Final Report

Waste-to–Energy Review of Alternatives

Prepared for

Regional District of North Okanagan

May 2009

CH2MHILL

Metrotower II – Suite 2100
4720 Kingsway
Burnaby, BC V5H 4N2

Contents

Exhibits

Acronyms

ASRDF	Armstrong/Spallumcheen Recycling and Disposal Facility
CH_4	Methane
CH2M HILL	CH2M HILL Canada Limited
CO	Carbon monoxide
CO_2	Carbon dioxide
EPR	Extended Producer Responsibility
GEM	Graveson Environmental Management
GVRD	Greater Vancouver Regional District (now Metro Vancouver)
GVRDF	Greater Vernon Recycling and Disposal Facility
H_2	Hydrogen
IGCC	Integrated Gasification Combined Cycle
LRDF	Lumby Recycling and Disposal Facility
MPA	Müllpyrolyseanlage
MSW	Municipal Solid Waste
PVC	Polyvinyl chloride
RCBC	Recycling Council of British Columbia
RDF	Recycling and Disposal Facility
RDNO	Regional District of North Okanagan
SCR	Selective Catalytic Reduction
SNCR	Selective Non-catalytic Reduction
TIFG	Twin Internally Circulating Fluidized-bed Gasification
WTE	Waste-to-energy

1. Introduction

1.1 Purpose

The Regional District of North Okanagan (RDNO) retained CH2M HILL Canada Limited (CH2M HILL) to prepare a Waste-to-energy (WTE) Review of Alternatives report. The purpose of this report is to conduct a preliminary review of selected Municipal Solid Waste (MSW) conversion technologies to provide a preliminary determination of their feasibility to treat MSW generated in the RDNO.

2. Regulatory Requirements

2.1 Applicable Regulations and Guidelines

A WTE facility should satisfy the requirements of the following regulations/guidelines:

- Environmental Management Act (Province of British Columbia [BC], 2003), Chapter 53, including:
  - Part 6 Clean Air Provision
  - Part 6.1 Greenhouse Gas Reduction
  - Part 6.1 Division 2, No. 76.2 - Management of Greenhouse Gases at Waste Management Facilities
  - Hazardous Waste Regulations
  - Waste Discharge Regulation
- RDNO Solid Waste Management Plan , Update (RDNO, 2002)
- Operational Certificate or Permit issued for WTE facility operation
- Environmental Assessment Act (Province of BC, 2002)
- Greater Vancouver Regional District (GVRD) Air Quality Management Bylaw No. 1082 (GVRD, 2008); for guidance purposes only

2.2 RDNO Solid Waste Facilities

The RDNO owns three operational disposal facilities, for which two Operating and Closure Plans have been approved by the BC Ministry of Environment. The RDNO also owns three operational transfer stations, two closed landfills and two recently closed landfills that now have transfer stations installed. Closure Plans have been approved for all closed facilities. Exhibit 2-1 presents RDNO's operational solid waste management facilities.

EXHIBIT 2-1
The RDNO Solid Waste Management Facilities

		Expected Closure Date	Notes
Operational Disposal Facilities	Greater Vernon Recycling and Disposal Facility (GVRDF)	2034	1
	Armstrong/Spallumcheen Recycling and Disposal Facility (ASRDF)	2034	2
	Lumby Recycling and Disposal Facility (LRDF)	2045	3
Transfer Stations	Silver Star	NA	
	Kingfisher	NA	
	Cherryville	NA	

EXHIBIT 2-1
The RDNO Solid Waste Management Facilities

		Expected Closure Date	Notes
Closed Facilities	Ashton Creek Facility	Closed	
	Pottery Road Facility	Closed	

Notes:

1. Reference: XCG Consultants Ltd., 2009
2. Reference: BGC Engineering Inc., 2009
3. Reference: BC Municipal Solid Waste Tracking Report 2003-2005, prepared by Recycling Council of British Columbia (RCBC)

2.3 RDNO Solid Waste Quantities

Approximately 100,000 tonnes of waste were received at the different RDNO operational facilities in 2007, and 55,570 tonnes of solid waste were landfilled in 2007. Exhibit 2-2 presents the historical quantity of solid waste landfilled, as well as projected solid waste quantities generated and landfilled for the RDNO.

		Solid Waste Landfilled		
Year	Population	Tonnes/ capita/ year	Tonnes/ year	Tonnes/ day
2001	73,227	0.515		
2002	74,691	0.554		
2003	77,965	0.579		
2004	79,097	0.713		
2005	80,474	0.654		
2007	77,301	0.719	55,570	152
2008	78,074	0.55	42,941	118
2013	82,057	0.55	45,131	124
2015	83,706	0.55	46,038	126
2018	84,543	0.55	46,499	127
2023	88,856	0.55	48,871	134
2028	93,388	0.622	51,363	141
2033	98,152	0.622	53,983	148
2034	103,158	0.622	56,737	155

2.4 Applicable RDNO Policy

The RDNO currently has solid waste policy in place that should be considered in the context of future actions concerning WTE. If the RDNO decides to pursue WTE as part of the overall solid waste system, it may be necessary to amend this current policy. The following existing policy was identified in the Solid Waste Management Plan (RDNO, 1996) and the Solid Waste Management Plan Update (RDNO, 2002) as follows:

- "The RDNO shall NOT, at this time, consider energy recovery as a component of its solid waste management system. This is based on an economic assessment of this type of venture which indicated that it would not be economically feasible at current energy costs. (Note: Need to rework this to include RDF gas utilization, pyrolysis, gasification, incineration)."
- "It is recognized that any energy from waste projects will require environmental impact studies prior to Provincial consideration. In addition, such projects would require a full public review process since a formal solid waste plan amendment would be required for implementation. "

The following is additional policy that also should be considered by the RDNO despite being in the feasibility stage. It is included in the Phase 1 - Solid Waste Management Plan Review (CH2M HILL, 2007) as a good potential candidate policy for the new RDNO Solid Waste Management Plan related to WTE:

- "Adopt a Zero Waste principle consistent with other Regional Districts that will serve as an ideal and a shift in attitude, while continuing to update new targets that are achievable in the foreseeable future."
- "Despite being beyond the definition of MSW, and, thus, the jurisdiction of the Solid Waste Management Plan, it may be prudent to include references to existing agricultural and industrial wood wastes as potential sectors to produce complimentary feedstocks to make solid waste initiatives more viable."
- "Design Disaster Debris Management Plans to address solid waste response during priority disasters (as defined by Emergency Services, such as interface fires)."

3. WTE Influent

3.1 Waste Quantity

Based on the assumption that the quantity of waste landfilled will be reduced by 70 percent by 2015, for the purposes of this report, the quantity of MSW (otherwise to be discharged in RDNO landfills) that would be processed by thermal conversion technologies will vary between 118 and 155 tonnes/day or between 43,000 and 57,000 tonnes/year.

3.2 Waste Characterization

In Table 2 of the 2005 Solid Waste Composition Study (Technology Resource Inc., 2005), weighted averages of the composition of primary categories for each of the MSW sources are provided. A combined weighted average for the sources is shown in Exhibit 3-1.

EXHIBIT 3-1
RDNO MSW Composition (1,2)

Primary Category	%
Paper	10.0
Glass	2.5
Metals	5.0
Plastic	8.3
Leather	0.3
Rubber	1.7
Organic	46.0
Brown Goods	3.4
Bulky Goods	0.3
Textiles	4.0
Construction	10.2
Residue	0.5
Hazardous	7.0
Other	0.3

Notes:

1. Reference: Technology Resource Inc., 2005
2. Solid waste landfilled only, does not include recycling, reuse, or composting.

The weighted average heating value for this MSW is calculated to be 11.55 MJ/kg (4,978 Btu/lb). This is consistent with other similar MSW streams.

Exhibit 3-2 presents the quantity of landfilled and diverted waste at RDNO in 2007.

EXHIBIT 3-2
Landfilled and Diverted Waste at RDNO – 2007 [(1)]

				Notes
Solid waste landfilled	55,570	55%	landfilled	
Not landfilled- reuse/recycled				
Demolition (asphalt, concrete, gypsum)	9,617	10%	recycled/reuse	2, 3
Construction (dimensional wood waste, clean, treated painted)	5,875	6%	chipped/reuse	2, 4
Land clearing (Brush and wood chips)	6,022	6%	chipped/reuse	2, 4
Leaf and yard waste	4,896	5%	chipped/reuse	2, 4
Metals, white goods, tires	1,882	2%	recycled	
Clean/contaminated soil	11,294	11%	reuse	
RDNO glass collection program	101	0%	recycled	
RDNO Drop-Centre program	670	1%	recycled	
RDNO Residential programs	3,541	4%	recycled	
Non-RDNO Managed Residential Programs	706	1%	recycled	
Total – 2007	**100,174**	**100%**		
Burned wood waste			Burned	5, 6

Notes:

1. Reference: CH2M HILL, 2008a
2. Reference: CH2M HILL, 2008b
3. Asphalt and concrete are banned from disposal in all RDNO landfills. Concrete is crushed periodically along with asphalt and masonry and is used for sub-base and roads onsite. Gypsum is shipped to recyclers (New West Gypsum and Okanagan Gypsum recycling).
4. Treated and untreated wood waste, logs/stumps/brush and chipped wood, and leaf and yard wastes are ground up at each site and the resulting wood chips are spread onsite, mixed with soil for daily cover, composted, or delivered to offsite users.
5. Wood waste burned is permitted within the RDNO. During the period from November 1 to November 15, 2008, 220 burning permits were issued (RDNO, 2008). These quantities could be used as carbon-based material for WTE feedstock. The quantity was assumed to be, as a minimum, equivalent to the construction and land clearing waste weighed at the RDNO's scales.
6. There is a gasification unit which converts wood residue into energy, The gasification plant is located at Tolko's Heffley Creek plywood mill near Kamloops, BC. Tolko Industries Ltd. (Tolko) is a private, Canadian-owned forest products company based in Vernon, BC, which manufactures and markets specialty forest products to world markets. To avoid burning operations in the RDNO, wood waste could potentially be sent to this gasification plant if no WTE is implemented.

Exhibit 3-3 presents the estimated quantity of wood waste that could potentially be used as carbon source for the WTE facility if burning operations were avoided in the RDNO.

EXHIBIT 3-3
Estimated Wood Waste Available as Carbon Source for WTE Facility, Based on RDNO-Issued Burning Permits in 2008

	Solid Waste Landfilled	Wood Piles		
Year	Tonnes/ year	Tonnes/year (1, 2) min	Tonnes/year (1, 2) max	% of Solid Waste Landfilled per Year
2008	42,941	672	941	1.5 to 2.0%
2013	45,131	706	989	1.5 to 2.0%
2015	46,038	720	1009	1.5 to 2.0%
2018	46,499	728	1019	1.5 to 2.0%
2023	48,871	765	1071	1.5 to 2.0%
2028	51,363	804	1125	1.5 to 2.0%
2033	53,983	845	1183	1.5 to 2.0%
2034	56,737	888	1243	1.5 to 2.0%

Notes:

1. RDNO record estimated volumes of wood waste when the open burning permits are issued. It appears that most of the piles reported measure 10 feet by 10 feet, and a height of 8 feet is assumed. This results in an estimated volume of wood waste to be burned of 800 cubic feet per permit.
2. Reference: Table 1, Material density factors; 250 pounds/cubic feet: Office of Recycling, Department of Environmental Protection, Trenton, New Jersey, 1990; 350 pounds/cubic feet: Organic Recycling, Valley Cottage, New York, 1991 (Apoteker, 1991).

4. MSW Conversion Technology Review

The following is a summary of conversion technologies for MSW. Per the scope of work for this project, the primary source of data for this section of the report are two prior comprehensive reports prepared for the City of Los Angeles Bureau of Sanitation (URS, 2005a) and the Los Angeles County Solid Waste Management Committee/Integrated Waste Management Task Force's Alternative Technology Advisory Subcommittee (URS, 2005b). The author of this section of this report was the lead technical author for those two prior reports. Additional information from a similar report prepared by the author for the Regional Municipality of Halton in Ontario, (Jenkins, 2007) was also included.

Thermal conversion technologies convert the carbon content of the MSW into a synthetic gas (syngas), which can then be used to produce liquid fuels, chemicals or fertilizers, or can be combusted to generate electricity. These processes work best when the carbon content of the feedstock is high, and the inorganic portion (ash and moisture) is low. Therefore, many thermal conversion technologies require (or benefit from) up-front pre-processing to remove metals, glass, and construction debris (i.e., rocks and concrete). A key advantage of thermal conversion technologies is that they actually increase recycling efforts based on the need for pre-sorting. Plastics not currently being recycled, which would go to a landfill, are an excellent feedstock for thermal conversion technologies, and increase the syngas quality.

While thermal conversion technologies have a long history with feedstocks such as coal, petroleum coke, and biomass, their use with MSW is still somewhat limited worldwide. For this report, the thermal conversion technologies evaluated are pyrolysis, conventional gasification, and plasma gasification. These are the primary technologies that are being used worldwide for treating MSW streams (either directly or after some amount of pre-processing).

There are literally hundreds of suppliers of pyrolysis and gasification technologies for MSW. However, the detailed analyses completed as part of the prior reports clearly shows that there are only a handful that have real operating experience. Many potential suppliers have basic or conceptual designs, or only bench scale experience with their technologies. While these emerging technologies may warrant further evaluation in the future, real-world operational experience is mandatory to increase the opportunities for the technical and financial success of a conversion technology that would be considered for treating RDNO's MSW stream.

4.1 Commercially Available MSW Conversion Technologies

4.1.1 Pyrolysis

Pyrolysis can be simply defined as the thermal decomposition of carbon-based materials using an indirect source of heat to produce a synthetic gas (syngas). Basically, the organic materials are "cooked" in an oven, at temperatures of 400 to 900°C, with no air or oxygen present. No direct burning of the feedstock takes place.

Most organic compounds are thermally unstable. At high temperatures, the organic compounds volatilize and bonds thermally crack, breaking larger molecules into gases and liquids composed of smaller molecules, including hydrocarbon gases and hydrogen gas. The temperature, pressure, reaction rates, and internal heat transfer rates are used to control specific pyrolytic reactions to produce specific products. At lower temperatures, liquid pyrolysis oils dominate; at higher temperatures, gaseous byproducts dominate. Pyrolysis reactions are endothermic, meaning that they require externally supplied heat to occur. Natural gas, propane, or some of the syngas produced from the pyrolysis process itself can be used as the sources of external heat. If the feedstock has a high heating value (in MJ/kg), the pyrolytic process becomes more self-sufficient, and once the process reaches equilibrium, the use of the self-generated syngas can reduce or eliminate the use of additional fuel sources for heating.

The main constituents of syngas produced by pyrolysis are carbon monoxide (CO), hydrogen (H_2), and methane (CH_4), all of which are combustible gases. Pyrolysis systems also produce oxidized compounds (carbon dioxide [CO_2] and water [H_2O]), which have no heating value and dilute the syngas. Since the temperature of pyrolysis is relatively low and excess oxygen or air is kept out of the process, pyrolysis typically results in a large unreacted portion of the feedstock remaining in the form of carbon char. This char is mixed with any of the inorganic materials (ash) present in the feedstock. In most cases, the char/ash mixture requires disposal.

Pyrolysis systems can process a wide range of carbon-based materials. Virtually any organic or thermally degradable material can be processed by pyrolysis. Historically, pyrolysis has been used to make charcoal from wood. There, the desired product is not the syngas, but the leftover carbon char. Pyrolysis has a long history of industrial use. It is used to process used tires to produce carbon black, which is used in chemical manufacturing and in making carbon electrodes. Currently, some manufacturers are using pyrolysis to produce activated carbon using coconut shells or wood as feedstock. If a homogeneous feedstock is processed by pyrolysis, it produces high quality byproducts.

MSW is not a homogenous waste stream. Since inorganic materials (metals, glass, rocks, concrete) do not enter into the thermal conversion reactions, the energy which could be used to pyrolyze the feedstock is expended in heating the inorganic materials to the pyrolysis reactor temperature. Then the inorganic materials are cooled in clean-up processes, and the heat energy is lost. This reduces the pyrolysis system’s overall efficiency. To make the pyrolysis process more efficient, some pre-processing of MSW is typically required. The pre-processing includes the separation of thermally non-degradable material like metals, glass, and concrete debris. Depending on the specific pyrolysis process, pre-processing may include sorting, separation, size reduction, and densification (for reducing overall volume of feedstock being fed into the unit). Such pre-processing techniques are common in the MSW recycling industry for recovery of paper, glass, and metals from MSW streams.

If the MSW has high moisture content, a dryer may be added to the pre-processing stage to lower the moisture content of the MSW to 25 percent or lower. Lower moisture content of the feedstock increases its heating value and the system becomes more efficient. The waste heat or fuel produced by the system can be used to dry the incoming MSW.

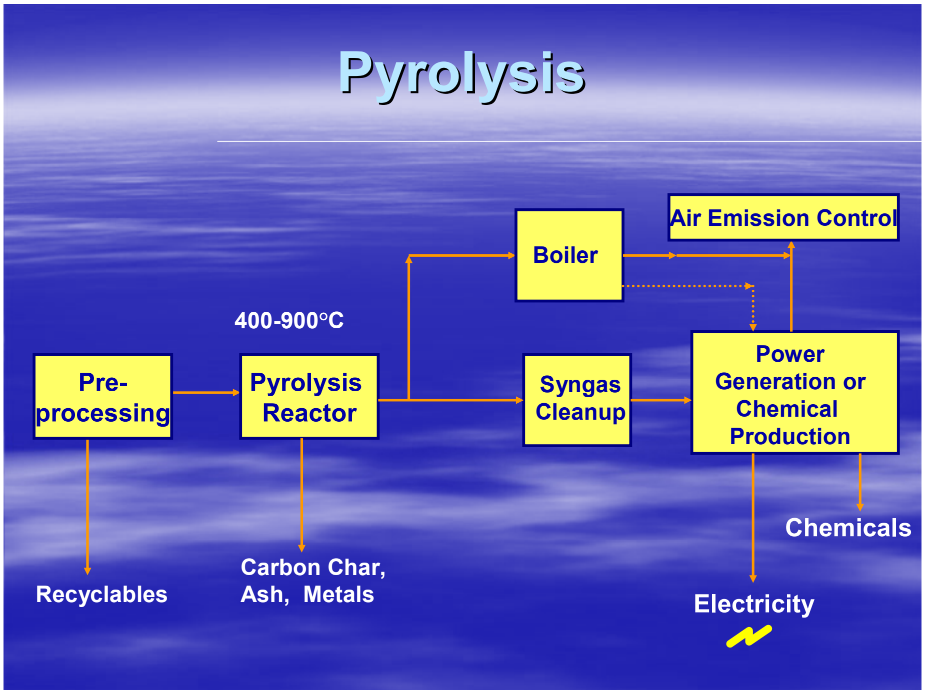
Pyrolysis systems use a wide range of designs, temperatures, and pressures to initiate the pyrolysis reactions. Typically, pyrolysis systems use a drum, kiln-shaped structure or pyrolysis tube, which is heated externally using either recycled syngas or another fuel (usually natural gas) to heat the pyrolysis reactor. Since pyrolysis occurs in the absence of oxygen, the feed system and pyrolysis chamber are sealed and isolated from outside air during the processing. This is typically accomplished through the use of inlet and outlet knife-gates.

In the reactor, pyrolysis may occur over a period of several minutes in a pyrolysis or "degassing" chamber or very quickly, as in the case of "flash" pyrolysis, where the feedstock encounters an extremely hot internal surface and volatilizes in less than a second. Slow pyrolysis is used to maximize the production of char, as in the case of producing charcoal or activated carbon. In those cases, the volatile fraction may be vented or used for providing the indirect heat source. Slow pyrolysis is used to convert low volatile coal to metallurgical grade coke for steel making. Coke is a very pure carbon product, which is then used to provide the reducing atmosphere necessary for converting iron ore (in its oxidized form) to molten elemental iron. Lower temperature pyrolysis technologies can also produce a pyrolysis oil, in addition to the syngas. Depending on the quality, it may have uses as a liquid fuel. Following the pyrolysis reactor, the syngas that is produced can be:

- Combusted directly in a thermal oxidizer or boiler, making steam for power generation; the exhaust gases then pass through an emission control system that may include fabric filters or electrostatic precipitators for removal of particulate matter, wet or dry scrubbers for removal of acid gases, and activated carbon beds for removal of heavy metals
- Quench-cooled, cleaned in an emission control system, and then combusted in a reciprocating engine or gas turbine for power generation
- Quench-cooled, cleaned in an emission control system, and then used for producing organic chemicals

A configuration for a MSW pyrolysis system for the production of power or chemicals is shown in Exhibit 4-1. For power generation, the syngas can either be combusted directly in a boiler, producing steam for a steam turbine generator, or cooled and cleaned for combustion in a reciprocating engine or gas turbine. The inorganic materials in the feedstock are removed as a bottom ash. It is usually combined with the unreacted char, and can be separated out for disposal (if the char is to be used as noted above) or used in making concrete block materials. Where no pre-processing is used, magnetic and eddy current separators can be used to recover metals from the char/ash mixture.

EXHIBIT 4-1
MSW Pyrolysis Facility Configuration



The solid byproducts from pyrolysis are mainly carbon char and non-thermally degradable materials such as silica (sand), metals, and glass. In the case of low temperature pyrolysis, a liquid fuel (tars and oils) may be produced. The metals can be separated from the char for recycling. The ash is usually disposed of in a non-hazardous landfill.

Analysis of a wide range of pyrolysis technologies shows that they can produce as much as 770 net kWh/tonne of processed feedstock. In lieu of producing electricity, the steam could be used for other nearby purposes. Additional steam from other sources could be used for drying the raw MSW to enhance its quality, or used to supplement the steam turbine generator production if that equipment was initially designed for the additional steam flow. Additional steam from other sources could also be used for start-up purposes or to drive the steam turbine generator (if used) when the pyrolysis system was not in operation, providing that it meets the steam quality and quantity requirements.

Pyrolysis uses indirect heat with the absence of free air or oxygen to process the MSW; therefore the air emissions are minimized. Pyrolysis reactors typically are closed, low-pressure systems, with no direct air emission points. Contaminants are removed from the syngas and/or from the flue gases prior to being exhausted from a stack. Specific design and operation characteristics of thermal conversion systems also reduce air emissions significantly, as follows:

- Pyrolysis technologies often incorporate pre-processing subsystems to produce a more homogeneous feedstock. This provides the opportunity to remove chlorine-containing plastics (such as polyvinyl chloride or PVC), which could otherwise contribute to the formation of trace organic constituents.

- The volume of syngas produced in the conversion of the feedstock is considerably lower than the volume of flue gases formed in the combustion of MSW in a mass-burn incineration facility. Smaller gas volumes are easier and less costly to treat.
- Pre-cleaning of the syngas is possible prior to combustion in a boiler, and is required when producing chemicals or prior to combustion in a reciprocating engine or gas turbine to reduce the potential for corrosion in this sensitive equipment. Syngas pre-cleaning serves to reduce overall facility air emissions.
- Syngas produced by pyrolysis is a much more homogeneous and cleaner-burning fuel than the raw MSW.

Air emission control and processing systems include some or all of the following:

- When the syngas is combusted in a boiler, reciprocating engine, or gas turbine, automated combustion controls and furnace geometry (for boilers) are designed to optimize residence time, temperature, and turbulence to ensure complete combustion.
- For combustion of syngas in a boiler, low-NO_x burners and/or a Selective Non-catalytic Reduction (SNCR) system is used for reduction of NO_x emissions. Selective Catalytic Reduction (SCR) is typical for exhaust gases from reciprocating engines and gas turbines.
- A baghouse (fabric filter) is used to remove particulate matter from flue gases produced from combustion of the syngas in a boiler.
- Activated carbon beds for syngas treatment or activated carbon injection (followed by a baghouse) are used for removal of trace metals (such as mercury).
- Wet scrubbers are used for removal of chlorides/hydrochloric acid (some control technologies may be able to recover these substances as saleable hydrochloric acid).
- Wet, dry, or semi-dry scrubbers are used for removal of sulfur dioxide (some control technologies may be able to recover the sulfur constituents as saleable gypsum, which can be used in the manufacture of cement or wallboard).
- A final baghouse is used for removal of fine particulate matter after dry or semi-dry scrubbers. Air emission control equipment to accomplish this syngas and/or flue gas cleanup is commercially available and is expected to reduce air emissions to levels well below regulatory limits.

Other issues related to pyrolysis technology will involve the following:

- Solid residual management – As stated above, pyrolysis can create several "residues", including char, silica (sand), and bottom ash. While many residues can be re-used, some small portion may require disposal in a landfill.
- Visual and land use – There may be impacts relating to the visual character of the facility or issues relating to compatibility of the facility with surrounding land uses.
- Other concerns - As with other facilities handling MSW, there will be concerns about odour, litter, noise, traffic, and dust.

Overall, pyrolysis technologies have the capability to comply with a wide range of air, water, and waste emission standards. The air emission controls can be designed to meet specific standards, as required. The char/ash may require disposal in a hazardous waste landfill; leachability testing is important to determine its potential hazardous characteristics. The amount of char/ash produced (potentially requiring landfill disposal) will be approximately 15 to 20 percent by weight of the feedstock throughput. Removal of metals and glass from the input stream will reduce this value.

Pyrolysis has been used to thermally treat MSW for 25 years. Still, there are only a few operating facilities worldwide, mostly in Europe and Japan. A list of some of those facilities is shown in Exhibit 4-2. Some key pilot and demonstration facilities are included. Several facilities using other technologies have been successfully demonstrated over the past several years and then shut down; however, these are viable technologies for further consideration. As the requirement to close existing landfills increases, more cities and US counties are evaluating pyrolysis as a viable option to use MSW for electricity generation.

EXHIBIT 4-2
Summary of Existing MSW Pyrolysis Facilities

Facility	Location	In-service Date	Technology	Tonnes/year	Energy Production	By Products
Müllpyrolyseanlage (MPA)	Burgau, Germany	1984	WasteGen Rotating Kiln	35,000 (raw, unprocessed)	2.2 MW at ~450 net kWh/tonne	Char/ash to landfill; steam to greenhouse
Six commercial facilities in Japan	Japan	2000 to 2003	Mitsui R21 Pyrolysis - Rotating Drum	50,000 to 120,000 (raw, unprocessed)	1.5 to 8.7 MW at ~300 net kWh/tonne	Char/ash
Davies Brothers facility – shut down in 2001; Graveson Environmental Management (GEM) – pilot plant	Port Talbot, Wales	2007	GEM Thermal Cracking Technology	14,000 (dried)	150 kW reciprocating-engine for testing	Char/ash
Intrinergy Coshocton, LLC	Coshocton, OH, U.S.	Mid-2009	GEM Thermal Cracking Technology	N/A – Blends of crumb rubber, shredded carpet fluff, wood chips, and biomass	Four 1 MW GE-Jenbacher reciprocating engines and one boiler	Char/ash
Scarborough Power	Seamer Carr, United Kingdom	2008	GEM Thermal Cracking Technology	18,000	1.8 MW with Deutz recip engine	Char/ash
International Environmental Solutions Demo Plant	Romoland, California	2004	Advanced Pyrolytic Technology	15,000 (MRF residuals and other wastes)	None	Char/ash
Pilot facility in Vermont (now shut down – several new facilities in design using MSW and biomass)	Burlington, Vermont	1999	Taylor Biomass circulating fluid bed pyrolysis – developed from FERCO SilvaGas process	85,000 (biomass)	Syngas piped to adjacent power plant boiler as supplemental fuel	Hot cyclone ash; fabric filter ash

Pyrolysis reactors are modular, and can typically be installed in parallel to increase overall facility throughput. They have very good turndown, so that operation at low throughput is possible with adjustments in residence time and external (indirect) heat requirements. The largest MSW pyrolysis plant in operation is the Toyohashi City facility in Japan, processing a total of 400 tonnes/day of MSW. Based on the commercial experience, a minimum throughput value would be about 30 to 40 tonnes/day, or about 15,000 tonnes/year. Therefore, pyrolysis technology is technically feasible for the RDNO throughput which could vary between 118 and 155 tonnes/day or between 43,000 and 57,000 tonnes/year. The higher the throughput level, the lower the cost per tonne for pyrolysis treatment.

Based on the evaluations provided in the cited prior studies and if the RDNO wants to pursue pyrolysis technology, then suppliers that should be further considered by RDNO are:

- GEM Canada (Owen Sound, Ontario)
- International Environmental Solutions (Romoland, California)
- Taylor Biomass Energy LLC (Montgomery, New York)
- WasteGen (United Kingdom)

Mitsui Babcock, which previously marketed the R21 pyrolysis technology, has been acquired by Doosan. Doosan Babcock no longer offers the R21 pyrolysis technology in its product line. As technologies from other suppliers go into commercial service, it will be important to evaluate whether they should be added to this list.

4.1.2 Gasification

Conventional gasification can be defined as the thermal conversion of carbon-based materials using a limited amount of air or oxygen to produce syngas. This typically occurs in the range of 760 to 1,500°C. The gasification reactions involve the volatilization and partial oxidation of the carbon-based feedstock to generate a syngas, which can be used as a fuel or for the production of chemicals. As with pyrolysis, no direct burning of the feedstock takes place.

Unlike pyrolysis, which uses an indirect heat source, gasification requires a direct heat source. In the gasifier, the addition of air or oxygen for gasification of the feedstock results in partial oxidation of a small portion of the feedstock, forming some CO_2 and releasing heat. The formation of too much CO_2 and heat reduces the conversion efficiency of gasification, so more advanced designs are based on methods to minimize CO_2 production. Utilizing that heat, the organic compounds in the feedstock begin to thermally degrade, forming pyrolysis gases, oils, liquids, and char. As these products move through the bed, or downstream through the gasifier, they react with limited amounts of air, oxygen, and/or steam, which are injected to initiate the gasification reactions. The gasification reactions produce the desired syngas, which is composed primarily of CO and H_2 (as with pyrolysis). Some of the carbon may react with the hydrogen to form methane. Methane formation also increases as the gasification temperature is reduced.

If air is used instead of oxygen, the syngas will include the nitrogen gas that enters with the air, diluting the syngas and lowering its overall heating value. Gasifier designs are optimized to a specific feedstock and to specific reaction products. Additional water or steam can be injected to initiate the water-gas shift reaction, which converts the water to H_2

and the CO to CO_2, resulting in the production of a syngas stream with a higher hydrogen concentration. The higher hydrogen concentration is useful when the syngas is to be used for chemical production. In such processes, the CO_2 can be separated and removed through commercially available physical, chemical, membrane, or cryogenic processes.

Gasification has been used worldwide for making “town gas” for street lighting and cooking for over 200 years. It played a major role in the industrial development of Europe. Many gasification technologies have been developed, primarily in Europe. The Fischer-Tropsch process was developed in Europe to take syngas from coal gasification and convert it to a wide range of hydrocarbon liquids, including diesel fuel. After WWII, the use of gasification declined as oil and gasoline became cheaper and more available. Gasification is now becoming an economical method for producing transportation fuels, chemicals, and synthetic natural gas through the use of low-cost feedstocks such as petroleum coke and biomass.

Examples of modern day commercial-scale gasification include:

- The gasification of lignite at South Africa’s Sasol complex to produce syngas that is used in the Fischer-Tropsch process to produce transportation fuels (started up in 1950)
- The gasification of coal by Eastman Chemical in their Kingsport, Tennessee plant to produce chemicals that are the precursors for the manufacture of photographic film and other consumer products (started up in 1983)
- The gasification of lignite at Dakota Gasification in Beulah, North Dakota to produce synthetic natural gas (started up in 1984)
- The gasification of a blend of coal and petroleum coke by Tampa Electric Company to produce syngas, which is burned in place of natural gas in a large combustion turbine to generate electricity (started up in 1996); process is referred to as Integrated Gasification Combined Cycle (IGCC), and is a rapidly growing method for power generation from coal and other carbon-based feedstocks

The use of commercial gasification technologies to treat MSW began in the 1980s in the U.S., Europe, and Japan. In these initial units, the use of unprocessed MSW resulted in many technical problems, primarily due to the heterogeneous nature of MSW. This caused handling and feeding problems, as well as difficulties with temperature and process control, and with ash removal. Many of these facilities were shut down for technical and/or economic reasons. With the worldwide success in large-scale coal and petroleum coke gasification, regulatory requirements in Europe and Japan for reducing MSW going to landfills, and difficulties in siting and permitting of conventional mass-burn incineration plants, gasification has become a major alternative treatment technology for MSW. Most of the recent use of this technology has occurred in Japan and Europe, primarily with blends of MSW and other feedstocks such as sewage sludge and industrial wastes.

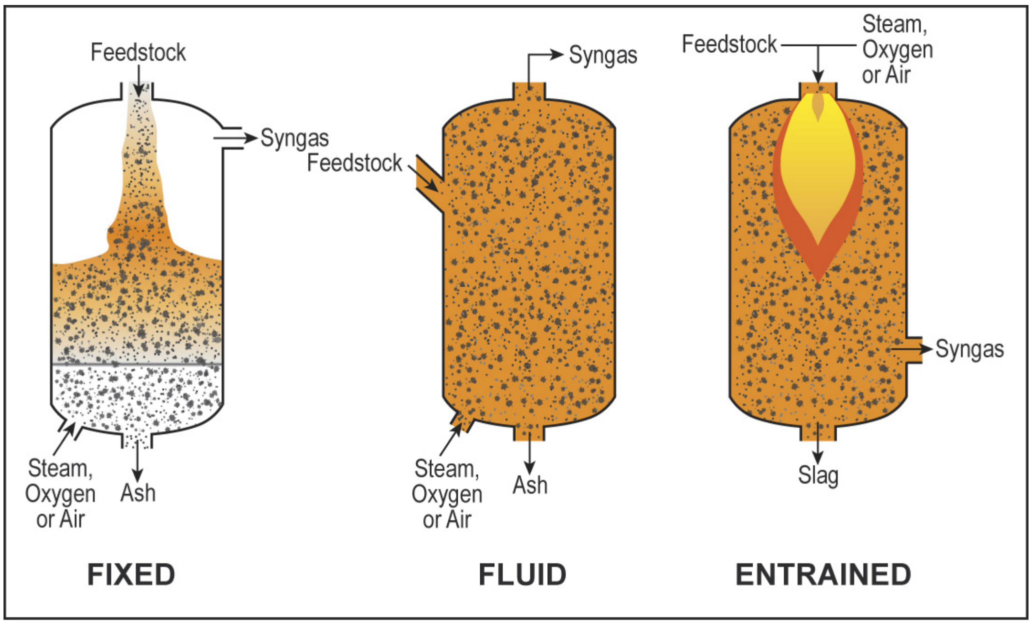
Prior to entering the gasifier, some pre-processing will likely be required, as described above in the section on pyrolysis. Some gasification technologies (primarily fixed-bed designs) may accept a minimum amount of pre-processing, such as removal of large appliances, shredding, and sorting. Others may require a significant amount of removal of recyclables, sorting, shredding, and drying to provide a more homogeneous feedstock and to improve overall system efficiency.

Gasifiers utilize one of three specific reactor designs (as shown in Exhibit 4-3):

1. Fixed bed
2. Fluid bed
3. Entrained flow

In fixed-bed gasifiers, the feedstock is usually fed into the system on a stationary or moving grate. The air or oxygen is injected either up, down, or cross flow. Fixed-bed gasifiers operate at relatively low temperatures and have a very long residence time. They are good for slow-reacting feedstocks.

EXHIBIT 4-3
Basic Types of Gasifier Reactors



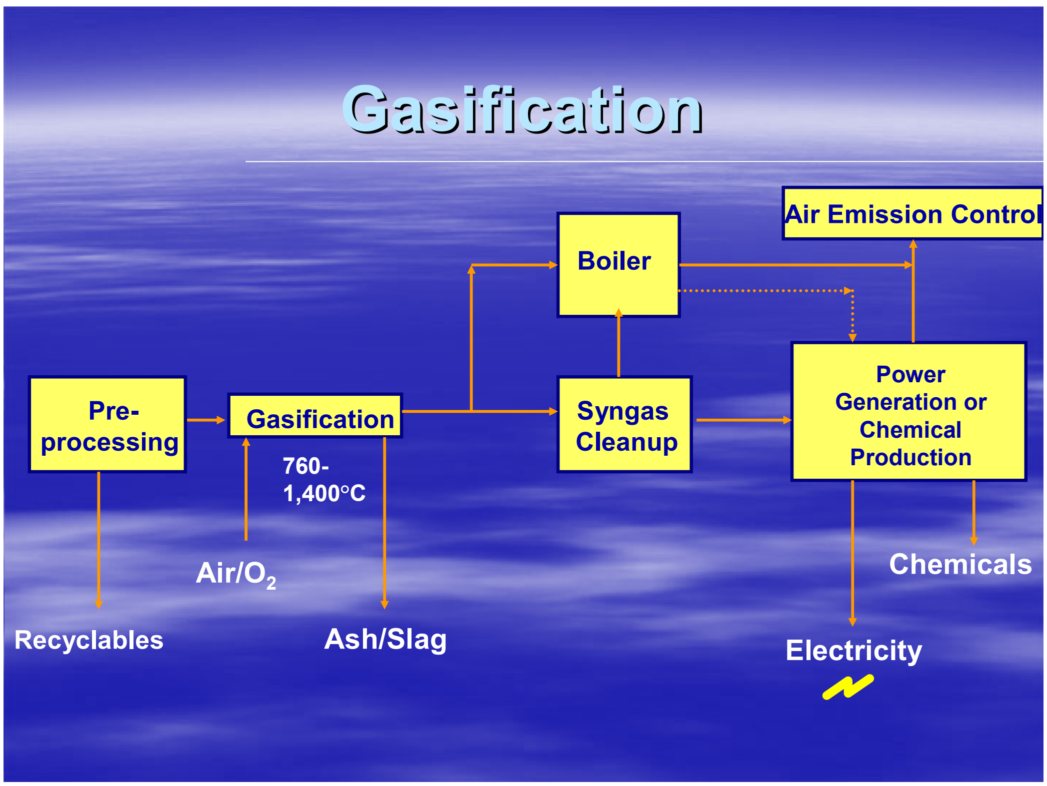
Fluid beds include bubbling beds and circulating fluid-bed designs. These are commonly used to enhance turbulence for more complete gasification of low quality, low reactivity feedstocks. Fluid-bed gasifiers operate at low pressures and temperatures, use air instead of oxygen, and have longer feedstock residence times, along with relatively low throughput. Entrained-flow gasifiers operate at high pressures and temperatures, have very low feedstock residence times, but have high feedstock capacity throughputs. Most large-scale gasification systems used today utilize the entrained-flow design. For MSW, fixed-bed and fluid-bed designs predominate due to the low reactivity and high moisture/high ash content of MSW.

Following the gasifier, the syngas can be:

- Combusted directly in a thermal oxidizer or boiler, where the heat is recovered for making steam for power generation; exhaust gases then pass through an emission control system that may include fabric filters or electrostatic precipitators for removal of particulate matter, wet or dry scrubbers for removal of acid gases, and activated carbon beds for removal of heavy metals
- Quench-cooled, cleaned in an emission control system, and then combusted in a reciprocating engine or gas turbine for power generation
- Quench-cooled, cleaned in an emission control system, and then used for producing organic chemicals

Exhibit 4-4 shows a configuration for a MSW gasification system for producing electricity or chemicals.

EXHIBIT 4-4
MSW Gasification Facility Configuration



If low temperature gasification is used, the inorganic materials (i.e., metals, glass, and sand) in the feedstock will be recovered as a powdery to clinker-like bottom ash. This can be disposed of or used for the manufacture of block materials. If high-temperature gasification is used (above 1,100°C), many of the inorganic materials will be subjected to temperatures above their melting points, forming a molten slag. The slag flows out a tap hole in the bottom of the gasifier and into a water bath. There, the slag is quench-cooled and it solidifies, forming a glassy, non-hazardous slag material. Slag can be disposed of safely, or used for the production of roofing tiles, sandblasting grit, cement, or as asphalt filler. The amount of char/ash produced (potentially requiring landfill disposal) will be approximately 15 to 20 percent by weight of the feedstock throughput. Removal of metals and glass from the input stream will reduce this value. Gasification systems utilize a wide range of feedstocks. As noted above, gasification has a long history with coal and petroleum coke (fixed-bed, fluid-bed, and entrained-flow gasifiers). Gasification has also been commercially applied to biomass, such as rice hulls, wood waste, olive processing solids, and other agricultural wastes. Gasifiers have the ability to process very low quality feedstocks. Gasifiers are usually designed for a homogeneous feedstock, although they can deal with some variability. This can be an issue with gasifiers that use a slurry feed, since significant changes in the feedstock result in different slurry characteristics. High moisture feedstocks, when used in slurry-feed gasifiers, result in inefficient gasification and poor carbon conversion. When changes in the feedstock are anticipated, bench-scale or short-term testing can be used to optimize gasifier operation. Slurry-fed gasification is not recommended for MSW due to its high moisture content. Dry-feed gasifiers are more applicable to MSW.

Due to the heterogeneous nature of MSW, significant pre-processing is often required. While some MSW gasification technology suppliers state that they can operate with little or no pre-processing, most include manual picking for large appliances. This may be followed by primary and secondary rotary/stationary trommel screens, primary and secondary shredders, air classifiers, and magnetic and eddy-current separators to remove glass and metals and reduce the feedstock size. Sizing/shredding varies with feedstocks ranging from 0.05 to 0.30 metre. Many systems incorporate an auger or ram feeder that compacts the processed MSW feed to as little as one-tenth of the original volume. To increase efficiency, many systems incorporate drying to 10 to 20 percent moisture content using steam or reciprocating engine exhaust. Depending on the technology supplier, as much as two-thirds of the raw MSW stream (including recyclables and moisture) may be removed prior to being fed into the gasifier. Post-diversion MSW would provide an even better feedstock than raw MSW due to the removal of metals and glass.

An analysis of conventional gasification technologies shows that they can produce up to 750 net kWh/tonne of processed feedstock. In lieu of producing electricity, the steam could be used for other nearby purposes. Additional steam from other sources could be used for drying the raw MSW to enhance its quality, or used to supplement the steam turbine generator production, if that equipment was initially designed for the additional steam flow. Additional steam from other sources could also be used for start-up purposes to drive the steam turbine generator (if used) when the gasification system was not in operation, providing that it meets the steam quality and quantity requirements.

The gasification process itself has no direct outlet or stack. Pre-cleaning of the syngas is necessary prior to being utilized for production of chemicals, or as a fuel for gas turbines or reciprocating engines, which require clean fuels to minimize corrosion and emissions.

With regards to air emissions, the prior discussion of pyrolysis technologies applies to gasification.

Other environmental issues pertaining to gasification include:

- Solid residue management – As noted above, the inorganic constituents may be produced as bottom ash or slag, depending on the temperature in the gasifier. Bottom ash will likely require disposal in a lined landfill. Slag, which is glassy and non-hazardous, is typically sold for the uses noted above. If markets are not available, it can be safely landfilled.
- Visual and land use – There may be impacts relating to the visual character of the facility or issues relating to compatibility of the facility with surrounding land uses.
- Other issues – As with other facilities handling MSW, there will be concerns about odour, litter, noise, and dust.

Overall, gasification technologies have the capability to comply with a wide range of air, water, and waste emission standards. The air emission controls can be designed to meet specific standards as required. It will be important to determine the leachability characteristics of bottom ash, if produced. Since slag is essentially non-leachable, it can be landfilled if no market is found for its use.

Gasifiers and the pre-processing, emission control, and power generation systems can be installed in parallel to increase throughput and power generation. Gasification systems can operate efficiently across a wide range of throughput levels, although start-ups and shutdowns, when operation at low throughput is necessary, typically result in inefficient gasification and reduced carbon conversion. Usually, the gasifier must first be heated up with an alternate fuel source (i.e., natural gas or propane, up to 25 or 30 percent volume flow rate) prior to addition of the MSW feedstock. The syngas may need to be flared during these times, especially if the power generation system is not able to combust the syngas.

There are many operating MSW gasification facilities worldwide, mostly in Europe and Asia. A list of some of those facilities (for the technology suppliers on the "short lists" from the evaluations provided in the cited studies) is shown in Exhibit 4-5. Some key pilot and demonstration facilities are included. Several facilities using other technologies have been successfully demonstrated over the past several years, and then shut down; however, these are viable technologies for further consideration. The largest MSW gasification plant is in Kawaguchi, Japan, processing 400 tonnes/day of MSW using three gasifier trains. As requirements to close existing landfills increase, more cities and counties are evaluating conventional gasification as a viable option to use MSW for electricity generation.

EXHIBIT 4-5
Summary of Existing MSW Gasification Facilities

Facility	Location	In-service Date	Technology	Tonnes/year	Energy Production	By Products
25 installations worldwide with 6 facilities in Japan using MSW	Japan	2000 to 2003	Ebara Twin Rec TIFG (Twin Internally Circulating Fluidized-bed Gasification and Ash Melting)	Up to 155,000	Boiler/steam turbine generator: ~360 net kWh/tonne	Slag; emission control wastes

EXHIBIT 4-5
Summary of Existing MSW Gasification Facilities

Facility	Location	In-service Date	Technology	Tonnes/year	Energy Production	By Products
Over 20 installations using MSW	Mostly in Asia	1989 to 2008	Entech Renewable Energy System	Up to 42,000 on MSW	Boiler/steam turbine generator: ~750 net kWh/tonne	Slag; emission control wastes
7 facilities in Japan on MSW or blends of MSW and other feedstocks	Japan	1999 to 2005	Interstate Waste Technologies – Thermoselect high-temperature gasification	Up to 170,000 on MSW (MSW or blends with other industrial waste materials)	Boiler steam turbine generator or recip engine: ~900 net kWh/tonne; syngas to steel facility	Slag, sulfur, metal hydroxides, mineral salts, metal aggregate
7 facilities in U.S. using biomass; pilot plant has used pre-processed MSW; 1 facility in Italy on biomass	U.S. and Italy	1990 to 2006	Primenergy fixed-bed gasification	Up to 175,000 on biomass; only pilot plant has used pre-processed MSW	Electricity, process steam; boiler/steam turbine generator: ~660 net kWh/tonne	Bottom ash; fabric filter ash

Based on a wide range of commercial experience, a minimum throughput for gasification is about 60 tonnes/day (18,600 tonnes/year). There is sufficient commercial-scale experience at throughput levels of up to 550 tonnes/day (170,000 tonnes/year). Therefore, conventional gasification technology is technically feasible for the RDNO throughput which could vary between 118 and 155 tonnes/day or between 43,000 and 57,000 tonnes/year. The higher the throughput level, the lower the cost per tonne for gasification facilities.

Based on the results of evaluations from the two prior cited studies (URS, 2005a and 2005b), along with updated information, if the RDNO wants to pursue gasification technology then it should consider the following suppliers:

- Ebara Corporation (Seattle, Washington)
- Entech Renewable Energy Systems (Mallorca, Spain)
- Interstate Waste Technologies –Thermoselect technology (Malvern, Pennsylvania)
- Primenergy LLC (Tulsa, Oklahoma)

As technologies from other suppliers go into commercial service, it will be important to evaluate whether they should be added to this list.

Enerkem Gasification Technology Project for City of Edmonton, Alberta

Enerkem Inc. of Montreal, Quebec markets its BIOSYN commercial gasification technology for MSW, biomass, and certain industrial wastes. It now includes methanol/ethanol production technology. The BIOSYN technology uses a pressurized, fluidized-bed reactor, which operates at about 1,000°C. Syngas is removed at about 800°C, quenched, and then cleaned in a three-stage scrubbing process. The syngas can be combusted for power generation or used for chemical production. Enerkem's full-scale facility has been operating in Spain since early 2003. It processes 25,000 tonnes/year of mixed industrial plastic wastes, and the syngas is combusted in reciprocating engines to produce power. Enerkem has also had a pilot plant in Sherbrooke, Quebec since 2003. This has been used for demonstrating and enhancing the basic BIOSYN process, as well as testing various feedstocks.

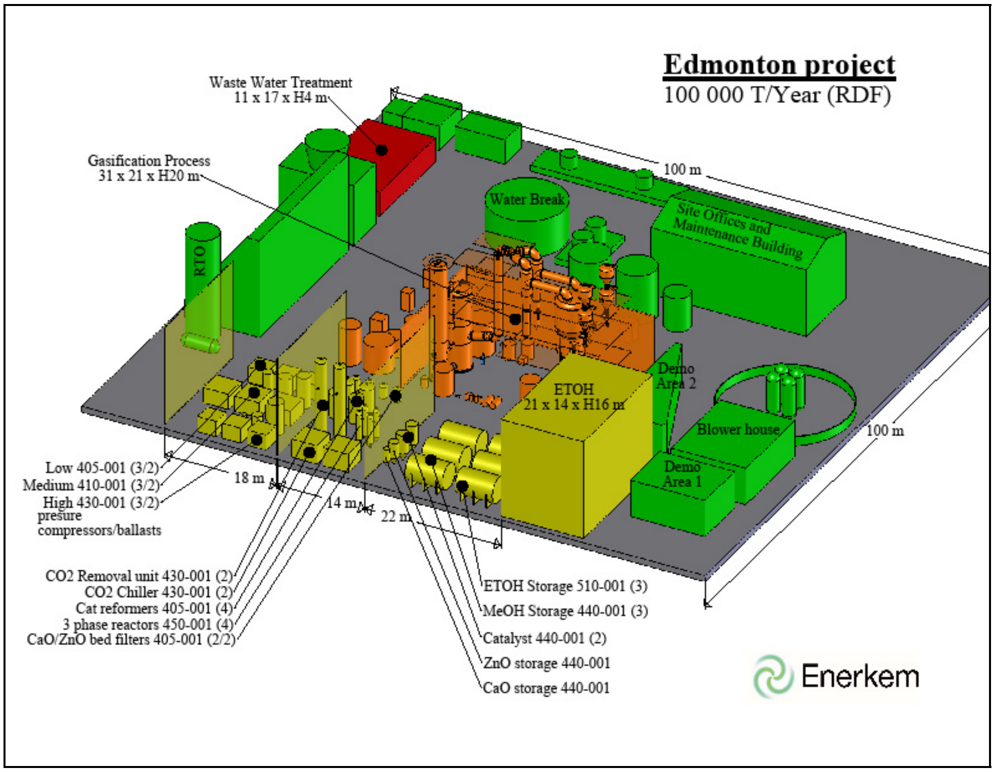
As part of a comprehensive MSW management program, the City of Edmonton (the "City") conducted a detailed study to identify a gasification technology for treating a portion of their MSW stream. Enerkem's technology was selected. Tests of various refuse-derived feedstocks (pellets and fluff) have been performed at Enerkem's pilot plant in Sherbrooke. The feedstock for the Edmonton facility will be a pre-processed feedstock in the form of coarse fluff.

Originally, the City planned to combust the syngas for power generation. However, it now plans to use the syngas for the production of methanol. The City will construct a full-scale plant (100,000 tonnes/year of feedstock) and a smaller research facility. Initially, the full-scale demonstration facility will use the syngas to produce 30 million litres/year of methanol, with eventual doubling of that capacity. The facility will have the capability to produce ethanol from the methanol, for use as a fuel additive. Enerkem is partnering with GreenField Ethanol, Inc. (Canada's oldest and largest producer of industrial alcohol and fuel ethanol) to construct and operate the facility. The facility is planned to be operational in 2010. Total cost of the facility is $70 million, with $20 million coming from the Alberta government and City of Edmonton. A layout of the Edmonton Waste Management Centre, with the Enerkem facility, is provided in Exhibit 4-6. A more detailed layout of the plant is shown in Exhibit 4-7.

EXHIBIT 4-6
Edmonton Waste Management Centre

Source: Image provided by Enerkem

EXHIBIT 4-7
Edmonton Facility Layout



Source: Image provided by Enerkem

Along with this project, Enerkem is constructing a biomass-fed gasification system in Westbury, Quebec. It will be located at a sawmill, and will gasify about 13,700 tonnes/year of wood waste (old power poles) into syngas for use in producing 5 million litres/year of ethanol. The facility can be expanded later to utilize other biomass feedstocks. Enerkem is also planning a MSW-to-ethanol facility in Pontotoc, Mississippi. The feedstock will be 172,000 tonnes/year from the Three Rivers landfill, and the plant will produce 20 million gallons/year of ethanol. Once these facilities have provided successful operational history, Enerkem should be considered as a viable technical option for MSW gasification technology for RDNO.

4.1.3 Plasma Gasification

Plasma is a hot ionized gas resulting from an electrical discharge. Plasma technology uses an electrical discharge (some use AC, some use DC, and some use both) to heat a gas, typically air, oxygen, nitrogen, hydrogen, argon, or a combinations of these gases, to temperatures above 3,800°C. The hot ionized gas, or plasma, can then be used for welding, cutting, or treating waste materials.

Plasma arcs have been used for years to treat waste products and incinerator ash, converting them to a non-hazardous, glassy slag. While application to MSW is still new, it has great potential to convert MSW to electricity more efficiently than conventional pyrolysis and gasification systems due to its high heat density, high temperature, almost complete conversion of carbon-based materials to syngas, and conversion of inorganic materials to a glassy, non-hazardous slag.

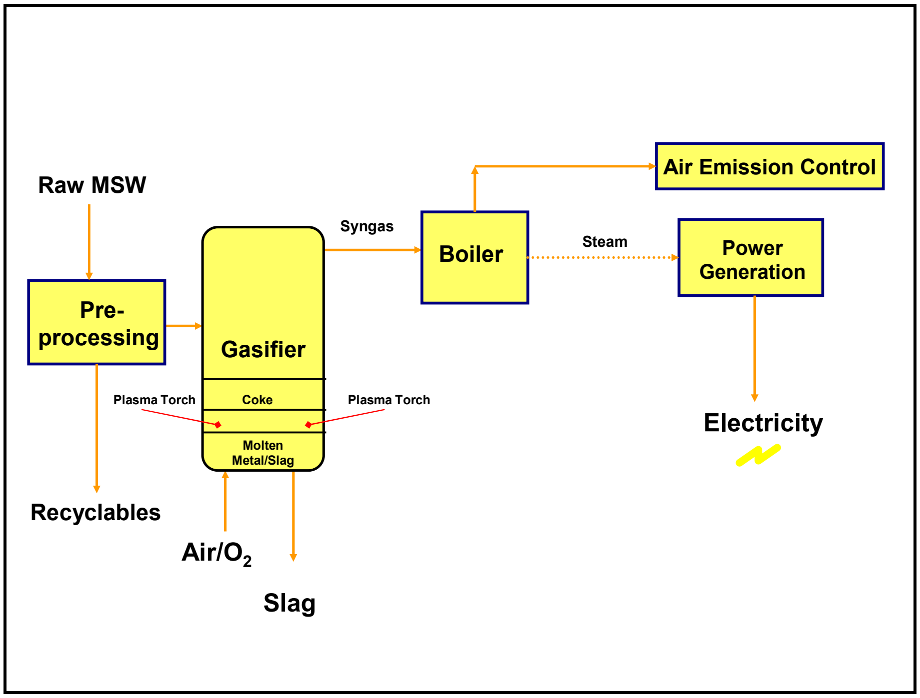
Most of the recent development and use of plasma arc technology has been for melting incinerator ash or for destroying hazardous or medical wastes. Only in the past 10 years has plasma technology been integrated with gasification technologies to process MSW on a commercial scale.

Plasma gasification typically occurs in a closed, pressurized reactor. The feedstock enters the reactor, where it comes into contact with the hot plasma gas. In some designs, several torches arranged circumferentially in the lower portion of the reactor help to provide a more homogeneous heat flux, as shown in Exhibit 4-8. When used for gasification, the amount of air or oxygen used in the torch is controlled to promote gasification reactions. The inorganic constituents are converted to molten form, then quench-cooled to form a glassy, non-hazardous slag.

There are two basic types of plasma torches, the transferred torch and the non-transferred torch. The transferred torch creates an electric arc between the tip of the torch and a metal bath or the conductive lining of the reactor wall. In the non-transferred torch, the arc is produced within the torch itself. The plasma gas is fed into the torch and heated, and it then exits through the tip of the torch.

There are several approaches to the design of the plasma gasification reactors. In one approach, developed by Westinghouse Plasma Corporation (plasma torch manufacturer, now part of AlterNRG) and Hitachi Metals (plasma gasification system developer and user), a medium pressure gas (usually air or oxygen) flows through a water-cooled, non-transferred torch located outside of the reactor. The hot plasma gas then flows into the reactor to gasify the MSW and melt the inorganic materials.

EXHIBIT 4-8
Typical Plasma Gasification System for Power Generation



Another design is an *in-situ* torch, where the plasma torch is placed inside the reactor. This torch can either be a transferred or non-transferred type. When using a transferred torch, the electrode extends into the gasification reactor and the arc is generated between the tip of the torch and the molten metal and slag in the reactor bottom or a conducting wall. The low-pressure gas is heated in the external arc. Alternatively, a non-transferred torch can be used in which the plasma gas is created within the torch and is injected into the reactor.

Several suppliers use a modified approach. In their designs, the reactor is heated by electric induction coils or a graphite arc, forming a molten metal and slag bath. The MSW enters the reactor, where it is subjected to high temperatures, resulting in partial gasification of the feedstock. From there, the syngas exits the reactor. A plasma torch is situated either in a secondary reactor or in a return line to the first reactor, assuring complete gasification of the feedstock.

Proponents of the *in-situ* torch claim its advantages include better heat transfer to the MSW and a hotter reactor temperature, resulting in more complete conversion to syngas. The main disadvantage is the potential corrosive effect of the hot MSW and gases on the torch in the reactor. Proponents of the external torch indicate that this approach protects the torch from the corrosive effects of the MSW and hot gas, and prolongs the mechanical integrity of the torches. Electrodes in all designs experience some wear and must be replaced. The disadvantage of the external torch is the possibility of a somewhat lower reactor temperature, resulting in lower carbon conversion.

The first two approaches have been applied to small-scale commercial waste and medical waste processing units. The throughput of the largest external system is approximately 4 tonnes per hour, and the throughput of the largest internal system is approximately 10 tonnes per day. The Hitachi Metals facility in Utashinai, Japan processes about 90 tonnes/day (per reactor) of a blend of MSW and auto shredder residue.

In the reactor, petroleum coke is often added to provide a bed for the MSW and to assure a reducing atmosphere in a portion of the reaction zone, initiating the pyrolysis reactions. Lime may also be added to the bed as a flux to lower the melting point of the inorganic components, and to stabilize the slag. Air, oxygen, or steam may be added through ports to provide the water and oxygen necessary to initiate the gasification reactions. Some designs include mechanical stirrers to keep the bed material agitated and promote efficient carbon conversion.

The syngas can either be burned immediately in a close-coupled combustion chamber or boiler, or cleaned of contaminants and used in a reciprocating engine or gas turbine. In the first approach, the exhaust gases are cleaned after combustion in an emission control system similar to what is used in mass-burn incineration plants. The hot gases flow through the boiler, creating steam used for power generation in a conventional steam turbine. In the second approach, the syngas is cleaned before it enters the reciprocating engine or gas turbine.

Feedstock preparation is similar to what is described above under conventional gasification. The primary solid byproduct from plasma gasification facilities is a glassy slag, as a result of melting the inorganic fraction of the MSW.

An analysis of existing and proposed plasma arc gasification systems shows that they can be one of the most efficient methods for processing MSW. Due to the high temperatures and throughput capability, these systems have the potential to produce up to 1,100 net kWh/tonne of processed feedstock. In lieu of producing electricity, the steam could be used for other nearby purposes. Additional steam from other sources could be used for drying the raw MSW to enhance its quality, or used to supplement the steam turbine generator production, if that equipment was initially designed for the additional steam flow. Additional steam from other sources could also be used for start-up purposes or to drive the steam turbine generator when the pyrolysis system was not in operation, providing that it meets the steam quality and quantity requirements.

With regard to air emissions and other environmental issues for plasma gasification, the prior discussion on conventional gasification applies here also. Plasma arc gasification has the potential to provide even better performance, since the plasma arc system operates at such high temperatures, the ash exits in a slag form with very little unreacted carbon. The amount of char/ash produced (potentially requiring landfill disposal) will be approximately 15 to 20 percent by weight of the feedstock throughput. Removal of metals and glass from the input stream will reduce this value.

Existing reactors operate at throughputs of up to 90 tonnes/day. Turndown is difficult with this technology, and plasma arc control of the gasification process becomes less efficient during start ups and shutdowns, when throughput is decreased. With only a few commercial-scale plants in service, much has still to be learned about the operating profile of this technology. The largest commercial-scale plant is the Hitachi Metals facility in Utashinai, Japan. It uses the Westinghouse Plasma technology in two Hitachi Metals reactors to process up to 180 tonnes/day of MSW and/or auto shredder residue using two operating and one spare torch per reactor. Plasma torches can be added to the reactors and multiple reactors can be added to increase total capacity.

While there are many companies that offer plasma gasification systems, they are typically based on the plasma arc technology from only a few suppliers. One of the major plasma torch suppliers, Westinghouse Plasma Corporation, was acquired last year by AlterNRG, a company which now designs and builds full-scale plasma gasification systems for MSW, biomass, coal, petroleum coke, and blends of these feedstocks. Plasco Energy Group, which developed its own plasma gasification technology, is using it in the Trail Road MSW plasma gasification demonstration facility near Ottawa.

Exhibit 4-9 provides a summary of existing MSW plasma gasification facilities. As with pyrolysis and conventional gasification, there have been pilot and demonstration plants that operated for some period of time and then shut down. While no longer in operation, they provided the design basis for the facilities listed in the table.

EXHIBIT 4-9
Summary of Existing MSW Plasma Gasification Facilities

Facility	Location	In-service Date	Technology	Tonnes/year	Energy Production	By Products
Mihama-Mikata (operated by Hitachi Metals)	Mihama-Mikata, Japan	2002	Westinghouse Plasma torches with Hitachi Metals' Plasma Direct Melting Reactor	7,300 (blend of MSW and sewage sludge)	Hot water for district heating	Slag
Eco-Valley WTE Facility	Utashinai, Japan	2003	Westinghouse Plasma torches with Hitachi Metals' Plasma Direct Melting Reactor	65,700 (60% MSW, 40% auto-shredder residue)	Electricity - boiler and steam turbine-generator; 568 net kWh/tonne feed.	Slag
Plasco Trail Road	Ottawa, Ontario	2007	Plasco	30,000 (MSW in existing Nepean landfill)	Syngas combusted in reciprocating engine; 1,150 net kWh/tonne	Slag

AlterNRG is planning several plasma gasification systems using the Westinghouse Plasma technology that is in commercial use in Japan:

1. A MSW gasification system is being developed for the city of St. Lucie, Florida. Originally, this was planned to process 2,000 tons/day of incoming MSW, along with 1,000 tons/day of MSW reclaimed from an adjacent landfill. Due to technical and economic issues, the plant is now planned to process a smaller throughput. This project is being developed by GeoPlasma (part of Jacoby Energy), and AlterNRG is a partner in this project.

2. NRG Energy (no relation to AlterNRG) is repowering its existing coal-fired Somerset Power Plant, Unit 6 in Somerset, Massachusetts. NRG Energy has a license to utilize the AlterNRG plasma gasification technology for gasifying coal and biomass. The plant will generate 120 MW. The facility has received its air permit and plans to start operation in 2010.

3. AlterNRG is constructing a cellulosic ethanol commercial demonstration project at the Westinghouse Plasma Corporation demonstration facility near Pittsburgh. They have partnered with Coskata Inc. and will use Coskata's proprietary syngas-to-ethanol conversion technology.

4. SMS Infrastructures is building two 68 tonne/day plants (hazardous waste), located in Pune and Nagpur, India. Each plant will provide comprehensive disposal services for a wide variety of hazardous waste, and will produce up to 1,600 kW (net) of electricity.

Plasco Energy Group is planning two new plasma gasification facilities for MSW:

1. An expansion of the Trail Road facility to 400 tonnes/day (145,000 tonnes/year) - This facility will be designed, built, and operated by Plasco.
2. A new gasification facility for MSW produced by the Central Waste Management Commission in Red Deer County, Alberta – This facility will treat 200 tonnes/day (73,000 tonnes/year) of MSW. According to Plasco, the process generates 1,200 kWh per tonne of MSW (not specified if this is gross or net kWh). This facility will be designed, built, and operated by Plasco.
3. A proposed gasification facility for MSW produced in the City of Vancouver – This facility will treat 400 tonnes/day (145,000 tonnes/year) of MSW and generate 21 MW.
4. A new gasification facility for MSW produced in the Bahamas – This facility will be located at the Harold Road Landfill on New Providence Island (location of Nassau). The facility will treat 400 to 800 tonnes/day (145,000 to 290,000 tonnes/year) of MSW and generate electricity using reciprocating engines. This facility will be designed, built, and operated by Plasco.

As with conventional gasification, the larger the system, the better the economics on a per-tonne basis. However, since the application of plasma technology to gasification is still new, it is wise to consider the potential technical risks from scaling up this technology from present experience levels. The smallest system using MSW is only 23 tonnes/day, with the largest at about 180 tonnes/day. Little to no size scale-up of the technology would be required to process the 118 to 155 tonnes/day or 43,000 to 57,000 tonnes/year throughput for RDNO. Based on the results of the cited studies and present commercial operating experience, plasma gasification suppliers that should be considered are:

- AlterNRG (Calgary, Alberta)
- Plasco Energy Group (Ottawa, Ontario)

In the two cited studies (URS, 2005a and 2005b), GeoPlasma proposed their technology in a consortium that included Westinghouse Plasma's technology, reactors designed by Hitachi Metals, and technical oversight by Georgia Institute of Technology's plasma laboratory. Since the acquisition of Westinghouse Plasma by AlterNRG, further interest in or evaluation of that specific technology should be directed to AlterNRG. There are other plasma gasification suppliers (i.e., Startech Environmental and Europlasma) that have MSW-to-power facilities planned. Due to the state of development of this technology, it is still considered to be somewhat risky. It is important to monitor these other facilities as they go into service to determine if those suppliers' technologies are technically viable and warrant further evaluation.

4.1.4 Changing Influent Composition in RDNO

Conversion technologies work best when using homogeneous, low moisture, high heating value feedstocks. Any change in the RDNO MSW stream that results in a reduction in moisture content and an increase in the amount of high heating value components will result in improved conversion technology efficiency.

Over time, the composition of RDNO's MSW is expected to change. Part of that change will be due to the implementation of the Extended Producer Responsibility (EPR) Programs. The concept of EPR is based on the principle that suppliers, manufacturers, and consumers share the responsibility to minimize environmental impact in a system that manages the cradle-to-cradle life cycle of the products they make, sell, and use. Industry-managed EPR Programs are gaining acceptance throughout the world and especially in BC. Other planned changes in the MSW influent are the eventual composting of yard and garden waste, as well as wet organic waste. This will remove them from the influent stream.

Through implementation of the EPR Programs, the amount of recyclable plastics in the MSW stream is expected to be reduced. Since plastics are the highest quality feedstock for conversion technologies, this will result in a reduction in the overall heating value of the MSW. However, since the plastics component of the influent (as shown in Table 3-1) is only about 8 percent, the overall impact is not considered to be significant with respect to the performance of conversion technologies. One of the benefits of conversion technologies is that plastics that are not being recycled are a very good feedstock. By using conversion technologies such as pyrolysis or gasification, plastics that are not being recycled do not have to be sent to a landfill; they can be utilized for efficient energy production.

A reduction in the amount of wet organics will be beneficial to the performance of conversion technologies. Since these wet organics have very low heating value (due to high moisture content), and contribute to 46 percent of the MSW stream, any reduction in their quantity will result in an increase in the overall MSW influent quality and improvement in conversion technology system efficiency.

Wood waste tends to be a medium heating value portion of MSW. Increasing the amount of wood waste in the MSW stream will increase the overall quality of the MSW and the performance of conversion technologies. However, some amount of pre-processing will likely be required (i.e., chipping and/or shredding the wood so that it meets size limitations for reactor feed).

Not included in this study is the provision for additional influent from additional sources such as adjacent Regional Districts, agriculture, and industry/manufacturing where there may be significant complementary high heating value materials. A facility such as this could benefit from a more inclusive influent stream to gain a greater economy of scale.

4.2 Summary of Mass-burn Incineration Technology

The most prevalent technology used for WTE is mass-burn incineration. In this technology, raw unprocessed MSW is fed directly onto a moving grate which is integrated with a boiler. The MSW is directly combusted *in an oxygen-rich environment,* typically at temperatures of 700°C to 1,350°C, producing an exhaust gas composed primarily of CO_2 and water, with inorganic materials converted to bottom ash and fly ash. The hot exhaust gases flow through a boiler, where steam is produced for driving a steam turbine-generator, generating electricity. The cooled exhaust gases flow through an emission control system designed to reduce nitrogen oxide emissions, and to capture sulfur dioxide, hydrogen chloride and other acid gases, dioxins/furans, and particulate matter. The byproducts of the emission control systems are typically blended with the boiler fly ash and bottom ash, and often used as daily cover for adjacent landfills. The amount of char/ash produced (potentially requiring landfill disposal) will be approximately 15 to 20 percent by weight of the feedstock throughput. Removal of metals and glass from the input stream will reduce this value.

More recent advanced designs actually include recovery of some of the pollutants from the flue gas, converting them to marketable byproducts such as gypsum (e.g., for cement or wallboard manufacture) and hydrochloric acid (used for water treatment). The bottom ash and fly ash are segregated, allowing for recovery/recycling of metals from the bottom ash and use of the bottom ash as a road base and construction material.

Mass-burn incineration is a proven technology with considerable commercial size experience. Typical systems in North America treat up to 3,000 tonnes/day of MSW, generating about 605 net kWh/tonne of MSW. There are seven facilities in Canada, some using single-stage and some using two-stage mass-burn technology. The oldest system in Canada started up in 1974, with the newest in 1995. The largest system in Canada processes 920 tonnes/day. Systems for treating the 118 to 155 tonnes/day quantity for RDNO are commercially available and proven in long-term commercial service.

While there are many of these facilities in North America, it has become much more difficult to site and permit new facilities. This is due to community objection to new mass-burn facilities, primarily focused on emissions of pollutants. Whenever new mass-burn facilities are proposed, international anti-incineration groups get very involved with the local communities to help to delay or stop the project from moving forward. This occurs even when WTE has a much lower life-cycle assessment impact than the existing landfill. Over the past few years, the only new units permitted have been additions at existing facilities, and these have been very difficult to develop and permit.

As a means of reducing the amount of solid waste going to landfills, the application of advanced mass-burn incineration technologies may be worthy of further consideration by RDNO if WTE as an option is of interest. It offsets the use of fossil fuels in the generation of electricity, while reducing the need for landfills. Studies have shown that mass-burn incineration can have a lower cost per tonne than conversion technologies such as pyrolysis and gasification. Although mass-burn incineration is a viable technology, the impacts to and concerns from the community will need to be fully addressed before moving forward with this technology.

4.3 Siting Requirements

WTE facilities can be implemented in industrial areas as well as in urban areas. There would be truck traffic bringing in the feedstock, as well as some noise created by the facility. Siting requirements would be set by local zoning regulations along with Provincial and Federal legislation.

4.4 Summary

Exhibit 5-1 provides a summary of key aspects of the technologies reviewed in this report and relates them to the current landfill practices in the RDNO.

EXHIBIT 4-10
Summary Table – Advantages/Disadvantages of MSW Alternatives

	Technology				
Advantages/ disadvantages	**Pyrolysis**	**Gasification/ Plasma Gasification**	**Incineration**	**Landfilling**	**Notes**
Minimum throughput quantity (tonnes/yr)	15,000	18,600	No minimum	No minimum	
Throughput quality (% wood, landclearing, plastic)	Higher heating value feedstock results in higher plant efficiency. Non-recyclable plastics are excellent feedstock.	Higher heating value feedstock results in higher plant efficiency. Non-recyclable plastics are excellent feedstock.	Higher heating value feedstock results in higher efficiency.	N/A	
Average costs, including capital recovery and Operations and Maintenance (O&M) (CDN $/ tonne)	50 to 115	50 to 115	50 to 70	47	1, 2
Operation/ maintenance complexity	Moderate to high	Moderate to high	Moderate	Not complex	
End product	Power, fuels, chemicals, steam	Power, fuels, chemicals, steam	Power and/or steam	LFG, leachate	
Quantity of electricity produced (net kWh/ tonne)	Up to 770	Up to 1,100	Average 605	135	3
Revenue from sale to BC Hydro (3)	30.80 $/tonne	44.00 $/tonne	24.20 $/tonne	5.40 $/tonne	4
Long term liability	None	None	Emissions	Surface/Ground water impacts, odours, LFG	
Byproducts	Char/ash mixture which may require landfill disposal. 15-20 % of MSW throughput	Bottom ash or slag which may require landfill disposal. 15-20 % of MSW throughput. Slag may have commercial value for making cement, roofing tiles, asphalt filler.	Bottom ash/emission control wastes may require landfill disposal or may be used for construction or as alternative daily cover on landfill. 15-30 % of MSW throughput.		
Proven technologies	✓	✓	✓	✓	
Existing facilities	Less than 20 worldwide, some in operation for 25 years; no full-scale facilities yet in North America using MSW	More than 50 worldwide, but none yet in North America using MSW	>500 worldwide; almost 100 in North America using MSW	Thousands worldwide	
Implementation time (permit, design, construct)	4 to 5 years	4 to 5 years	4 to 5 years	10 to 20 years	

Notes:

1: Based on information provided by RDNO on May 11, 2009.

2: The recovery period and the facility life expectancy are both estimated to range between 15 to 20 years.

3: Electricity potential (kW-h/tonnes) based on:

- landfill gas recovery up to estimated landfill closure in 2034.
- Based on CH_4 generation rate constant (k) estimated for the Okanagan Valley.

4: Based on sale price of energy only: 0.04 $/kW-h.

5. Conclusions

Based on the above review of technologies, and understanding the long term goals of the RDNO and the changes in the solid waste stream, the following is concluded:

1. Conversion technologies, including pyrolysis, conventional gasification, and plasma gasification, are technically viable and are being implemented worldwide. Presently, there are no full-scale facilities in North America, but several are being constructed.
2. Conversion technologies actually enhance recycling programs, as they can utilize plastics contained in the waste stream that are not being recycled. These plastics would otherwise be disposed of in landfills.
3. The efficiency of conversion technologies (i.e., net kWh of electricity generated per tonne of MSW) is greater than that for mass-burn incineration.
4. Conversion technologies offer energy alternatives that mass-burn incineration can not (i.e., production of chemicals and fuels from the syngas generated in these processes).
5. The environmental profile of conversion profiles is better than for either landfills or mass-burn incineration, but worse than for reuse/recycling.
6. Capital and operating costs of conversion technologies are presently higher than for either landfills or mass-burn incineration. As more of these technologies are implemented, and at higher throughput levels, these costs are expected to decrease.
7. In lieu of open burning of wood waste created in the RDNO area, it could be processed (i.e., chipped) for use as a blend feedstock with the MSW. This would raise the overall heating value and quality of the feedstock used by conversion technologies.
8. The RDNO could improve the viability of such a system by drawing from more influent sources, such as the forest industry, agricultural sector, and other non-MSW sources.
9. Plasma gasification has the potential to provide the highest efficiency and energy production (net kWh/tonne) of all conversion technologies. In addition to the one operating facility in Ontario, others are being planned for British Columbia and Alberta. It may be beneficial to monitor the progress of these projects and to further evaluate this technology.
10. The City of Edmonton is moving forward with a facility that will use 100,000 tonnes/ year of processed MSW in an Enerkem gasification facility, producing methanol and ethanol. It may be beneficial to monitor the progress of this project and to further evaluate this specific technology.
11. If the RDNO wishes to pursue WTE as part of their solid waste system, it would be necessary to review its current policies to ensure they are consistent with this decision.

12. Because the Province of British Columbia is implementing new EPR programs at a rate of two new products every 3 years, WTE may serve an interim purpose as diversion increases well into the future.

6. References

Apoteker, S. 1991. *Volume-to-weight factors: recycling's manifest density*. Resource Recycling. November.

BGC Engineering Inc. 2009. *GVRDF Operations and Closure Plan, Final*. February 9.

CH2M HILL. 2007. *Phase 1 - Solid Waste Management Plan Review*. Prepared for Regional District of North Okanagan. September 2007.

CH2M HILL. 2008a. *RDNO Organic Waste Strategy Technical Memorandum*. Prepared for Regional District of North Okanagan. September 30.

CH2M HILL. 2008b. *Recommendations for DLC Diversion Practices Technical Memorandum*. Prepared for Regional District of North Okanagan. August 1.

Greater Vancouver Regional District. 2008. *Air Quality Management Bylaw No. 1082*.

Jenkins, S.D. 2007. Thermal Conversion Technologies. Draft report prepared for the Regional Municipality of Halton.

Province of British Columbia. 2002. BC *Environmental Assessment Act* [SBC 2002] Chapter 43. http://www.bclaws.ca/Recon/document/freeside/--%20E%20--/Environmental%20Assessment%20Act%20%20SBC%202002%20%20c.%2043/00_02043_01.xml. Accessed on May 6, 2009.

Province of British Columbia. 2003. *Environmental Management Act* [SBC 2003] Chapter 53. Queen's Printer, Victoria, BC. http://www.bclaws.ca/Recon/document/freeside/--%20E%20--/Environmental%20Management%20Act%20%20SBC%202003%20%20c.%2053/00_Act/03053_00.htm. Accessed on May 6, 2009.

Recycling Council of BC. *BC Municipal Solid Waste Tracking Report 2003-2005*. http://www.rcbc.bc.ca/files/u3/bc_mun_solid_waste_tracking_report.pdf. Accessed on May 7, 2009.

Regional District of North Okanagan. 1996. *Solid Waste Management Plan*.

Regional District of North Okanagan. 2002. *Solid Waste Management Plan Update*.

Regional District of North Okanagan. 2008. *Minutes of the Regular Meeting of the Electoral Area Advisory Committee*. November 18. http://www.rdno.ca/meetings/minutes/easervices/081118.pdf. Accessed on May 6, 2009.

Technology Resource Inc. 2005. *Solid Waste Composition Study*. Prepared for Regional District of North Okanagan. January 22.

URS. 2005a. *Evaluation of Alternatives Solid Waste Processing Technologies*. Prepared for the City of Los Angeles Bureau of Sanitation. September.

URS. 2005b. *Conversion Technology Evaluation Report*. Prepared for the City of Los Angeles. August.

XCG Consultants Ltd. 2009. *Draft Design and Operations Plan, Armstrong-Spallumcheen Recycling and Disposal Facility, Armstrong, BC*. February 25.