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### CASE STUDY OF WTE AND GASIFICATION

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#### ABSTRACT

Great interest surrounds new technologies that are being offered as alternatives to conventional combustion of waste. Developers have identified the benefits of emerging technologies over existing technologies. In the years since many of today's existing waste-to-energy (WTE) facilities were built in the United States, the technology required to process waste has improved dramatically in both environmental and operational performance.

This technical paper presents a hypothetical study comparison of a generic WTE plant with plasma-arc gasification or other gasification technology. The case study represents a greenfield facility that would process 1000 TPD of MSW in two trains of 500 TPD each. The comparison includes the following elements: 1. General physical description of the facilities; 2. Emissions performance; 3. Byproduct and waste generation; and 4. Energy production. The comparison also discusses differential capital and operating costs, but does not attempt to establish these costs or compare economic feasibility.

#### INTRODUCTION

For many years there was little interest in expanding waste-to-energy (WTE) in the North American market. Today interest appears to be on the rise with the recent startup of an expansion unit at Lee County, two other expansion units under construction, and proposal and permitting activity for several other locations. This change is the result of several factors, including:

- increased landfill cost;
- increased energy costs;
- from a legal perspective, the Oneida-Herkimer decision opened the door for public authorities to control waste stream and direct waste to their facility; and
- greenhouse gas (GHG) considerations.

The rebirth of WTE and other advanced technologies in the North American solid waste industry appears to be underway, although the industry today is different from the industry in the late 1980s and early 1990s. For one thing, fewer established technologies exist today based on consolidation and lack of projects leading to some technologies no longer being available from vendors. Surviving vendors continue to build facilities in Europe and Asia and new innovations bring performance improvements. At the same time, costs have increased significantly. Some issues remain unchanged, including the

NIMBY (not in my backyard) tendency, political pressures, and concerns about recycling impacts and emissions.

This atmosphere has encouraged innovation in developing alternative technologies. Some recent proposals have been made in:

- anaerobic digestion
- autoclave
- catalytic cracking
- hydrolysis
- pyrolysis

Solid waste authorities around the country are being approached by entrepreneurs and investors who propose a “better way” to deal with waste. Many concepts can be quickly dismissed as not viable, while others have gained some traction. Sometimes they even cite failed projects from 25 years ago as a selling point.

Two of the more prominent technologies that appear to have a large number of vendors and a great deal of interest include:

- gasification in various forms
- plasma arc as a special subset of gasification technology

Many claims have been made regarding performance of these technologies. This paper will examine available data related to gasification, plasma arc, and mass burn technologies in a hypothetical case study. Not all data applies to all technologies, nor is all data supported by demonstrated commercial facilities. Gaps in information or claimed performance data will be pointed out and identified as “yet to be demonstrated,” “projected” or similarly labeled.

### **CASE STUDY BASIC ASSUMPTIONS**

A comparison of available alternatives for WTE was completed. Some basic assumptions remained identical to ensure a fair and reasonable comparison. Basic assumptions included:

- clean greenfield site with no differential costs considered
- 1000 tpd facility size
- two units
- municipal solid waste at 5200 Btu/lb
- 85% availability to process 310,250 tpy
- electricity generation, no steam sales

- cooling tower and condenser
- state-of-the-art air pollution control technology

### **MASS BURN WTE FACILITY**

Packer trucks and transfer trailers will use the tipping floor. Refuse trucks will enter the site from an access road and are weighed before proceeding to the tipping floor. An enclosed maneuvering area is provided with a clear span and 30-foot roof height that allows tipping for packers and roll-offs. The concrete floor surface is made from high strength concrete to maximize surface life. A large pit is used for storage of waste. Waste may be deposited directly into the pit or pushed in by a front-end loader. Redundant cranes mix the waste and charge the combustor hopper.

Waste is charged to the processing trains with the same cranes used for storage. Cranes may be controlled manually or with semi-automatic controls. The use of automation generally reduces wear and tear on the cranes. The crane control pulpit may be located on the charging deck or arranged in the same room as the control room. When located together, critical communication between the boiler operators and crane operators may improve. Material is fed into a feed hopper. The waste falls by gravity through a chute onto a ram feeder where it is pushed into the combustion chamber. More waste is placed into the feed chute to maintain an air seal for stable controlled combustion. Waste in the hopper is maintained within a determined range to allow for steady operation and must be charged continually, 24/7. Thermal sensors located in the chute walls detect fires and quench systems are provided to manage premature combustion.

The ram feeder will push waste into the waterwall combustion chamber with a refractory tile-lined enclosure, an Inconel overlay, or other means of protection. A sophisticated grate system consisting of grate bars and grate sections with steps and combustion air mixing is provided for complete burnout. Depending on the fuel heating value, some vendors offer water-cooled grate bars in which circulating water cools the grate, extending life and performance. The use of water cooled grates allows more operational flexibility for combustion air flow. The primary air passing through the grate can be optimized for the desired combustion characteristics. The energy captured in the water circulated through the grates can be used to preheat condensate or combustion air to recover some of the energy and improve efficiency.

Various technologies address furnace air management in different ways. The trend appears to be toward decreasing excess air in mass burn plants. Lower excess air increases boiler efficiency improving performance. NO<sub>x</sub> emissions may also be reduced due to lower levels of nitrogen in the combustion zone. With the advent of the MACT rules, major reductions were demonstrated for nearly all emissions, reductions were less for

NO<sub>x</sub>. Flue gas recirculation (FGR) has also been proposed for some recent facility expansion units. Use of FGR allows for reduced secondary combustion air addition with proper mixing and turbulence to provide uniform and complete destruction of volatile organics. Significant reduction in NO<sub>x</sub> emissions using advanced selective non-catalytic reduction (SNCR) and other proprietary control technologies have been proposed or demonstrated on some new units. These measures are achieving improved NO<sub>x</sub> control.

Increased use of Inconel and newer tile and refractory systems are found in more parts of the furnace and in the second pass or tail end boilers to reduce corrosion and extend the useful life of the boilers. A wide range of steam pressure and temperature conditions have been proposed for projects. Higher temperature and pressure steam increases turbine efficiency but also may require more complex metallurgy and higher maintenance costs. Other proposals have lower temperature and pressure conditions. This approach may offer lower corrosion and less outage time when properly designed. In some cases run times of 8000 hours between planned outages have been proposed. To support higher boiler efficiencies and longer run times, advanced online cleaning techniques have been developed. Retractable water wash systems for empty passes have been proposed. Greater use of rappers and more sophisticated sootblower systems also keep the boilers clean longer with less potential tube damage. Online blasting is also used in some cases to extend run time.

Generally, an ash extractor is used to seal the boiler and cool the bottom ash. Fines that fall through the grate system usually are combined with the bottom ash. Historically, in the United States, bottom ash has been combined with fly ash and scrubber residue for discharge as a single ash stream. New ash management techniques have been proposed to keep the fly ash and scrubber residue separate from the bottom ash so the bottom ash may be available for reuse alternatives once reuse options are mature. Ferrous and nonferrous metal is normally recovered from the residue prior to disposal.

Combustion controls are provided for stable operation. Control of primary and secondary combustion air, refuse feed rate, grate management are used to control the thermal release and burnout of the waste. Feedback from instrumentation helps the operator know how the unit is performing. More extensive data collection for operations and maintenance support is the norm in today's facilities.

Downstream of the boiler economizer, a spray dryer absorber (SDA) and fabric filter (FF) along with activated carbon injection (CI) is generally used to control acid gases, particulate-related emissions, mercury and dioxins. Some newer technologies are being proposed that offer the advantage of better reagent usage for the same emissions performance. Flue

gas recirculation (FGR) has been used for combustion and NO<sub>x</sub> control. FGR also results in slightly smaller gas volumes.

New municipal solid waste facilities were initially required to achieve the New Source Performance Standards (NSPS) requirements under the Maximum Achievable Control Technology (MACT) rule Subpart Eb of 40 CFR Part 60 of the Clean Air Act. The EPA has voluntarily remanded these requirements and is reviewing how the emission floor was determined. All of the alternative facilities considered are expected to achieve these requirements. Table 1 presents the basic emission requirements from Subpart Eb as well as a range of emissions that might be expected based upon performance of existing facilities.

Expected electrical power production has increased with the higher efficiency of new units. Net electrical power per ton of waste processed is expected to be in the range of 600 to 650 kWh per ton on a net basis. Facility capacity factors are also increasing. A minimum of 85% is expected with some recent proposals stating 88% or higher expected performance. A number of existing units are achieving these levels of performance.

The cost of a modern WTE facility has increased as enhancements have been added. Better performance and lower emissions result in a large investment for any community. In addition, construction costs for industrial and power-related projects have increased rapidly as demand for new facilities in these broad markets has increased. Specific costs for any particular project vary based on market conditions, making it impractical to provide universal cost comparison information.

## **PLASMA ARC GASIFICATION FACILITY**

While there are no current operating plasma arc facilities in the United States, a significant number of projects of various sizes have been offered by various entrepreneurs. For example, a plasma arc gasification system being demonstrated in Canada by Plasco Energy Group is reported to be testing MSW gasification. If this nominal 90 tpd facility is successful, a nominal 250 tpd MSW gasification facility is planned. This discussion will present an approach proposed in several cases but not specific to any commercial project. Many proposals offer limited data and do not clearly define key issues. This comparison assumes two 500 tpd units in a 1000 tpd facility that is substantially larger than the referenced demonstration facility. Nonetheless, a number of very large facilities have been proposed and many advocates claim units of this size are practical.

Typically waste preparation is required for a gasification facility. A large tipping floor is used for receipt and storage of feedstock. Large front-end loaders are required to stack and handle the MSW. Generally, the preparation is assumed to be production of a refuse-derived fuel (RDF). Many proposals

assume post-recycling waste is the feedstock. Recycling may occur on site or the waste may be received from a material recovery facility or other sources. The recycling system may be designed to remove problematic materials undesirable for downstream processes, such as trace metals, chlorine-containing materials, grit and glass and bulky objects. Nominal particle size required may be as small as a half-inch, but usually is two inches or larger. This is generally a finer size than most existing refuse derived fuel (RDF) WTE facilities. In some cases, pelletizing is proposed. Pelletizing increases fuel density, allowing certain feeding advantages. Front-end processing increases in-house power consumption, operating costs and staffing requirements. Certain operational risks also increase because of waste shredding and contact between operators, process equipment and the MSW. It may be necessary to remove moisture content and trace metals to protect the gasifier and allow it to function properly. This may require additional stages of metal recovery, hand sorting and the addition of mechanical dryers or other equipment.

The prepared fuel must be charged to the gasification unit. It is expected that in most cases this will be achieved by using conveyors and surge bins. To maximize gas production, the reaction in many gasifiers is designed to be controlled oxygen with no air addition. This may require more thought and tighter requirements for sealing the in-feed system to manage air leakage under all conditions. Steam and air may be injected to manage the gas composition downstream. Control of injection rates is presumed to be based upon downstream syngas characteristics as well as other gasifier conditions.

The gasifier is the heart of the system. Many unique designs are currently being promoted. Low temperature chambers are designed to drive off volatiles. Often these technologies are expected to look like large cylindrical vessels, perhaps with a fluid bed or recirculation of material back into the vessel. The ash and carbon char remain. Some propose to use the carbon as an activated carbon product and expect to be able to sell the material as well as reuse the ash. High temperature gasifiers may vitrify the ash and more fully process the carbon char into carbon monoxide (CO). These units may be cylindrical vessels, possibly multi-vessel design. To achieve full processing of the carbon char, controlled levels of oxygen, air or steam may be introduced. This results in partial combustion with elevated temperatures and use of some of the product synthesis gas (syngas) in process.

For plasma arc or higher temperature gasifiers, ash is reported to be between 16 to 20%. If the ash is molten, it can be quenched to a glass-like mixture. Depending on downstream APC residues it may not require moisture to minimize dusting. The vitrified ash has been reported to meet requirements of the Toxicity Characteristic Leaching Procedure (TCLP) very reliably.

A popular approach today is to include a plasma arc chamber. The plasma arc unit may replace the gasifier or supplement the waste processing system. With the plasma arc unit, the very high temperature electronic arc or plasma torch developed from the arc heats the ash and metal to a molten condition at a temperature of more than 10,000 degrees Fahrenheit and converts the carbon to CO. The power consumption required for this process is high, resulting in increased in-house consumption rates. The vitrified ash is quenched and a number of potential uses, including sand blasting grit, road aggregate, ceramics, and insulation have been proposed as possible products that can be produced from this material. Metals may be separated from the slag and sold as mixed metals. Markets for the mixed metals in the recovered form may or may not exist. Much information about electrodes and plasma arc vessels is available in the literature. It should be noted that the Westinghouse plasma arc technology was developed by Westinghouse Corporation, but has been sold and is no longer supported by Westinghouse. The technology has been demonstrated for a variety of applications and achieves the temperatures and performance presented in the literature.

The hot syngas must be transferred to the downstream equipment. This equipment can vary significantly for various facility designs. The simplest concept may be to add a waste heat gas-fired boiler to recover the energy. It has been reported that the syngas is relatively clean with little fly ash or other contaminants and that it may be possible to use a more efficient boiler design than is practical to use in a mass burn WTE facility.

To increase energy recovery, many proponents propose using gas engines or gas turbines with or without heat recovery. Some gas cleanup may be required for these systems to protect the turbine and other equipment from particulate, deposits or other trace gas components that may damage the equipment. It is reported, however, that the gas cleanup is not very extensive because of limited gas volume and minimal particulate generated in the gasifier. In addition, low Btu syngas may require supplemental firing of natural gas or other fuels to maintain heat input within required ranges. Energy recovery is reported to be more efficient than conventional WTE. When processing MSW, power production rates from 800 to as high as 1200 kWh/ton have been claimed. In many cases it is not stated whether this is a gross or net power production and if net, whether it includes all APC, slag handling, and front-end processing equipment electrical demand. Assuming these values are generator sizing values or gross power production, it can be expected that at least a 20% reduction from the gross value will be required for process needs and possibly 50% reduction or more may be required. Claims are then at or below a range expected for a new, comparably-sized WTE facility to perhaps 40% higher production.

Use of the syngas for chemical feedstock applications has also been proposed. It is reported that the syngas can be used to generate various transportation fuels, such as diesel or ethanol or may be used to regenerate plastics. This technology offers the promise of higher value and energy recovery than achieved by a combustion process. It may also alleviate some environmental concerns with combustion emissions. Additional stages of gas cleanup may be required to protect downstream catalysts. Certain trace gas contaminants may prematurely damage the expensive catalysts. Particulate removal, acid gas removal, metals and mercury reduction likely would be required. Moisture, carbon dioxide or other gases may need to be removed for processing. It is not clear how clean the gas stream must be to allow the processes to function properly and other steps may be required to complete the conversion process. Use of MSW to provide chemical feedstock may result in a facility that looks more like a refinery than a traditional waste facility. Considerable cost and complexity may result in additional issues for a young technology to master.

An effort was made to find a commercial or pilot scale project with all necessary components in place and operational, but this effort was unsuccessful. It is reported that all or nearly all of the technology required is off-the-shelf and ready to be applied. In some cases, it is stated that the required components have not been put together in the required manner. As gasification projects are advanced it may result in a few failed operations because there are so many undemonstrated issues. Careful planning of a development project may reduce the potential for failure and increase the ability to demonstrate the effectiveness of some new technologies. Some of the remaining issues and demonstrations required to prove the technology are discussed below.

Front-end processing systems, such as RDF production or pelletizing equipment used to generate the feedstock, does exist but may not normally be operating at capacity or under the requirements required of a 1000 tpd gasification facility. In theory, this can be solved by adding more processing lines or equipment. A tougher requirement may be to consistently deliver a product that is free of trace contaminants or oversized components required by some gasification processes.

Another potential weak link in the development process may be the interface between system components. Since no commercial facilities exist, demonstrated means of providing an air seal at the feedstock supply has not been proven. Processes that have successfully worked on biomass gasification systems may be transferable. The interface between the gasifier or a plasma arc gasifier and a waste heat boiler or other downstream devices may be more difficult to perfect. The plasma torch inside the plasma arc unit has been reported to be hotter than the surface of the sun. In some cases, the syngas leaving the plasma arc may be quite hot, possibly 1800o F to several thousand degrees. Special insulation materials may be required

to protect structures until the syngas can be cooled. At least one proposal has involved the use of insulating tiles similar to those on the space shuttle, but it is not clear that this technology has been adequately demonstrated. Thermal growth of any ductwork and equipment may require relief. Conventional expansion joints may not adequately seal combustible gas from in-leakage, possibly resulting in undesired combustion. The quantity of fly ash is expected to be low in the gas stream but may be unique based on the temperature of the syngas. This may cause problems until the gas is cooled to more conventional temperatures. Build up of ash on the sides of the gasifier or in the ductwork may be the result. Some WTE facilities that may not be operating under challenging conditions have experienced slagging problems, so similar issues may develop in gasifier systems.

Use of syngas in a waste heat boiler may not provide enough economic value to offset the added cost of RDF production and syngas generation. This may encourage use of engines or gas turbine-combined cycle systems to increase efficiency. The energy content of the syngas may be as low as one-third of the energy in natural gas. Stable operation of engines may not be practical under these conditions.

Gasification systems are subject to the same emissions requirements as WTE facilities. The emissions are reported to be naturally lower than for WTE facilities due to the generation of a syngas and completing energy or chemical recovery using this fuel. Particulate generation for gasification is reported to be less than for a WTE facility, but control is still required along with some reduction of acid gases and metals. Organics are reported to be low or nonexistent as a result of the combustion process. In a similar manner, NOx is also reported to be very low. The types of APC equipment may be similar, but smaller for the same waste throughput because the reduced gas volume resulting if the syngas is combusted in a boiler, engine or gas turbine. Particulate capture and control of other pollutants may be required prior to the combustion device if a gas turbine is used or if the syngas is used for a chemical process. Because the syngas is combustible at this point, some significant modifications may be required to some equipment to avoid in-leakage of air or loss of syngas to the atmosphere. Packed beds or other devices may be required for mercury control.

If the syngas is used as a chemical feedstock, additional steps must be carefully considered. At some point, the syngas may be processed through a fan and downstream components will be pressurized. At this point, air in-leakage is not a concern, but leakage of syngas from the system can still occur. If leakage is significant, the potential for explosion or fire exists. Controlling fugitive emissions from leaks can be a difficult task. Typical leakage rates of one percent are common in WTE APC systems. Such conditions may not be tolerable for processing syngas.

Special procedures may need to be developed for transition operating conditions. Startup and shutdown of systems may require extensive periods of controlled temperature change to protect refractory and equipment from differential thermal expansion. Purging equipment of air or syngas may require use of nitrogen or other inert gas. Procedures to address upset conditions will be required to address appropriate operating conditions.

Multiple claims have been made about emissions from a gasification facility being lower than a WTE facility, but such statements are often not adequately backed up with data or projections. Since there are no gasification facilities operating in the United States, comparison of emissions is not practical. Comparison of data from limited facility information available from Japan is also problematic. A demonstration plasma arc facility in Canada has a temporary permit that could be used for comparison. This data is presented in Table 2. This facility will process MSW diverted from a landfill, but may also process a limited quantity of high Btu waste, such as non-recyclable plastic. In addition, some projected performance data is listed for expected emissions for a plasma arc gasification facility. It should be noted that no available emissions testing data has been provided to support these values.

Cost information for proposed gasification facilities is difficult to project. Most vendor-provided cost data appears to project favorable capital and operating costs for gasification facilities. In some cases, basic assumptions about the availability of grants, tax breaks, and other financial assistance have been included. Some reported agreements may not require public investment for a facility. Thus, it can be difficult to determine what the vendor estimates may actually include. In general, many such estimates prove to be low and costs may actually be higher than for conventional mass burn facilities. Some reported information from Japan indicates that costs may be much higher, making plants economically challenged, however it is difficult to verify this data.

## **CONCLUSIONS**

Table 3 compares modern mass burn WTE and gasification facilities and summarizes some of their features. Not all aspects are possible to compare and verification of projected performance is not possible.

Clearly, mass burn WTE facilities have demonstrated a potential for commercial application in the United States. The technology has been proven for more than 30 years. Advancements have made the units cleaner and more efficient and will continue this pattern in the years to come. Gasification facilities have received much attention in recent years as a potential and better alternative to mass burn technology. Claims of better energy recovery, lower emissions, and lower costs have been made, but there are no commercial facilities to prove these claims. Advances in technology may lead to gasification

as a better solution, but it will probably take more than a decade before proven technologies are available commercially after resolving remaining information gaps. The proven choice today remains mass burn technology, but it will be interesting to keep an eye on gasification technologies to see what might develop.

**Table 1**

**2006 Large MWC MACT Rule and Range of Expected Emissions**

<b>NSPS (Subpart Eb) Emission</b>	<b>Requirement</b>	<b>Expected Range of Actual Performance</b>	<b>Comments</b>
Dioxin/furan (ng/dscm)	13	1 - 8	Total Tetra – Octa
PM (mg/dscm)	20	0.3 – 10	
Cd (ug/dscm)	10	ND* – 5	
Pb (ug/dscm)	140	5 – 20	
Hg (ug/dscm)	50	2 – 15	
Hg (%)	85	85 – 95%	
HCl (ppmv)	25	2 – 10	
HCl (%)	95	95 – 99%	
SO2 (ppmv)	30	5 – 15	
SO2 (%)	80	80 – 90%	
CO (ppmv)	100	25 - 50	
NOx (ppmv)	150	90 – 140	

\*ND – Non-detect  
All concentrations corrected to dry 7% O2.

**Table 2**

**Demonstration Permit Limits for a Plasma Arc Gasification  
Facility and Reported Range of Expected Emissions**

<b>Emission</b>	<b>Permit Limit for a Demonstration Plasma Arc Facility</b>	<b>Reported Expected Performance</b>	<b>Comments</b>
Dioxin/furan (ng/dscm)	0.06	ND*	ITEQ <sup>†</sup>
PM (mg/dscm)	17	3.6	
Cd (ug/dscm)	20	1.4	
Pb (ug/dscm)	203	17	
Hg (ug/dscm)	29	0.71	
HCl (ppmv)	18	1.4	
SO2 (ppmv)	20	5.6	
CO (ppmv)	NA <sup>‡</sup>	42	
NOx (ppmv)	154	28	
Organic Matter (ppmv)	140	35	

\*ND – Non-detect  
<sup>†</sup>ITEQ – International Toxicity Equivalence  
<sup>‡</sup>NA – Not applicable  
 All concentrations corrected to dry 7% O2.

**Table 3**

**Comparison of Selected Mass Burn WTE and Gasification Facilities**

	<b>Mass Burn Facility</b>	<b>Gasification Facility</b>
MSW Fuel Preparation	Minimal – removal of bulky objects or other items that may impact operation	Production of a high quality RDF fuel with removal of any materials that may adversely impact facility
Process Heat Recovery	Reciprocating grate and integral waterwall boiler with steam turbine generator	Gasification chamber(s) with waste heat boiler and turbine generator or possibly use of engines, gas turbines, or syngas as chemical process input
Air Pollution Control Technology	Spray dryer absorber, fabric filter, carbon injection, SNCR Nox control with possible use of other advanced technologies	Variable but generally consists of a spray dryer absorber or wet scrubber, fabric filter, carbon injection or packed beds, and possibly other controls for NOx, or other gas components
Ash Handling	Traditionally combined bottom and fly ash but possibly separate ash handling if reuse alternatives can be developed; ferrous and non-ferrous recovery	Various concepts – plasma arc and some other gasification systems expect vitrified ash with various reuse alternatives <ul style="list-style-type: none"> <li>- some proposals anticipate reuse of ash and carbon char</li> <li>- metal recovery</li> </ul>
Net Energy Recovery per ton of MSW	600 – 650 kWh/ton	Various projections ranging from <400 to 1200 kWh/ton with most projections around 800 kWh/ton
Facility Capacity Factor	85% - 88% guarantee; actual 80 – 93+%	85%?
Overall Plant Efficiency*	+20%	20 – 45%?

\*Does not consider steam usage