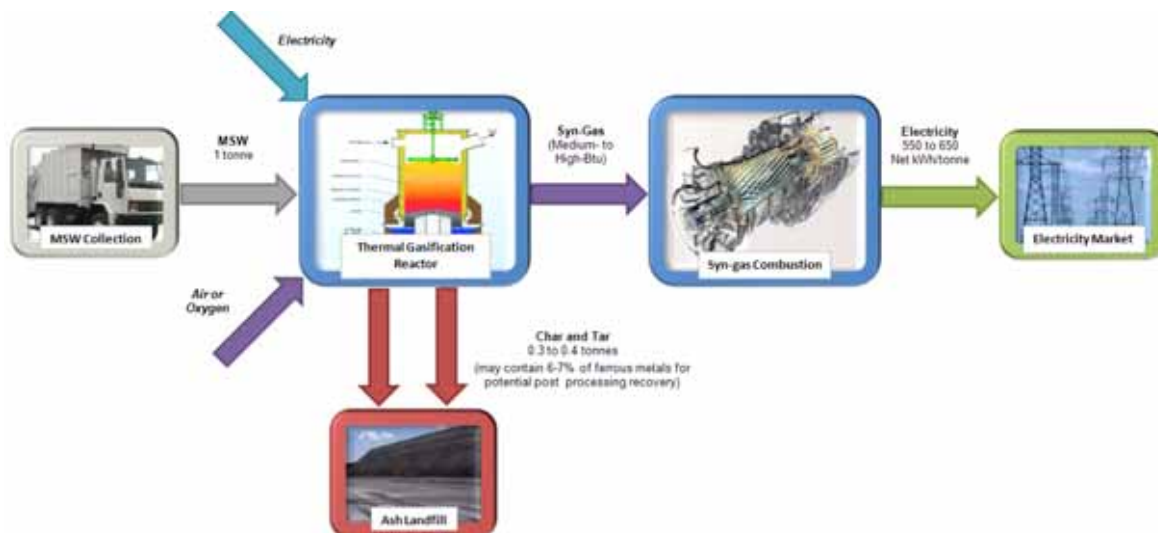
The technology proponents claim that this technology can generate energy in the range of between 550 and 650 net kWh/tonne of waste. Although data was not readily available, the use of power is

purportedly on the level with direct combustion, and water usage is purportedly less than that used with direct combustion. In Europe and particularly in Japan, the byproducts of gasification (i.e. char and tars) are beneficially reused as construction aggregate or as an additive in asphalt. If a similar use would be acceptable in Ontario, HDR would expect a gasification facility could potentially be developed as a zero-waste discharge facility.

The syngas generated can also be used as a chemical building block in the synthesis of gasoline, diesel fuel, alcohols and other chemicals. There are a number of technologies that currently have demonstration and pilot facilities in North America that are using some form of gasification of waste feedstocks for this purpose. The most notable of these technologies is Enerkem, which has a pilot facility in Quebec and is building commercial-scale facilities in Alberta and the United States.

Examples of a number of potential gasification vendors include: Thermoselect; Ebara; Primenergy; Brightstar Environmental; Taylor Biomass Energy; SilvaGas; Technip; Compact Power; PKA; and New Planet Energy.

**Figure 5 – Schematic Diagram of a Gasification System**



**2.4.1.1.1 Plasma Arc Gasification**

One special type of gasification technology being offered recently by the industry to handle MSW is plasma arc gasification. Plasma arc technology uses carbon electrodes to produce a very-high-temperature arc ranging between 3,000 to 7,000 degrees Celsius that vaporizes the feedstock. The high-energy electric arc that is struck between the two carbon electrodes creates a high temperature ionized gas (or plasma). The intense heat of the plasma breaks the MSW and the other organic materials fed to the reaction chamber into basic elemental compounds. The inorganic fractions (glass, metals, etc.) of the MSW stream are melted to form a liquid slag material, which when cooled and hardened, encapsulates heavy metals. The ash material forms an inert glass-like slag material that may be marketable as a construction aggregate. Metals can be recovered from both feedstock pre-processing and from the post-processing slag material.

Similar to gasification, the MSW feedstock is pre-processed to remove bulky waste and other undesirable materials, as well as for size reduction. Plasma technology also produces a syngas; this fuel

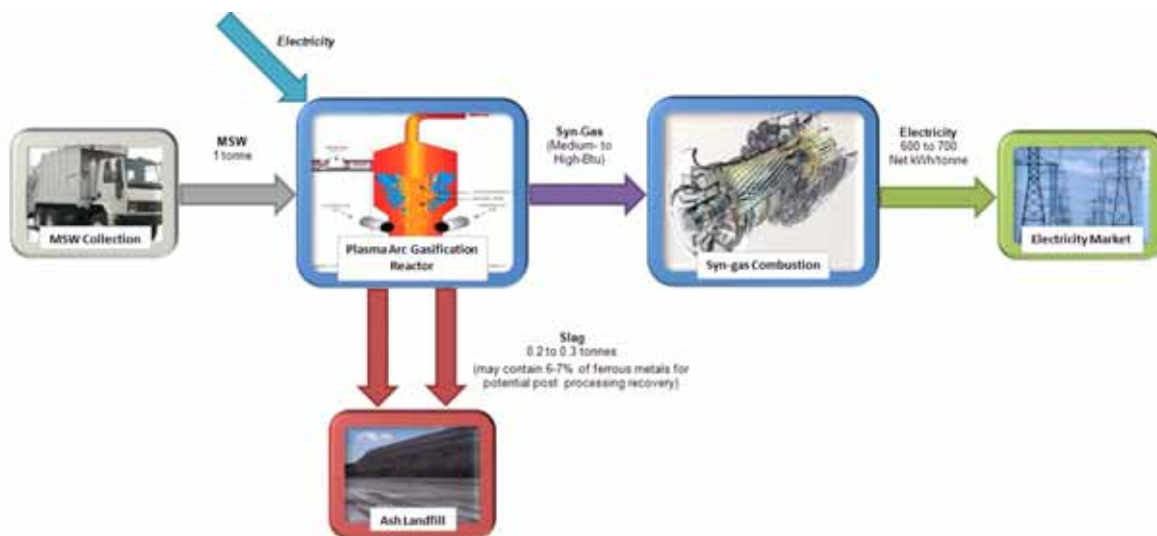
can be fired directly in a boiler, or the syngas can be cleaned and then combusted in an internal combustion engine or gas turbine. Electricity and/or thermal energy (i.e. steam, hot water) can be produced by this technology. Vendors of this technology claim efficiencies that are comparable to conventional mass burn technologies (600-700+ kWh/tonne (net)). Some vendors are claiming even higher efficiencies (900-1,200 kWh/tonne (net)). These higher efficiencies may be feasible if a combined cycle power system is proposed. A great deal of electricity is required to generate the plasma arc, as well as power other auxiliary systems. This high power input demand suggests that the net energy balance of the overall plasma arc gasification and energy conversion system should be carefully scrutinized when verifying feasibility.

This technology claims to achieve lower harmful emissions than more conventional technologies, like mass burn and RDF processes. However, air pollution control equipment similar to other combustion technologies would still be required for the clean-up of the syngas or other off-gases.

Plasma technology has received considerable attention recently, and there are several large-scale projects being planned in North America (e.g. Saint Lucie County, Florida; Atlantic County, New Jersey). In addition, there are a number of demonstration facilities in North America, including the Plasco Energy Facility in Ottawa, Ontario and the Alter NRG demonstration facility in Madison, Pennsylvania in the U.S. PyroGenesis Canada, Inc., based out of Montreal, Quebec, also has a demonstration unit (approximately 9 tonnes per day) located on Hurlburt Air Force Base in Florida is in start-up.

There are a number of Plasma Arc technology vendors, including: Plasco Energy Group; Alter NRG; PyroGenesis Canada, Inc.; Startech; AdaptiveArc; Integrated Environmental Technologies; and, Geoplasma.

**Figure 6 – Schematic Diagram of a Plasma Arc Gasification System**



**2.4.1.2 PYROLYSIS**

Pyrolysis is a process whereby organic matter is converted to gaseous, liquid, and solid fuels under high temperatures (approximately 350° to 800°C) nearly absent of oxygen. The appropriate feedstocks for pyrolysis could include coal, wood, and theoretically organic materials in MSW. Pyrolysis is similar to the



gasification process, but pyrolysis generally occurs at lower temperatures due to the lesser availability of oxygen. Similar to the case of thermal gasification, the pyrolysis process can be designed to optimize the production of gases or liquids. Syngas can be used as fuel in boilers, or in internal combustion units or gas turbines, provided that the gas is adequately cleaned. Pyrolysis technology proponents claim that this process will yield an energy production of a net 400 to 500 kWh/tonne of incoming waste; however we are not aware of scientific demonstration of these outputs. Parasitic electrical usage for this type of facility is similar to that of direct combustion. In addition, there are claims that the water usage for this technology is lower than direct combustion, and close to the water use of gasification. Based on similar treatment technologies, we would expect that this technology could be designed as a zero-waste discharge facility by returning any surplus water back into the process.

The technology vendors assert that a facility can be developed in modular form; we understand that unit sizes can range from 40 to 200 tonne/day throughput.

The pyrolysis process is performed in an air- or oxygen-free environment, and therefore the system usually must have a complex design and control system to prevent air or oxygen from intruding into the process, or a provision must be incorporated into the design to purge air from the reaction chamber. However, we have seen in many instances that this process usually introduces a very small amount of air/oxygen into the system.

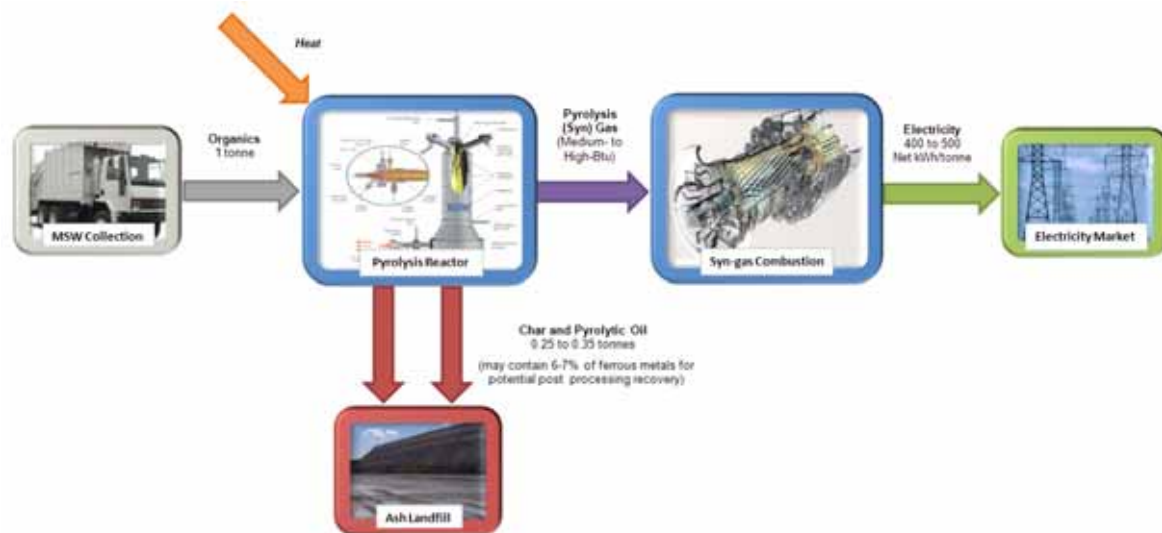
Air emissions from waste conversion systems employing pyrolysis are primarily those discharged from the energy recovery device, which, for example, could be an internal combustion engine-generator set or a steam boiler. The treatment of syngas produced from pyrolytic processing of MSW for use in energy conversion equipment and emission control of syngas constituents has little history but is believed to be somewhat similar to the process of gasification described above.

Similar to conventional gasification systems, the syngas generated in a pyrolysis system can be used as a chemical building block in the synthesis of gasoline, diesel fuel, alcohols and other chemicals. There are a number of technologies that currently have demonstration and pilot facilities in North America that are using some form of gasification of waste feedstocks for this purpose. The most notable of these technologies is Enerkem, which has a pilot facility in Quebec and is building commercial-scale facilities in Alberta and the United States.

Several projects employing a pyrolysis process have been developed over the years to treat MSW or specific feedstock materials typically found in MSW. Some of the facilities have processed MSW at the pilot-scale and at the demonstration-scale; however, none have been developed to a commercial scale in the United States. Similar to the situation with gasification, pyrolysis of mixed organic residues has had limited operational history and success.

Some examples of vendors that offer the pyrolysis technology include: Brightstar Environmental; Mitsui; Compact Power; PKA; Thide Environmental; WasteGen UK; International Environmental Solutions (IES); SMUDA Technologies (plastics only); and, Utah Valley Energy.

Figure 7 – Schematic Diagram of a Pyrolysis System



### 2.4.1.3 TRADITIONAL COMBUSTION OR INCINERATION

#### 2.4.1.3.1 Mass-Burn Combustion

Mass burn combustion technology can be divided into two main types: (a) grate based, waterwall boiler installations; and (b) modular, shop erected combustion units with shop fabricated waste heat recovery boilers. The modular units are typically limited to less than 200 tonnes per day and are historically used in facilities where the total throughput is less than 500 tonnes per day. The larger mass burn combustion process with waterwall boilers feed MSW directly into a boiler system with no preprocessing other than the removal of large bulky items such as furniture and white goods. The MSW is typically pushed onto a grate by a ram connected to hydraulic cylinders. Air is admitted under the grates, into the bed of material, and additional air is supplied above the grates. The resulting flue gases pass through the boiler and the sensible heat energy is recovered in the boiler tubes to generate steam. This creates three streams of material: steam, flue gases and ash. The steam is sent to a turbine generator and converted into electrical power. In the smaller modular mass burn systems, MSW is fed into a refractory lined combustor where the waste is combusted on refractory lined hearths, or within a refractory lined oscillating combustor (e.g. Laurent Bouillet). Typically there is no heat recovery in the refractor combustors.

Mass burn technologies utilize an extensive set of air pollution control devices needed for flue gas clean-up. The typical air pollution control equipment used includes: either selective catalytic reduction or non-catalytic reduction for NO<sub>x</sub> emissions reduction; spray dryer absorbers or scrubbers for acid gas reduction; activated carbon injection for mercury and dioxins reduction; and a fabric filter baghouse for particulate and heavy metals removal.

Large-scale and modular mass-burn combustion technology is used in commercial operations at more than 80 facilities in the U.S., two in Canada, and more than 500 in Europe, as well as in Asia.

Examples of larger-scale grate system technology vendors (some offer more than one design) include: Martin GmbH; Von Roll Inova; Keppel Seghers; Steinmuller; Fisia Babcock; Volund; Takuma; and Detroit

Stoker. Some examples of smaller-scale and modular mass burn combustion vendors include: Enercon; Laurent Bouillet; Consutech; and, Pioneer Plus.

**2.4.1.3.2 Fluidized Bed Combustion**

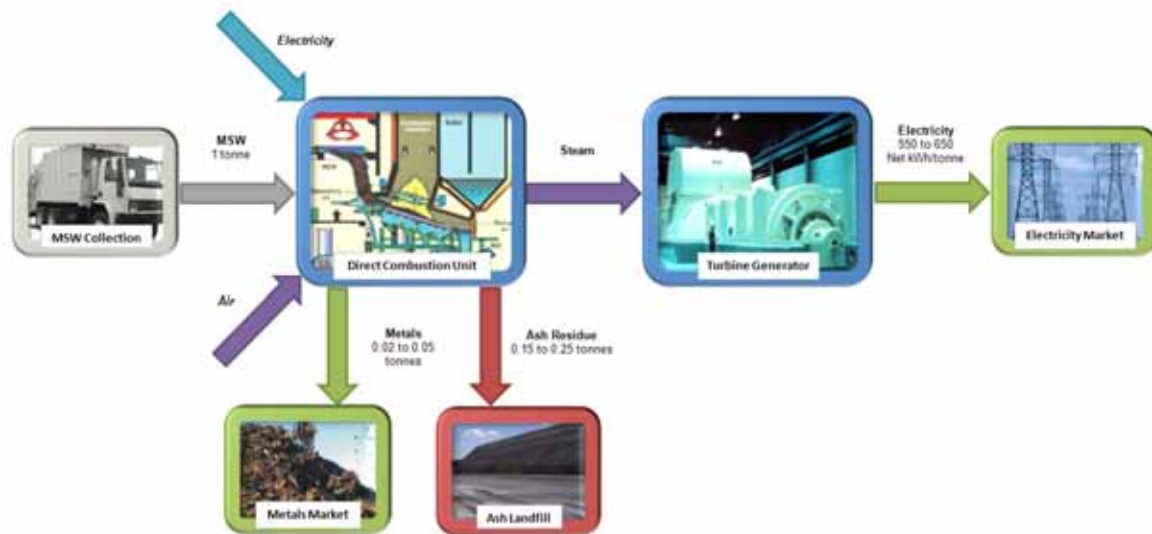
This technology uses a fluidized bed of circulating sand to combust MSW. The technology requires the use of a front-end processing system to produce a consistently sized feedstock similar to the system described below for RDF technology. Much of the metal, glass, and other non-combustible materials are removed during the front-end processing. Combustion performance and stable operation has been reported to be a challenge at some facilities, although some operational advantages could offer opportunities for better performance. A downstream waste heat boiler is used for thermal recovery, and air pollution controls are generally similar to that for mass-burn combustion.

One advantage of the fluidized bed technology is that lime can be added directly to the combustion chamber, which helps better control acid gases (e.g. sulfur dioxide (SO<sub>2</sub>)). Generally, NO<sub>x</sub> emissions are lower in fluidized bed units than for mass-burn facilities. However, the air pollution control equipment required would still be similar to mass burn and RDF combustion units.

This technology is in limited commercial use in the U.S. for waste applications with only one commercial-scale operating facility located in La Crosse, Wisconsin. Fluidized bed combustion is more commonly used for certain other biomass materials and for coal combustion. It is more often considered for more uniform waste streams, such as woody wastes, tires, and sludge.

Some examples of fluidized bed combustion technology vendors includes: Environmental Products of Idaho (EPI); Von Roll Inova; Foster Wheeler; and Ebara.

**Figure 8 – Traditional Combustion or Incineration Systems**



**2.4.2 Industry Experience and Reference Facilities**

There are over 80 traditional combustion facilities (i.e. mass burn and RDF combustion) operating in North America, and more than 400 facilities operating in Europe and Japan. There are also commercial scale gasification-type systems operating in Europe and Japan on select feedstocks and some MSW, as

well as a number of demonstration and pilot facilities in North America. The list of facilities below is a small sample of the existing commercial scale facilities in North America.

Facility Location	Design Capacity	Technology Type	Start-Up Date
<b>Brampton, Ontario</b>	160,000 tonnes/year	Modular Mass Burn (Consutech)	1989
<b>Burnaby, B.C.</b>	770 tonne/day	Mass Burn (Martin GmbH)	1988
<b>Detroit, Michigan</b>	1,000,000 tonnes/year	RDF Combustion	1991
<b>Sault St. Marie, Ontario</b>	1,000 tonnes/year	Elementa Rotary Kiln Gasifier	2007
<b>Westbury, Quebec</b>	125,000 gallons of methanol and ethanol annually	Gasification-to-Ethanol	2009
<b>Ottawa, Ontario</b>	100 tonne/day	Plasma Arc Gasification	2007 – currently not in operation

## 2.5 Refuse Derived Fuel (RDF)

Refuse derived fuel systems involve pre-processing of incoming waste to produce a “refuse derived fuel” (RDF) and subsequent use of that fuel as a substitute for some of the conventional fossil fuels in industrial manufacturing (e.g., cement kilns), utility power generation and institutional (e.g., district heating) applications. Mechanical processing of the waste is utilized to recover combustible materials from the waste. The direct advantages of processing waste into an alternative fuel include: improved air emissions; better ash quality; economic benefits from recovered marketable recyclable materials; and, access to a greater range of potential energy recovery opportunities given the readily transportable state of the solid recovered fuel. The indirect advantages lie in the net environmental benefits of replacing consumption of fossil fuels (typically coal) with RDF, which may be used in place of conventional non-renewable carbon sources in heat intensive industrial applications such as cement manufacturing after required approvals are in place. It can also be used at electricity generating stations, particularly as a substitute for coal, again assuming that the required approvals are in place.

### 2.5.1 Technology Description

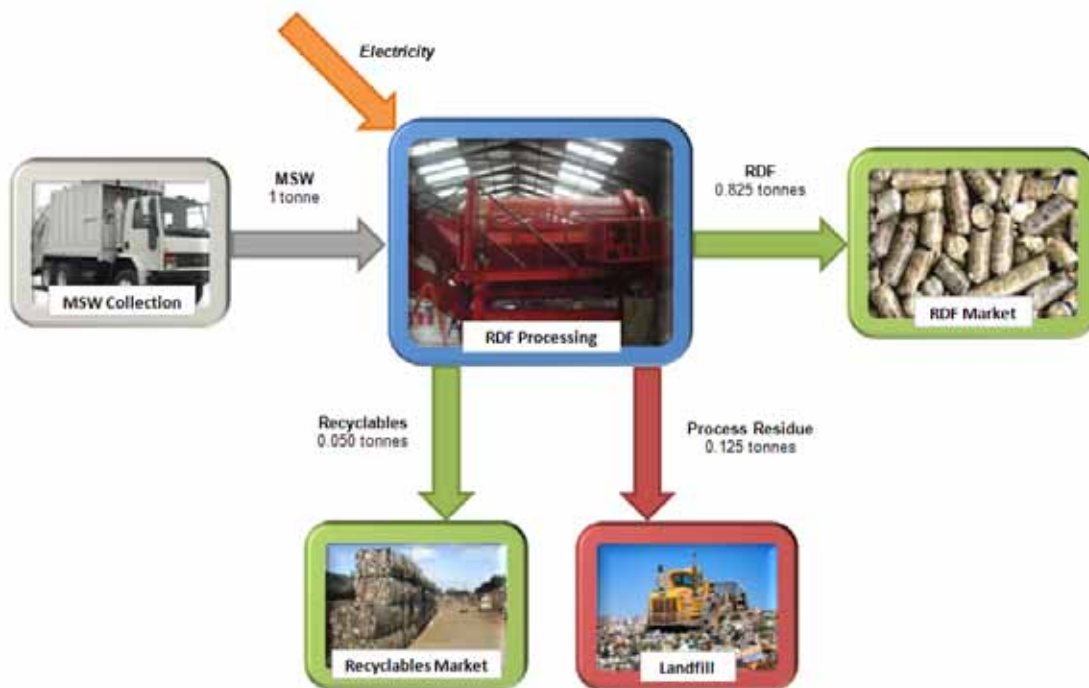
This technology prepares MSW into a fluff by shredding, screening, and removing non-combustible materials prior to additional processing, such as pressing the remaining feedstock into a pellet form or firing the fluff into a dedicated boiler. The goal of this technology is to derive a better fuel (uniform in size and composition) that can be used in a more conventional solid-fuel boiler as compared to a mass-burn combustion waterwall boiler. The fuel goes by various names but generally is categorized as a refuse-derived fuel (or RDF). The RDF process typically results in a fuel yield in the 80% to 90% range (i.e., 80 to 90 percent of the incoming MSW is converted to RDF). The remaining 10% to 20% of the incoming waste that is not converted to RDF is composed of either recovered ferrous metals (1-5%) which can be sold to market, or process residue (15% to 19%) that must be disposed of in a landfill.

The RDF output can be marketed to solid fuel consumers when approved for use in combustion equipment equipped with appropriate emission controls. More commonly, the RDF is used on-site to produce energy which is then used or sold. The RDF may also be used as a feedstock or fuel in conjunction with other thermal technologies discussed in Section 2.4, such as combustion or gasification-type systems. Air pollution controls required for a facility combusting RDF would be similar to traditional combustion or gasification-type systems, as necessary to meet emissions regulations.

RDF technology is a proven technology that is used at a number of plants in the U.S., Europe and Asia (generally larger plants with capacities greater than 1,500 tonnes per day). There are also a number of commercial-ready technologies that convert the waste stream into a stabilized RDF pellet that can be fired in an existing coal-boiler or cement kiln. The Dongara facility located in Vaughan, Ontario is one example of a facility where RDF pellets are produced from mixed MSW and then marketed to off-site fuel consumers. There is a risk associated with the generation of these pellets if a defined and sustainable market does not exist for the pellets.

Some examples of RDF technology vendors includes: Energy Answers; Dongara; WastAway Services, LLC; Westroc Energy; Ambient Eco Group; and, Cobb Creations.

**Figure 9 – Schematic Diagram of a Refuse Derived Fuel System**



### 2.5.2 Industry Experience and Reference Facilities

There are a number of RDF to combustion systems operating in North America (Detroit, MI; Hartford, CT; Massachusetts, Honolulu, Hawaii). The Dongara facility located in Vaughan, Ontario is an example of a commercial-scale facility where RDF pellets are produced from mixed MSW to be marketed off-site as an alternative fuel in conventional fossil fuel boilers. The list of facilities below is a small sample of the existing commercial scale facilities in North America.



Facility Location	Design Capacity	Technology Type	Start-Up Date
<b>Detroit, Michigan</b>	1,000,000 tonnes/year	RDF Combustion	1991
<b>Hartford, Connecticut</b>	900,000 tonnes/year	RDF Combustion	1987
<b>Vaughan, Ontario</b>	Up to 200,000 tonnes/year	Dongara, EnerPax RDF Pelletizer System	2008

## 3.0 Summary of Findings

The following table provides a summary of the findings as applicable to the City of Kingston.

Technology	Applicability to City of Kingston
<b>Mechanical Treatment</b>	Depending on the effectiveness of Kingston’s existing Blue box and recovery programs and the type of equipment employed, a well operated front-end mechanical separation system can recover up to an additional 15%-20% of recyclable materials in the waste throughput. Given the relatively small throughput of the Kingston’s residual waste stream (i.e. 20,000-25,000 tonnes per year) and the already high blue box material capture rate the benefits of the additional recovered materials (revenues, public relations) would be limited when compared with the additional costs of the this system.
<b>Biological Treatment</b>	AD facilities have commercial experience in a range of sizes from as small as 5,000 to over a 1,000,000 tonnes per year. An AD system can used be in conjunction with an SSO program in Kingston, as well as used to treat the remaining residual waste stream. The capital and operating costs associated with an AD system, as well as the benefits from utilizing the biogas (whether selling directly or combusting to create electricity) would need to be investigated further to evaluate the applicability of this system to Kingston’s Integrated Waste System. These facilities can have odour problems, so the siting issues associated with an AD facility within Kingston will also need to be considered.
<b>Mechanical/ Biological Treatment</b>	<p>The optimal size of an MBT facility ranges from 50,000 to 200,000 tonnes of residual waste per year. The amount of residual waste available for processing in an MBT system within Kingston makes it not feasible economically unless other communities could truck their waste to a larger regional MBT facility.</p> <p>This technology has been used in Europe, including in Germany, Austria, Italy, and the United Kingdom. There has been some commercial application of the MBT technology in North America. The City of Toronto is currently developing a commercial-scale MBT facility.</p>



Technology	Applicability to City of Kingston
<b>Thermal Treatment</b>	<p>The relatively modest quantities of residual waste available in Kingston (20,000 to 25,000 tonnes annually) make the applicability of the larger scale established technologies (i.e. mass burn, RDF combustion and fluidized bed combustion) not economically viable unless a regional facility that took waste from nearby municipalities was implemented. There are smaller-scale modular mass burn systems, such as the Consutech technology used at the energy from waste facility in Brampton, Ontario, that may be economically viable for Kingston.</p> <p>The 55 to 70 tonnes per day of available residual waste may be applicable to some conventional gasification, plasma arc and pyrolysis technologies that offer smaller more modular systems. Although many of these technologies have limited larger-scale application in North America, there are demonstration and pilot facilities that have some operating experience in the size range applicable to Kingston. The actual direct capital and operating costs associated with these technologies would have to be reviewed in more detail before a decision to move forward with a gasification-type system is made.</p>
<b>Refuse Derived Fuel</b>	<p>RDF combustion facilities are built on a larger scale (typically over 1,000,000 tonnes per year) to make them economically feasible, and would not apply to the projected Kingston residual waste quantities. Using Kingston’s waste to make RDF pellets may be feasible if a defined and sustainable market for those pellets is identified. The RDF fluff and pellet systems may be applicable to Kingston if used in conjunction with a thermal treatment system, such as the gasification-type systems described in Section 2.4. The technical, environmental and economic impacts and feasibility of a combined RDF and thermal treatment technology would have to be evaluated in more detail before a decision was made to include or exclude this as a system option for Kingston.</p>

Based on this technical investigation and review it is concluded that the original recommendation that ... *“The City of Kingston further investigate systems for Residual Waste Processing identified as a component of the preferred System #2 to process the waste that remains after recycling and composting in consideration of the waste management hierarchy.”...is still appropriate and accurate.*

In particular small scale thermal treatment facilities and refuse derived facilities should be closely considered as they present the greatest opportunity to the City to meet the overall objectives of the integrated waste management study.