Waste to Energy

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INTRODUCTION

Providing the community with opportunities to diversify utilities, provide energy, heating and/or cooling or provide electricity have been holistically explored within the St. Alberta area. There are opportunities to become better stewards of the environment, diversify income portfolios and/or implement alternative linear and vertical assets to provide opportunities to a community. Waste, district heating and cooling system, co-generation, and plausible spin-off ventures have been researched and examined at a high level.

Waste to Energy

Urban waste generation and disposal has become a major global issue. As the world's population continues to grow towards the 8 billion mark and more people move to urban areas, the amount of waste generated therein will soon become unmanageable. In 1900, only 10% of the global population lived in an urban environment. Just over 100 years later, the number of people living in cities surpasses those living in rural areas and it has been estimated that by 2030, 5 billion people will be living in cities. Projects from the United Nations show that the rapid depletion of essential human resources will only speed up as the population continues to grow at exponential levels[1]. As a result, there is a conceptual push by public intellectuals for the growth of "Ecopolis" or sustainable communities, with coupled Smart Grid adaptations [2]. Ecopolis is a special form of urbanization in which cities are "greened" by employing current and future technologies to minimize energy requirements, water and food requirements, waste outputs, air pollution, greenhouse gases, and water pollution. Additionally, in the late 1990's "Smart Grids" were used to describe an approach to modernize electrical distribution to transform the way that a utility interacted with its customers to provide a high level of service and reliability. Loosely defined, the Smart Grid included increased automation from premise to the utility infrastructure, increase use of distributed renewable generation, a high adoption rate of plug in electric vehicles that could be used to support the need for energy during critical times, and self healing mechanisms. The Ecopolis and Smart Grid premises provides a community an ability to sustain itself with minimal reliance on the surrounding area for energy input, and there is the ability to get most if not all its power from renewable sources, including waste to energy, solar, and geothermal avenues.

Co-Generation

Co-generation is defined as sequential generation of two forms of useful energy from a single primary energy source, the typical two forms of energies are mechanical energy and thermal energy. Mechanical energy may be used to either drive an alternator or produce electricity or rotate equipment like a motor, compressor, pump or fan etc., for

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[1] United Nations population Funds, Report: Two-Thirsds of the World's Population Will Live in Cities by 2050. https://www.usnews.com/news/world/articles/2018-05-17/report-two-thirds-of-worlds-population-will-live-in-cities-by-2050 , August 2018.

[2] Fre Pearce, "Ecopolis Now," New Scientist, June 17, 2006; pages 36-45.

the delivery of different services. Thermal energy may be used directly for heating purposes or indirectly to produce steam to be used in power generation, hot water or hot air for dryer use and chilled water generation for process cooling.

Generation of three different forms of energy from the single primary energy source is call Tri-generation, i.e., generation of Electricity, Steam or Hot water and Chilled water from a single source of primary fuel. These systems are referred to as “Total Energy Systems”.

Provided the co-generation is optimized, there are a number of benefits that arise, additionally it is recognized as a cleaner alternative to traditional centralized power generation. Co-generation is projected to be a long-term feasible option across the world, as it provides operational, financial and environmental benefits over utilizing a single fuel source.

Operational advantages include:

- Base load electricity supply,
- Security supply,
- Increased diversity on heating and hot water,
- Steam raising capability, and
- Tri-generation, using absorption/mechanical chillers for cooling.

Financial advantages include:

- Reduced primary energy costs,
- Stabilized electricity cost over a fixed period,
- Flexible procurement solutions, and
- Reduced investment in surrounding plants.

Environmental advantages include:

- Improved fuel efficiency,
- Reduced CO2 emissions,
- Reduced transmission loses, and
- Lower SOX emissions with the use of natural gas.

Environmental Stewardship

As part of the goal of building a more sustainable community and reducing the community’s environmental footprint, closing the waste generation loop, by coupling harnessed energy and converting the final products that cannot be recycled into a useable form of energy supports and overall sustainable functionality for a community.

WASTE TO ENERGY

Waste to energy (WTE) technologies use waste to make up fuel-like products that could be utilized to produce energy, preferably heat and electricity. The Waste or more specifically Municipal Solid Waste (MSW) refers to residential waste, construction debris, agricultural, industrial and commercial waste[3]. It is possible to produce energy from collected waste and using technology to convert to a fuel in solid form; or from waste material that has been turned into gaseous fuel, such as syngas; or alternatively, from heat and steam that result from incineration of the waste. Waste to Energy (WTE) processes have various options for electricity, combined heat and power (CHP) and liquid fuel production. A production option would be a fuel rich in methane (CH_4) and carbon dioxide (CO_2), called biogas; or produce syngas (largely H_2 and CO), which can be used to produce liquid biofuel (ethanol and biodiesel), pure hydrogen and even water, in additional to electricity[4][5]. Thermal processes, biological or biochemical processes and finally chemical processes are in fact the main branches of WTE industry. Waste to Energy (WTE) refers to any type of waste processing methods that produces energy from a waste material that otherwise, should have been handled in the landfilling process. Some WTE technologies result in production of useable fuels. In practice, Waste to Energy means the use of modern thermal technologies mainly for the purpose of energy recovery, usually in the form of electricity and heat from variety of sources. These methods can significantly reduce the volume of waste material depending on the composition of the input and the desired output – if they are fully commercialized in a region. Apart from the nature of the output product (either it is power, heat or fuel) specific emissions standards must be met by these thermal processes.

The implementation of a waste to energy program requires a comprehensive understanding and knowledge of the MSW stream. ASTM delineates recommendations for quartering sampled waste stream and developing a computer program that can utilize statistically sound sampling protocols for estimating the specific composition of wastes. Fewer categories are required than suggested by ASTM when examining the feasibility of a waste to energy facility.

In a materials flow approach, the number and types of products within an MSW stream are used to make products with regards to quantity and composition of waste. A major consideration used to develop predictive models in this system is the estimated product life. The advantage of this method is that an estimate of the overall solid waste stream composition can be accomplished for very large geographical areas. Some drawbacks include the fact that some material compounds may be left out or poorly estimated because they are not part of the production sector. There is also a materials flow approach (also known as the economic input/output method) to compare to estimates obtained from sorting studies. This can provide a useful complement or alternative to conventional sorting.

Waste streams audits are a regular occurrence throughout communities across the province, a few communities are shown below in order to reliably provide an

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[3] Klien,A. “gasification: An Alternative Process for Energy Recovery and Disposal of Municipal Solid Waste”, Master’s thesis submitted to Columbia University, 2002, p. 6.

[4] Wagner, l. Waste to Energy (WTE) Research Report, MORA Associates, July 2007.

[5] Waste to Energy : Section 3.4.3 Waste, Cleantech report, lux research 2007, p. 188.

examination of suitability of a WTE system. In order to reliably examine the implementation of a WTE technology a comprehensive waste audit is required to provide the necessary information to consider technologies and implementation parameters:

Table 1.0, Waste composition by % weight at several locations in Alberta

	Edmonton	Red Deer	Town of Stettler
Inert	9	9	9
Wet putrescible	37	44	37
Dry putrescible	45	41	40
Plastic	9	6	11
Other	0	0	3

The below table provides a summary of waste stream composition data in Alberta

Table 2.0, Summary of Alberta Waste stream composition

		Alberta Community A		**Alberta Community B**		
Broad Category	Material	Residential (%)	Commercial (%)	Residential (%)	Commercial (%)	Rural (%)
Wet Putrescible	Food waste	22.6	28.9	32.3	33.4	27.7
	Yard waste	16.9	1.6	3.5	1.0	0
	Textile/leather/rubber	2.1	1.3	3.1	5.9	1.9
	Total	**41.6**	**31.8**	**38.9**	**40.3**	**29.6**
Dry Combustible	Newsprint	6.8	5.5	10.7	2.7	8.1
	Cardboard	3.3	18.6	1.2	22.3	3.7
	Mixed Paper	21.5	21.9	23.7	19.5	19.1
	Wood	0.7	1.1	0.1	1.0	1.2
	Total	**32.3**	**47.1**	**35.7**	**45.5**	**32.1**
Plastic	Plastic	11.4	9.8	9.8	6.8	8.7
	Total	**11.4**	**9.8**	**9.8**	**6.8**	**8.7**
Inert	Metal	4.5	4.5	6.1	2.3	6.6
	Glass	2.9	1.8	3.0	0.9	9.3
	Ceramic/Ashes/Fines	2.1	2.0	4.0	0.3	2.2
	Total	**9.5**	**8.3**	**13.1**	**3.5**	**18.1**
Other	Other	5.2	3.0	2.5	3.9	11.5
	Total	**5.2**	**3.0**	**2.5**	**3.9**	**11.5**
	TOTAL	**100**	**100**	**100**	**100**	**100**

Factors that affect the composition of the waste stream of a household or a community are:

- Population,
- Dwelling size and character,
- Income level, and
- Cultural characteristics.

Research has been able to correlate some of the waste generation categories to the delineated factors that affect waste stream. More paper in the waste stream was related to high income communities. Higher occupancy rates resulted in higher percentages of food, while lower occupancy rates resulted in higher percentages of glass. The percentage of metals increased with increasing average temperatures.

The principle components involved in recovery the energy from the heat, steam, gases, oils and other products produced in the waste to energy process are similar and typically include: boilers for the production of steam, steam and gas turbines, for motive power, and electrical generators for the conversion of motive power into electricity.

Renewability of Waste to Energy

The strength and depth of waste to energy as a renewable energy source is depending on the nature and composition of the waste being fed into the process. To delineate whether the WTE being utilized in a plant is considered renewable, a measurement of the biological percentage of the feedstock is needed. This pertains to the measure of the amount of food scraps, paper, fabric, wood, leather in the feedstock, to see whether it qualifies as a renewable energy source.

In order to investigate the renewability of the MSW, some experts claim that only the part coming from the living organisms can be considered renewable source. The rational behind this argument simply comes from the fact that the materials originated form non-biogenic waste are made by fossil fuel resources and are not renewable. Others however, believe that the entire category is renewable, simply because the alternative is more environmentally disturbing and except methane extraction, does not give back energy that could be put into any useful process.

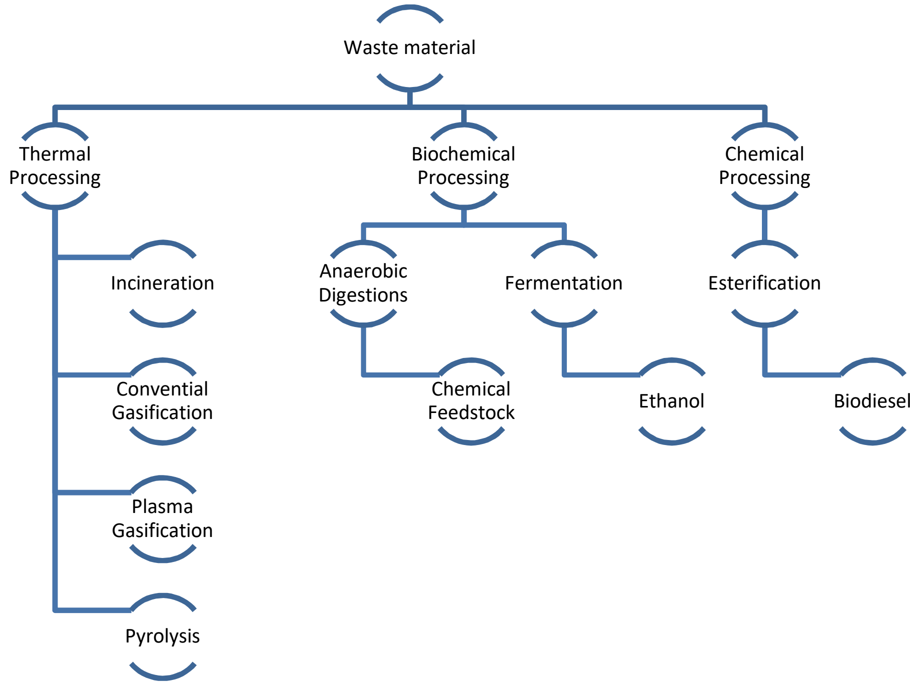

Figure 1. Waste Management processes

As shown in Figure 1 WTE projects in the modern world can be classified as thermal, biochemical/biological or chemical processes. Biochemical or biological processes are divided into anaerobic digestions which leads to production of chemical feedstock and fermentation, which results in ethanol. Chemical processing further becomes esterification and that finally gives biodiesel.

Sources of Waste to Energy

Biomass

"Biomass" is a category of materials with one important element in common: they are all originated from recently living organisms. Therefore, biomass totally differs from fossil fuels, as the latter requires millions of years to be made, although they are derived from somewhat the same sources (plants and animals). In today's global energy market, biomass is not a major fuel for industries; however, still accounts for 15-20% of total fuel world wide. This clearly indicates the significant of energy use in non-industrial and developing economics, which still use biomass as their main energy source.

Vegetable Biomass

Some data regarding vegetable biomass is shown in Table 3. High heating values (HHV), Moisture content, ash, sulfur and chlorine content of various sources of biomass derived from vegetables.

Table 3.0, Vegetable biomass composition

Biomass	HHV (MJ/Kg)	Moisture (wt. %)	Ash (wt. %)	Sulfur (wt. %)	Chlorine (wt. %)
Charcoal	25- ~30	1-10	0.5- ~6	-	-
Wood	10-20	10-60	0.2-~1.7	~0.01	~0.01
Straw	~15-16	10	4-5	~0.07	~0.5
Sawdust	11	35	2	-	-

Animal Biomass

The term biomass is mostly used for vegetable biomass; however, animal-derived waste is a type of source that cannot be disregarded. It is worth mentioning that the water production by poultry is approximately 8 kilograms per head per year. This number for swine, beef cattle and dairy cattle is 300kg, 900kg to 1200 kg, and 1200 to 2000kg per year per head respectively. In the Shell Coal Gasification Process plant in the Netherlands, animal waste has been minimized with coal up to 12% for the gasification process and it has been planned to go up to 30%. Properties of animal waste vary from type to type. Literature reports that the poultry litter for instance has the Higher Heating Value (HHV) of 13-14 (MJ/kg), with moisture content of 63 (wt. %), volatiles of 25 (wt. %) and finally 20 % Ash.

Municipal Solid Waste

Municipal Solid Waste (MSW) can be defined as the water output from households and some other industrial sectors that contain product packaging, clothes, food left over and some unconventional wastes. MSW does not include wastes of other types such as automobile scraps, municipal sludge, ash resulting from combustion and also some industrial wastes that might be disposed in landfilling operations. The main specification of MSW is that it should originate from either residential, commercial, institutional or some specific industrial process.

In order to design an application process for waste management and its economic evaluation, access to MSW properties is crucial and can affect the big picture of waste management practices. Literature suggests that the Low Heating Value (LHV) of the MSW could be as low as 10 MJ per Kg; however, evaluating these types of data is believed to be sensitive to the location and to local regulations for sorting and recycling waste. It is reported that MSW mainly consists of carbon (with 35.5 wt. %), oxygen (with ~25 wt. %) and moisture (with 26.5 wt %). Concentration of hydrogen is around 5% and ash accounts for about 7.5%.

Landfilling may be the most common waste management solution, but it is not the only plausible solutions. There are several additional waste processing technologies that are currently employed around the world that fall under the *incineration and biological processing* heading.

WASTE TO ENERGY TECHNOLOGIES

Thermal

The general consideration for thermal processes to transform stored potential energy into useable energy involves a chemical reaction in which carbon, hydrogen and other elements in the waste mix with oxygen in the combustion zone and generate heat. The air requirement for combustion is significant, generally a design would incorporate approximately 5000kg of air per tonne of waste burned. Generally excess air is supposed to ensure complete combustion and to regulate operating temperature and control emissions. Excess air requirements, however, differ with moisture content of waste, heating values and type of combustion technology. The principle gas products of combustion are carbon dioxide, carbon monoxide, water, oxygen and oxides of nitrogen.

Many incinerators are design to operate in the combustion zone of 900 °C – 1100 °C. This temperature selected to ensure good completion, complete elimination of odours and protection of the walls of the incinerator. Incinerator systems are designed to maximize waste burn out and heat output, while minimizing emissions by balancing the oxygen (air) and the three "Ts", i.e., time, temperature and turbulence. Complete incineration of solid wastes produces virtually an inert residue, which constitutes about 10% of the initial weight and perhaps a larger reduction in volume. The residue is generally landfilled.

The incineration facility along with combustion of waste emits air pollutants (i.e., fine particulate and toxic gases), which are an environmental concern, and, therefore, their control is necessary. Other concerns relating to incineration include the disposal of the liquid wastes from floor drainage, quench water, scrubber effluents and the problem of ash disposal in landfills because of heavy metal residues. By optimising the combustion process, we can control the emission of combustible, carbon-containing pollutants. Oxides of nitrogen and sulphur, and other gaseous pollutants are not considered a problem because of their relatively smaller concentration.

It is important to have a complete understanding of the waste streams considered as they can provide a better understanding of the stored energy within the waste. The below table provides the information about the elemental breakdown of each of the traditional waste stream.

Table 4.0, Combustible components of waste

Percent by Weight (dry basis)						
Component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Food	48	6.4	37.6	2.6	0.4	5
Paper	43.5	6	44	0.3	0.2	6
Carboard	44	5.9	44.6	0.3	0.2	6
Plastic	60	7.2	22.8	-	-	10
Textile	55	6.6	31.2	4.6	0.15	2.5

Rubber	78	10	-	2	-	10
Leather	60	8	11.6	10	0.4	10
Garden Trimmings	47.8	6	38	3.4	0.3	4.5
Wood	49.5	6	42.7	0.2	0.1	1
Dirt,ash, brick etc.	26.3	3	2	0.5	0.2	68

In case energy values in KJ/kg or BTU/1lb are not readily available, you can calculate an approximation from the data in the above table using the Dulong formula (below):

Energy value (BTU/1b) = 145.4C = 620(H-1/8O) + 41S

Where C, H, O, and S are in percent by weight (dry basis) and can be converted to KJ/KG by 1 BTU/1b x 2.326

Incineration

Incineration is a waste disposal method that involves combustion of waste material at high temperatures and is often referred to as 'thermal treatment.' Incinerators convert waste materials into heat, gas, steam and ash and in the process reduce the volume of the original MSW by up to 80%. The heat and steam produced can be used to power a turbine to generate electricity and thereby qualifies incineration as a "waste to energy technology.

The drawbacks of incineration are the toxicity of the flue gases and the fly ash and bottom ash produced during the process. The flue gases need to be scrubbed of particulates, acids, and dioxins and furan content as they pose serious environmental and health hazards. The primary form of air pollutants are nitrogen oxides, sulphur dioxides and hydrogen chloride. Additionally the fly ash left over from the incineration process is toxic as it contains significantly high concentration of heavy metals such as lead, cadmium, copper and zinc. This ash needs to be buried in a designated toxic area and many communities are not comfortable with toxic materials being located nearby. Incinerators remain a contentious environmental and social issue but are still employed around the world in places like Japan and Denmark that are short on space. Denmark and Sweden have been using this waste disposal technology for more than a century and often have district heating schemes that run exclusively off the heat produced by the process. In 2005, Denmark produced 14% of its domestic heating and almost 5% of its electricity through waste incineration [6].

Theoretically incinerations can be combined with anaerobic digestions, wherein the residual from anaerobic digestion is incinerated. By using steam from incineration as well as the methane from anaerobic digestions, the efficiency of the combined system might be increased to 63% compared to the 32.6% from anaerobic digestion alone.

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[6] R.P.J.M. Raven, K.H. Gregersen, "Biogas plants in Denmark: Successes and Setbacks," Renewable and Sustainable Energy Reviews, Volume 11, Issue 1, January 2007, Pages 116-132.

Efficiency in this case is defined as the amount of energy produced as a faction of the theoretical yield based on the total calorific value of the waste. The capital costs of a system that combines anaerobic digestion and incineration would be significantly higher than each of the systems on their own, but the payback time would be much less.

There are notable disadvantages of incineration, such as high capital and operating costs. A major consideration is operating problems which can occur as a result of waste variability over time. Public perception can also be a notable problem because of the produced air pollution caused by the incinerators. This pollution cannot be completed avoided using an incineration program. The most difficult factors to be accommodated in the combustion process are the amount of moisture and non-combustible materials in the refuse. In general, incineration is not recommended for small cities, unless costs are not a factor. This is due to the high capital and operating costs, and the requirement for expensive, dedicated and sophisticated operators. A large system can better accommodate for these operating expenditures.

Pyrolysis/Gasification

Pyrolysis/Gasification is another waste to energy treatment that is related to incineration, but it occurs at higher temperatures and produces different by-products due to the fact that it is done without oxygen. Pyrolysis is the chemical decomposition of organic materials at temperatures above 430°C and it produces two main by-products: a syngas made of carbon monoxide and hydrogen that can be burned for energy and a biochar ash which is rich in carbon and can be used as a fertilizer. Instead of the carbon in the organic materials bonding with oxygen and forming CO_2, as occurs in incineration and decomposition, the carbon is essentially “stored” in the biochar. As a result, Pyrolysis is considered a “carbon negative” process because it breaks the natural occurring carbon cycle by sequestering the carbon. Storing carbon in biochar has received interest recently as a possible tool to use against global warming patterns. The syngas produced by the process can be can used as a fuel and has about half the energy content of natural gas. Data on pyrolysis of MSW is scarce although it is a promising technology. Not much is known about emissions and cost analysis as there are currently no large-scale pyrolysis plants operating in North America.

There are several advantages and benefits in gasification utilization. One of the most important features of this thermal process is the conversion of waste or biomass (relatively inexpensively) into expensive and high value chemicals. Although there are numerous advantages for the gasification, some related to power generation are:

- Cost: Gas cleaning is less expensive in gasification plants compared to coal fired plants
- Product Variety: in gasification, multiple products could be delivered. It could be modified to produce steam, or electricity for the grid and gas for synthesis and the chemical industries. Moreover, by-products of gasification plant could be sold; for example, the slag can be used for cement manufacturing, road and building construction.

- Efficiency: overall efficiency of gasification plants designed for power generation can be between 38-41%; therefore, this technology has relatively lower power generation costs.
- Carbon Dioxide Capture and Sequestration Compatible: In an integrated Gasification Combined Cycle, the plant is capable of capturing and sequestering CO2 in a feasible way.
- Environmental Benefits: gasification offers some benefits in compared with other competing technologies
- Water Consumption: water requirements is an important parameter for any industrial plant

In order to better understand the thermal processes better, it is necessary to delineate the thermodynamics of this technology. In gasification reactions, the key parameters are fixed carbon, carbon monoxide, hydrogen, carbon dioxide, water (moisture and steam) and methane. Gasification in fact has various phases. Some of the simple chemical reactions that occur in different phases of the gasification process are as follows:

- Drying (moisture is removed from biomass or feedstock),
- Pyrolysis (heating the feedstock with absence of air/oxygen; complex chemical reactions), and
- Combustion (injection of air/oxygen to produce required heat from combustion to move the endothermic reaction forward.
  - Combustion Reactions
    $C + 0.5\ O_2 \rightarrow CO$ -110 MJ/Kmol (1.1)
    $CO + 0.5O_2 \rightarrow CO_2$ -282 MJ/Kmol (1.2)
    $H_2 + 0.5O_2 \rightarrow H_2O$ -241 MJ/Kmol (1.3)
- Reduction (production of syngas)
  - Boudouard reaction
    $C + CO_2 \leftrightarrow 2CO$ + 171 MJ/Kmol (1.4)
  - Water-gas shift reaction
    $C + H_2O \leftrightarrow CO + H_2$ +130 MJ/Kmol (1.5)
  - Methanation reaction
    $C + 2H_2 \leftrightarrow CH_4$ -75MJ/Kmol (1.6)

Reactions (1.1) to (1.3) occur in combustion and are all exothermic to provide head for the endothermic reactions. By occurrence of the complete carbon conversion, the heterogeneous reactions (1.4) to (1.6) could be modified to be homogeneous reactions, see below:

  - Carbon monoxide shift reaction
    $CO + H_2O \leftrightarrow CO_2 + H_2$ -40 MJ/Kmol
  - Steam methane reforming reaction
    $CH_4 + H2O \leftrightarrow CO + 3H_2$ +205 MJ/Kmol

In gasification systems a limited amount of air or oxygen enters the gasifier and reacts with materials inside the reactor. The synthesis gas or syngas leaves the gasifier and enters the cleaning/quenching section; then the syngas is delivered to the power plant.

As the gasification system requires energy itself, the electricity generated is cycled for the systems first and the remainder can be sold to the grid. Finally, ash is removed from the reactor and is usually disposed which is one of the environmental draw backs of this technology.

The most important component of a gasification system is the gasification reactor. Typically, in gasification, the fixed bed gasifiers, the fluidized bed gasifiers and the entrained flow gasifiers are used. Based on literature review the downdraft gasifiers are the most popular ones in western countries.

Generally, in an updraft gasifier the feedstock enters from the top, where syngas also leaves the gasifier. The gasifying agents (could be air, steam or a gaseous mixture) are pre-heated and are fed into the gasifier at the lower part or bottom. The produced syngas then goes up through a bed of biomass that moves downwards. The temperature in the bottom section of the gasifier is higher than the ignition temperature of carbon; therefore, combustion with exothermic reactions occurs with sufficient amount of oxygen. In fact, the produced heat moves upwards and meets the gas and the descending solids; hence reduction reactions take place.

In cross-draft gasifiers, the feedstock comes to the reactor from the top and air is fed into the system via a nozzle on the side. The primary application of the cross-draft gasifiers is to gasify charcoal that has low ash content. One of the differences between this type of gasifier and both updraft and down/draft is that the product is released from the side, which is exactly parallel with the stream of air. Cross-draft gasifier is normally used in small projects and pilot plants. Here, the reaction zone is quite small and the thermal capacity is also low, this makes this system faster in terms of response time, comparing to the other fixed bed reactors. Moreover, the tar formation in this type is low and therefore, the cross-draft should be connected to a gas cleaning system.
In cross draft gasifiers, the limitation arises when fuel contains considerable amount of ash or high levels of tar; however high level of moisture does not affect this system. Thus, this design is capable of handling that type of fuel. In fact, if the top of the gasifier is open, the moisture evaporates and leaves the system from the top. The size of the fuel should be controlled to avoid problems such as bridging and channeling. The below table provides a few parameters comparing updraft, downdraft and cross draft gasifier.

Table 5.0, Characteristics of fixed bed gasifiers

Wood	Updraft	Downdraft	Cross-draft
Moisture (%)	<60	<25	10 – 20
Ash (%)	<25	<6	0.5 – 1
Feedstock size (cm)	0.5 – 7	2 – 7	0.5 – 2
Gas Exit Temperature (°C)	200 – 400	700	1250
Tar (g/Nm^3)	30 – 150		0.01 – 0.1
Gas LHV (MJ/Nm^3)	5 - 6	4.5 – 5	4 – 4.5

The operating temperature in the fluidized gasifier are generally between 800 to 1000°C. This range is suitable to use biomass and the MSW. This feature is essentially important for wood and agricultural waste; thus, large-scale biomass gasification systems use fluidized-bed gasifiers. In a bubbling fluidized bed reactor, the feedstock can enter the system from the top or the side in a somewhat short period of time over the whole surface of the fluid bed. The gasification agents serve as the fluidizing gas and thus, are channeled to pass through the bottom of the reactor. In a general type of this gasifier, new solid fuel particles meet with solids that are hot and located on the bed; therefore, particles will heat up quite fast and subsequently, go through drying and pyrolysis and eventually produce char and syngas, in a short period of time. The fluidizing gas enters the gasifier from underneath and exits from the top of the reactor. When the oxygen enters the bottom of the chamber, it reacts with charcoal in an exothermic manner. As the gas travels upwards, the reduction reaction takes place. The bubbles act as a channel to the top of the gasifier. One of the issues in the bubbling fluidized bed gasifier is the fact that the complete conversion of the char does not occur. Therefore, it is essential to have a good mixing of solids to guarantee the temperature uniformity in all parts of the gasifier although the ideal case can never be achieved in this manner.

One of the other types of fluidized bed gasifiers is called Twin or Dual type. This design is important as it physically separates the combustion zone from the gasification zone. It is in fact well known that the most challenging issues in air gasification of biomass is the dilution of the syngas by the high concentration of nitrogen content of air, which is used for the heat releasing reactions in the combustion zone. It is possible to overcome this problem by introducing oxygen, as the gasification agent; however, this solution is expensive and increases the required energy significantly. In twin bed fluidized gasifier, combustion chamber is separated from the gasification reactor. The reason for such a design is to prevent the nitrogen content of the air that is supplied to the combustion chamber from mixing with the product gas in the gasification reactor.
This design has its own limitations:

- As we know, there is less char in biomass compared to coal, and if the char is used for the gasification purpose it generally is not sufficient to provide heat for gasification reactions to take place, then external heating should be supplied to keep the temperature above 900 °C.
- In the case that the gasifier is running on steam, just a small percentage (less than 10%) of the steam contributes to the gasification reaction and the majority of it actually leaves the system, which means a considerable amount of heat is wasted and the gas is diluted.

The most suitable type of gasifier for an Integrated Gasification Combined Cycle (IGCC) plant is the entrained-flow gasifier. The temperature in this type reaches approximately 1400 °C. Entrained-flow gasifiers are in two types: side fed and top fed. The gasification agent and the fuel that has been pulverized (less than 75 microns) enters from the side of the reactor; in the second type they enter from the top. The concept in this design is to mix the pulverized feedstock with water to improve the efficiency. The gas velocity in this type of reactor is high, which results in entraining the fuel particles. This phenomenon increases the temperature in the gasifier far above the melting point of the produced ash; therefore, any remaining carbon will be converted.

Entrained flow reactors are somewhat superior than other types due to:
- Low levels of tar in the process,
- Flexibility of material feed,
- No ash (conversion of ash to slag),
- High temperature and pressure,
- High conversion rate of carbon, and
- Low levels of methane.

From the thermal input perspective, downdraft gasifiers have the lowest power (10kW to 1MW) where entrained-bed gasifiers could go p to 1000MW. The range for fluidized bed also varies from 1MW to 100MW.

The below table compares some of the commercial gasifiers with each other. It can be shown that the challenge in the fix bed gasifiers is the tar production and the use of fine particles; however, in fluidized bed gasifier the problem arises from the carbon conversion issue and finally in the entrained bed the problem is the syngas cooling.

Table 6.0, Commercial gasifier comparison

Factor/Gasifier type	Fixed-Bed	Fluidized -Bed	Entrained-Bed
Feed Size	Less than 50mm		
Gas Temp (exit)	450 to 650 °C	800 – 1000 °C	Above 1260 °C
Feedstock Type	Coal	Coal and Excellent for Biomass	Coal but no biomass
Need for Oxidizer	Not much	Fair	Very much
Reaction Zone Temp	1090 °C	800 - 1000°C	1990 °C
Cold Gas Efficiency	~80%	~90%	~80%
Applications	Small scale	Medium scale	Large Scale
Challenges	Tar formation fine particles	Carbon conversion	Syngas cooling

There are a number of disadvantages that should be considered for pyrolysis. Both the capital and operating costs are high due to the highly skilled operators required to manage these systems. The use of municipal feedstock has only had limited success in application, but there has been success in producing energy from coke, charcoal and other homogenous materials. Full scale plants implemented in north America have not been successful in achieving operational coals, due to the complexity of the system and the difficulty of producing a very consistent feedstock from heterogenous MWS. When examining gasification significant challenges have been noted. Reliable results on either full scale or pilot scale plants have not been achieved, some pilot plants have been in operations throughout North America although due to the lack of large scale implementations this technology should not be considered a commercial pre-sorting is an expensive requirement but necessary in order to reduce air pollution and improve performance. Particle size distribution, which is difficult to control, is important to ensure the flow through the gasifier is uniform and blockage does not occur. If moisture content is adequate (between 10% and 20%), air can be used rather than steam. However, most MSW normally has a moisture of 50% and some drying may be necessary in order to optimize operations.

Plasma Arc Incineration

Although technically falling under the label of "incineration," plasma arc technology is a different entity than the other forms of incineration though it is often confused or lumped in with the rest. Plasma exists as a fourth state of matter in the physical world and occurs when a gas is heated to the point where it becomes ionized. Lightning is a natural example of plasma and the phenomenon has been turned into a technology with the plasma torch. When used in a lab or with an industrial purpose, plasma torch technologies can reach temperatures of around 7,000-14,000 degrees Celsius. In the case of plasma incineration of MSW, the electrical arc formed in a vacuum chamber can vaporize organic materials into syngas and inorganic materials into an inert solid rock-like material. The rock-like aggregate can be used for building, ceramic tiles, bricks, or gravel to make roads. The syngas produced can be used as fuel for gas turbines, boilers, and low BTU reciprocating generators and can be further processed to produce various hydrocarbon fuels such as gasoline, diesel, ethanol, and methanol which are usually refined from fossil fuels. This makes plasma gasification a renewable energy technology and an attractive candidate for waste to energy technology. Unfortunately, at this time, there exist few environmental or engineering standards for the technology as a waste-to-energy candidate and there are currently no examples of large scale treatment plants in North America.

By definition, plasma is in fact an extremely high-temperature ionized gas that has been produced using a source, which is a good conduction of heat and electricity. When this source is utilized in the gasification, the process is referred to as plasma gasification. In this technology, the organic materials in the MSW form a fuel that is called syngas. The inorganic compounds then form a second compound called slag. A high qualify syngas should mainly consists of hydrogen and carbon monoxide. Electric sparks in the plasma torch create extremely high temperatures, forming the plasma. Within this process, a reactor is equipped with the plasma torches to thermally process organics. The operating temperatures of a plasma gasification reactor is usually between 4000 °C and 7000 °C. The utilization of the plasma torch is not a new technology, it has been in place since he 1960s, although its application to MSW is a relatively new field. This reactor requires a more delineated process stream to manage the input stream, pre-treatment, plasma conditioning, cooling/cleaning and power production. As operating temperatures are high, the inorganics in the MSW are converted into a vitrified slag which will be largely metals and glass
Plasma gasification or plasma-assisted gasification in general has some advantages and disadvantages as listed below:

- Advantages

  - The energy required for reduction reactions comes from the plasma rather than a combustion zone, resulting in better process control.
  - As there is no combustion phase, no combusting gases will be in the system, therefore reducing emissions and environmental pollutants.
  - The temperature in the plasma reactor is easily controlled as the power of the plasma and the feedstock feed reacts could be easily controlled.
  - By optimizing the location and power of the plasma torches in the reactor, high temperatures and also the temperature uniformity can be easily maintained. This, results in the minimization of tar production in the system.
  - As the operating conditions and composition of the products could be controlled, a plasma facility can produce a variety of products such as electricity, liquid fuels and chemicals.
  - Syngas dilution is minimized, and energy loss is lower than conventional gasification.
- Disadvantages
  - Requires continuous supply of high voltage/current to the plasma torches, if supply is disrupted the process cannot continue.
  - Due to limitations in supply of electricity, this technology cannot be developed everywhere.
  - Plasma gasification is new and very few plants are currently utilizing it as such few pilot plants exists.
  - Large volumes of MSW are needed to make this plant economically feasible to operate, additionally feedstock requires pre-sorting which is expensive.
  - It is anticipated that capital costs are between $30 to 40 Million for a town in Alberta with 20,000 residents, costs for larger municipalities would increase with population.

A British company, Organics Ltd., estimated the costs of building a facility in England to be $7M (CAD), with operating costs of approximately $400,000/year and a revenue of about $1.5M/year. Payback was estimated at only 2.3 to 3.8 years This excludes the cost of the front-end separator, and is based on a facility that obtains 100 tonnes of waste per day. This appears to be an attractive venture but is based by high tipping fees per year which are attributed to European waste streams.

The below table summarizes the fundamental differences between plasma gasification and incineration technologies.

Plasma-assisted Gasification	Incineration
Presence of very small amount of oxygen, preventing from combustion	Presence of excess air, complete combustion
Syngas is formed and energy and industrial chemicals are then produced	Energy is all converted to heat

Non-organic materials are converted to slag (6 to 15% of the original waste volume	Inevitable production of hazardous ash
Emissions are much lower	Far more emissions of Greenhouse Gases and other pollutants

Summary of Thermal Processes

Traditional incinerators may be a possibility for smaller cities. The capital investment is relatively high, if you were solely looking at European case studies this technology would not be recommended, although the economics of waste to energy are different in Canada and this technology has been successfully utilized on a small scale in Canada. Combined annualized capital and operating costs (net of recovered energy revenue) range from $125 to $150 per tonne of waste processed, estimated over a 25-year capital payback period. Rotary kiln incinerator technology applications can meet all Canadian environmental regulatory requirements. However, they produce large amount of ash and some air pollution, control of which can add to the life cycle costs. Public perception of these facilities does provide additional challenges during implementation and operation.

A mass burn incinerator is not a recommended technology for a community the size of St. Albert, as the quantity of waste required is substantially larger than what can be provided. Ideally the population would be between 100,000 and 310,000 based on generalized waste generation values.

Starved Air incineration could be a possibility as a they can handle approximately 10 to 100 tonnes per day. Combined annualized capital and operating costs (net of recovered energy revenue) range from $100 to $150 per tonne of waste processed, estimated over a 25-year capital pay back period. This incinerator technology can also meet all Canadian environmental regulatory requirements and particulate matter emissions are lower than other incineration methods.

A fluidized bed combustion process is not recommended, as it has not been widely used world wide and poses a number of operational, environmental and permitting challenges. It includes extensive air pollution control equipment and is operationally has heavy maintenance requirements.

A modern gasification system, at pilot scale is a conservative application in a City framework, as it provides the opportunity to examine the interactions of the technology with the municipal solid waste stream without coupling the City to a system that may not be able to adapt and function.

Biological Processes

There are two main forms of biological processing used to treat the organic fraction of municipal solid waste: composting and anaerobic digestion. Although they both employ the use of microbes and bacteria to convert organic material into gas and fertilizer, only anaerobic digestion produces a fuel that can be burned to generate electrical power.

Composting

As a process, composting can be described as the decomposition of organic materials that occurs anywhere in nature where oxygen is available (aerobic). Organic constituents are converted into carbon dioxide, heat, and a stable fertilizer by microorganisms – mostly bacteria. As a technology, composting dates to the early Roman Empire and is mentioned specifically as far back as 60AD in the writings of Pliny the Elder as a way to organize and process organic wastes. Many different organic substrates can be composted but the ratio of carbon to nitrogen remains the most important factor. Carbon-heavy inputs that are dry and brown often called “browns” (leaves, paper, straw, branches) must outweigh the nitrogen-heavy inputs (fruits, vegetables, grass, coffee grinds), or “greens,” by a 30:1 ratio in order for the process to occur most efficiently. Greens have a much higher moisture content (60-80%) and decompose quickly while the browns are dryer and decompose more slowly providing a buffer for the faster breakdown of the greens. Cooked meats, fats, greases, and oils are not ideal composting candidates as they attract flies and rodents and release terrible odors as they putrefy. Composting releases the carbon dioxide originally sequestered by the organic material from the atmosphere and as such is considered a “carbon-neutral” process. No energy is available from this process.

This technology is currently highly practiced within the City of St. Albert framework and it would be recommended to continue this practice.

Anaerobic Digestion

Anaerobic Digestion is a naturally-occurring digestive process in which microbes convert organic materials into biogas and neutral digestate sludge in the absence of oxygen. It is considered a renewable waste-to-energy technology because the methane rich biogas produced (often 55-70% methane) can be burned as a fuel and offset the need for fossil fuels. Most of the methane is produced within 30 days of adding the organic material to the digestion process whereas in composting, a full year is often required for neutralization. Unlike incineration technologies, there are no toxic by-products and the digestate that comes from this process can be spread directly as a fertilizer. This process can reduce the volume of the input material substantially. The advantage of using anaerobic digestion in an urban environment to treat organic waste as opposed to composting it is that anaerobic digestion produces biogas with a high percentage of methane which can be used as fuel whereas composting produces mostly carbon dioxide which can’t be burned as fuel. Importantly, Anaerobic Digestion also prefers cooked and oily food waste to be digested where composting does not. In fact, the Anaerobic Digestion process produces more biogas when used cooking oil and cooked meats are added. Anaerobic Digestion could be applied to the organic fraction of MSW either “in situ” or directly at the landfills if it is pre-sorted by the producers.

Anaerobic Digestion has three main steps, the first involves the preparation of the organic fraction of the waste including sorting, separating and size reduction. The second step involves adding moisture and nutrients, blending, adjusting the pH to about 6.7 and heating the slurry to about 55-60 °C. The contents are well mixed for 5-10 days. For colder climates, such as those in Alberta, the slurry is heated to a lower temperature but mixed over a longer period of time. The third step involves the capture, separation and storage of gas components. The residual sludge may be disposed of and treatment of this residual could be considered an additional step in the process train.

The microorganisms involved in anaerobic digestion can be divided into two general categories: acid formers and methane formers. The acid formers degrade the complex organic compounds to simple acids, then the methane formers convert acids to methane. Methane forming bacteria are sensitive to many environmental factors; maintaining the appropriate temperature is important, as is preventing oxygen and other substances toxic to microbes from entering the system. Either high solids digesters or low solids digesters can be used. Low solid digesters are a well-developed technology, but considerable amounts of water must be added to the waste. High solids digesters require little addition of moisture, but their technology does now have the same strength of historic implementation. A minimum of 5 ha of land is required for a 900 tonne/day anaerobic digestion plant, however, this size of plant is much larger than would be required in St. Albert. Anaerobic digestion of MSW has successfully been implemented in Europe where high cost of landfill space makes it more economical. When trucking and land costs are lower, it is challenging to make the economical feasibility of this process function.

The purpose of anaerobic digesters is to utilize the gas produced by decomposing refuse as a source. Wastes can also be composted after anaerobic digestion to obtain the benefits of both biogas a well as humus for soil improvements and fuel for power plants. High rate anaerobic composting with biogas recovery can also be an economically viable implementation for waste streams and processes. This process is similar to anaerobic digestion, but the pathogenic materials are moved, allowing for the residual of the digestion to be useable compost. Research suggests that anaerobic digestion, even with the natural moisture content of organic MSW is possible, assuming moisture content of approximately 60%. Considering life cycle cost, anaerobic digestions is comparatively more cost effective.

Assuming the removal of toxic substances before a waste stream goes into the digester, the concern is managing the residual. Anaerobic digestion is only feasible when combined with sewage or agricultural waste digestion as this would enhance the digestion process.

For smaller cities and towns anaerobic digestion is a more challenging technology to implement. Plants require a minimum of 10,000 tonnes of organic waste per year. The cost decreases when 50,000 tonnes per year is available for utilization. Waste is required to be meticulously sorted, which if required to be done by operators can drive the operational costs of the facility. Based on case studies there are few plants throughout industry that exclusively use anaerobic digestion to manage solid waste.

Table 7.0 provides a summary of anaerobic digestion.

Table 7.0, Anaerobic Digestion Summary

Factor	Summary
Description	Organic biodegradable waste is broken down without oxygen to produce methane gas, carbon dioxide, water and digestate (which could be composted). Can be wet or dry.
General Performance	Can divert all or most organic and biodegradable products (food, yard waste, some paper).
Community Characteristics	Anaerobic digestion is a high tech system that requires skilled technical operators. It is most suitable to reasonably large urban areas with at least 18,000 to 40,000 households as a minimum threshold to justify the construction of a system.
Costs	Costs requires a plant of at least 10,000 tonnes/year or organics. Costs decrease dramatically towards the 50,000 tonnes/year. Greatest economies of scale at 100,000 tonnes per year.
Factors that influence Acquisition	Availability of Local Energy
Environmental Effects	Diverts organic waste from landfill, minimizing generation of acidic leachate and methane. Generates methane under controlled conditions, as an energy source, displaces other sources of power.
Energy Implications	Net energy generator, with 50% (wet plants) to 80% (dry plants) availability for export.
Lessons Learned	Plants of 10,000 to 20,000 tonnes/yr source separated organics work well in Europe. Little track record for larger plants currently in operation .

FEASIBILITY CONSIDERATIONS

Decision analysis was considered in assessing the investigated waste to energy technologies to determine the suitability for implementation. In decision analysis the information relevant to the problem and the uncertainty surrounding the problem is systematically represented and examined. In this case, the uncertainty lies in the waste composition, quantity and costs associated with maintaining each of the waste to energy facilities. The options of doing nothing must also be considered as it may be the wisest choice if none of the other options prove feasible.

The different types of technologies are affected by the amount of biomass in the waste stream, since none of them will utilize the inert portion. The amount of biomass is affected by the waste produced per capita and the waste composition. Each form of waste to energy will result in a certain amount of energy produced, and will produce certain costs, including but not limited to:

- Start up (capital and commissioning)
- Operations and maintenance
- Decommissioning
- Environmental implications

The start up costs will differ for all of the different waste to energy technologies, as will the operations and maintenance costs. The decommissioning costs were assumed to be fairly similar for each of the technologies; since waste to energy is a fairly new practice and very little information is available on decommissioning costs. Putting a cost on the environmental implications of waste to energy technologies is difficult and would require additional studies and work to better delineate these costs. Since all the technologies can be built to regulation standards, the extra costs associated with bringing their pollution control within these standards is already factored into the price. The costs, subtracted from the revenues, equals the potential profits from each type of technology, which will provide the basis on a hierarchy of technologies within the current market.

Costs and revenues are not easy to obtain as most companies will not share with the public such information about their projects. Costs and revenues were found for some projects in operation today in Canada. This demonstrates how the costs change in relation to the tonnes/day processed into energy at the facility. The costs are the actual total unit costs, including all capital, maintenance and operation costs. This allows for a truer net cost comparison on an equitable basis between projects with high capital and low operating costs and those with low capital but higher operating costs. Data could not be acquired for sizes of all facilities. Some values were extrapolated from available data, assuming a linear trend between cost per tonne of waste processed and the tonnes of waste per day processed.

Table 8.0, Anaerobic digestion costs[7]

Tonnes/day	Cost ($/tonne)
30	180
140	100
270	80

Table 9.0, Thermal Treatment Costs[8][9]

Type of Thermal Treatment	Tonnes/day	Cost ($/tonne)
Kiln Incinerator	10	150
	50	125
	90	100
Mass Burning	400	85
	850	65
Starved Air Incinerator	0.5	200
	3	72
	140	100
Fluidized Bed	50	110
	500	80
Gasification/Pyrolysis	600	100
	71	408
	71	360
	71	806
	71	57

The above tables, the incurred costs and revenues are combined into one value in units of $/tonne. All costs associated with each type of waste to energy are taken into consideration, including the operations and maintenance costs and capital costs. The capital costs are amortized over a 25-year period. FCM data was already available in this form; for other sources, an interest rate of 3% was used to calculate the payments over a 25 year period. For the decision analysis the City of St. Albert produces approximately 20 tonnes/day of organics, 8 tonnes/day of blue bag collectables (mixed paper, plastic and metal) and approximately and approximately 15 tonnes/day of inerts are landfilled. Without having completed a comprehensive waste audit a number of assumptions and inferences are required at this stage to provide a level or recommendation in terms of 25 year amortized costs of a process.

Anaerobic digestion -$190/tonne
Thermal Conversion -$140/tonne

A substantial consideration is the cost of electricity, this system is not viable as a stand alone waste to energy system as the revenue opportunity to purely sell electricity to the

[7] FCM, 2004
[8] FCM, 2004
[9] Earth Tech, 2005

grid has a very small return. Within the last year contracts have been awarded with electricity sales yielding 2.79 cents/KWh. Where valuation and economies lie is having a comprehensive community that is primarily supported by a waste to energy where electrical generation costs and/or cost saving opportunities lie in district heating and off grid community development.

ENVIRONEMNTAL CONSIDERATIONS

Each type of waste to energy has different effects on the environment. All can be built to meet Canadian regulatory requirements and environmental standards, however not all are considered green energy. Anaerobic digestions and gasification and pyrolysis are considered green energy alternatives, whereas rotary kiln, mass burn, starved air incineration and fluidized bed construction are not.

Anaerobic digestion is the most environmentally friendly option for the organic portion of waste as it can be designed to have no negative impacts on the environment. The sludge left over from the process can be used as compost if the process is done properly, and methane gas can be collected from the organic matter as it decays, thus reducing greenhouse gas emissions.

For thermal facilities the environmental control systems, on average constitute between one third and one half of a facility's total capital and operating costs. Gasification and pyrolysis are considered green technologies, but produce air pollution and residual that require expensive equipment for reduction to low levels. The remaining thermal technologies all produce air emissions and solid residual, none burn as cleanly as gasification. They require extensive air pollution control systems to manage off gas and any ash or slag does need to be managed.

Based on total saving of greenhouse gas emissions, research has compared three technologies incineration, gasification and biogas production (anaerobic digestion). It has been documenting that biogas is the most green implementation followed by gasification then incineration. Greenhouse gas emissions are a good measure of environmental impact, but other wastes such as the ash produced from combustion and incineration processes are also produced. Based on greenhouse gas emissions as well as the residues produced, the ranking of technologies considered here from least to most impact on the environment is:

1) Anaerobic digestion
2) Gasification and pyrolysis
3) Fluidized bed combustion
4) Other thermal processes

Anaerobic digestion is the most favourable since it eliminates the greenhouse gas emissions that would have been produced from the decaying organic matter. Furthermore, the sludge if composted can be a useful fertilizer. Gasification and pyrolysis burn cleaner than other incineration technologies and produce less ash residue. Fluidized bed combustion produces less ash residual but more air pollution. Finally, the remaining thermal technologies produce more air pollution and more hazardous ash than the other mentioned technologies.

COMMUNITY IMPLEMENTATION OF ENERGY SYSTEMS

The feasibility of an alternative revenue opportunity does not lie within the implementation of one technology. The successes of alternative revenues from the utilization of renewable assets (WTE or Solar or Geothermal) lie with a holistic look at a community implementation. The opportunity of placing requirements on an area to create a community with net zero carbon emissions from building operations, powered 100% through renewable energy with a net energy export, with a shared energy system (SES), energy storage and integrated community design will provide opportunities for dollars saved. The implementation of a large-scale community campus where substantial savings could be met in building operation costs would provide non-traditional revenue (moneys saved from operating costs could be re-applied to capital budgets).

Buildings within this community should be done such that there are no greenhouse gases released from operating on a net annual basis. This is achieved through high performance building design, including the use of the PassivHaus standard, which limits annual energy requirements for space heating and cooling to 15 kWh/m^2 per year. By comparison a typical home in the capital region uses between 150 and 40 kWh/m^2 per year. Heat pump technology can further reduce PassivHaus building heating requirements by a factor of 2 to 4, depending on the heat source. The remaining energy requirements, including space cooling, appliances and lighting, can be met through the production of renewable energy.

A community with specific energy needs should be considered to provide the delineated area with specific energy needs. The City would then need to amortize the equipment and consider standards square meter energy costs for similar structures to provide a standardized energy bill. The servicing using standard industry rates to the delineated community would provide the alternative revenue when the reality is the system is a closed loop energy system.

Variable energy production technology may be considered depending on loading that is required. Wind turbines could be considered along greenspaces or in designated agricultural lands, photovoltaic systems and biofuel generators utilizing waste to energy technology could be implemented as well. Space heating and cooling could be assisted by ground source heat pump loops and the use of a district energy system with large scale thermal storage may provide the final energy requirements, depending on modelled loadings. This utilization of a multi-technology energy projection community would allow the efficient delivery of both energy, heating and cooling. It may still require support from the grid during peak periods or depending on any specific industry needs.

District Heating and Cooling

The concept of district heating has been around since the ancient Roman times, when hot water from bath houses were distributed to greenhouses. The ancient city of Hierapolis had mineral bath houses fueled by hot spring water that was fed by aqueducts. In North America the first district heating system dates to 1853 at the US Naval Academy in Annapolis, and the first steam heating system dates to 1877 in Lockport, New York. It wasn't until 1906, that Thomas Edison built a downtown power plant in Philadelphia. During his financial analysis of the facility it was determined that waste heat needed to be sold to increase profitability. He combined power production and heat capture to produce the first combined heat and power system, (CHP). There are currently over 6000 district energy systems in North America.

There are three main components associated with a district energy system: A source of thermal energy, a piping network to distribute the energy, and a mechanism for utilizing that energy in the building.

District heating and cooling covers the generation and distribution of thermal energy in district networks. A Smart District allows district heating and cooling grids to improve the management of energy systems. These systems are optimized using heat meters and heat exchanges. New energy control functions of heat exchanges include monitoring and controlling the exchange of heat through SCADA systems. At the consumer end, in hot water and radiator systems, new devices such as variable speed pumps may be implemented to facilitate the movement of fluids. They are able to de-couple fluctuations in the heat demand of a building from the network conditions without changing the ambient conditions within a building. This allows the network heat demand to be stabilized, energy efficiency improved and heat losses in the system to be reduced.