Renewable Energy from Gasification of Refuse Derived Fuel

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1.0 Executive Summary

EnviroPower Renewable, Inc. (EPR) and Synergy World Power (SWP) are developing projects in North America and worldwide that will provide baseload generation of thermal and electrical power from refuse derived fuel (RDF). These projects range from a 10 MW thermal steam power plant that will be fueled by combustible refuse, to a 100 MW plant fueled by renewable biomass only.

The purpose of this document is to introduce air-fed gasification technology developed by EPR and its manufacturing partner, Metso, for renewable energy power plants The document describes EPR proprietary LoNOx gasification technology for RDF from the combustible fractions of municipal solid waste (MSW) as well as construction and demolition (C&D) waste. Overall plant layout and operation are described, as are environmental and economic advantages of gasification for final disposal of combustible solid waste. For conversion of the plastics in solid waste to diesel fuel, EPR is developing hydrothermal liquefaction (HTL), which makes more efficient use of the latter energy rich materials.

In the US, most EPR plants are designed to use only the renewable biomass fraction of construction and demolition (C&D) waste and municipal solid waste (MSW) as fuel. In some jurisdictions, however, the entire combustible fractions of MSW and C&D waste, including plastics and waste tires, can be used as fuel. Compared to placement in a landfill or conventional incineration, gasification for energy generation from solid waste offers several advantages including:

- Reduced air emission compared to generation of electrical power by incineration
- Elimination of incineration ash as hazardous or special waste
- Clean generation of renewable thermal or electrical energy from biomass
- Substantial reduction in the volume of material placed into landfill
- Substantial reduction in land area required for landfill
- Reduced emission of greenhouse gas equivalents compared to landfill
- Reduced air emission of volatile organic compounds compared to landfill
- Reduced contamination of terrestrial environment compared to landfill
- Elimination of ground water contamination associated with dumping or landfilling
- Reduced NOx emission on a per MWh basis compared to legacy coal or gas fired power plants.

Independent reviews and approvals for commercial application of EPR LoNOx gasification technology have been carried out by several qualified independent third parties, including Oak Ridge National Laboratory, GDS Engineers, Leidos and the US Army. NV Energy, the largest electrical utility in Nevada, has reviewed EPR gasification technology and approved it for commercial use.

2.0 Background

While great progress has been made in the deployment of renewable energy generation from wind and solar, many jurisdictions are now facing new challenges in developing and operating electrical grids to cope with the increasing proportion of renewable energy from these intermittent sources.

Baseload Power and Grid Stability: Rapid increases in the use of intermittently available sources of power, together with a reluctance to continue use of fossil fuel fired baseload power plants, has created areas of power grid instability on some western State power grids, and increasingly, overseas as well. In short, intermittent renewable energy sources do not always generate power when and where it is needed. While the use of battery storage can partially address the problems of intermittent power sources, baseload (24/7/365) generation of renewable power at a competitive price is needed to fully stabilize the grid and provide the reliability demanded by consumers. With poor prospects for new hydro and nuclear, viable baseload renewable energy options are effectively limited to geothermal and biomass thermal conversion.

Distributed Generation and Microgrids: Movement away from large coal fired power plants, in favor of smaller capacity and intermittent renewable energy generation, is placing a strain on tradition long distance power transmission systems. The 10MW to 100 MW baseload gasification power plants described here are an ideal component of the distributed generation and microgrid systems that will help stabilize the electrical power infrastructure as the world moves away from large centralized fossil fuel generation plants.

Gasification in Integrated Solid Waste Management Systems: Recent decisions by China to greatly reduce or discontinue import of combustible recyclable materials from other countries, including the US, is placing increasing pressure on existing landfills. This change in the recyclables market will further exacerbate already acute disposal problems in many cities. This is especially problematic in the Northeast, where MSW is already being sent out of state for disposal. Adaptive measures, including deployment of smaller scale gasification waste to energy plants, will be required to manage disposal of domestic combustible MSW in many areas of the world. Combustible fractions of MSW and C&D are comprised primarily of biomass (wood, cardboard, paper, green waste, etc.) and can be sorted to yield a clean biomass only fuel that is ideal for gasification. It is this 100% renewable fuel for which the 100 MW North Las Vegas described in this document was designed.

In some jurisdictions, waste to energy gasification is of interest primarily as a component of an integrated and sustainable solid waste management system. In these applications, the waste to energy plant is generally co-located with a landfill. In areas where landfills have become environmental hazards due to objectionable odors, smoke from landfill fires or blowing fugitive trash, a gasification power plant can be an important component in remediation.

These landfills can be mined for combustible materials that would otherwise be a substrate for anaerobic decomposition giving rise to greenhouse gasses and toxic air emissions, or fuel for fires. Processing of incoming waste streams can be designed so that combustible materials are diverted to the gasification power plant, metals are reclaimed for recycling, and only inert non-recyclable materials are placed in the landfill. In areas where the MSW includes a great deal of wet organic matter, this material (mainly food waste) can be dried before gasification or treated by anaerobic digestion to produce a biogas and a compost material.

Renewable Energy Credits for RDF from Combustible Mixed Waste: In many EU jurisdictions, renewable energy credits, or their equivalent, can be earned by waste to energy plants that use RDF that includes plastics, waste oil, tires and other fossil carbon containing materials. Fossil carbon materials such as coal and oil can be distinguishable from contemporary carbon (plant fiber) by determination of the relative abundance of carbon 14 (^{14}C) to carbon 12 (^{12}C) contained in the material (*Aylott, 2011*). Carbon 14 is a naturally occurring and unstable isotope, formed in the upper atmosphere. Carbon 14 undergoes radioactive decay to form carbon 12 with a half-life of some 5,700 years.

It is therefore possible to determine whether carbon is contemporary (renewable: incorporated from the atmosphere into plant life within the last few centuries) or fossil, (non-renewable: incorporated into plant material millions of years ago.) The determination is done by measuring the ^{14}C to ^{12}C abundance ratio in the stack gas of thermal plants using waste as fuel. For waste to energy plants in the EU, typically 60% to 70% of the waste used for fuel is contemporary carbon or biomass.

Depending on local laws, renewable energy credits can be allotted for the percentage of carbon that is renewable, since this renewable carbon offsets the fossil carbon that would otherwise be used to generate the same amount of electrical energy.

3.0 Gasification

Gasification is a process wherein carbonaceous materials are dissociated at high temperatures in an oxygen-starved thermal reactor to form a fuel gas that is mainly composed of carbon dioxide, carbon monoxide, hydrogen, methane, and water vapor. If the thermal reactor is air fed (as opposed to oxygen fed only), the fuel gas also contains inert nitrogen (N_2) and is referred to a producer gas. The fuel gas product of oxygen fed gasification is synthesis gas, or syngas. In this document, the producer gas will be referred to as fuel gas.

Gasification reactions take place at somewhat lower temperatures than complete combustion and require less mass flow through the gasification reactor. This reduced mass flow means that gasification reactors can be smaller than incinerators for a given rate of fuel use or thermal output. The fuel gas from the main reactor can be reformed to crack tars prior to combustion in the well-controlled LoNOx burner developed by EPR. In EPR power plants, the thermal energy from burning of the fuel gas is used to make steam, which drives a steam turbine to generate power. This steam Rankine cycle process is described in more detail below.

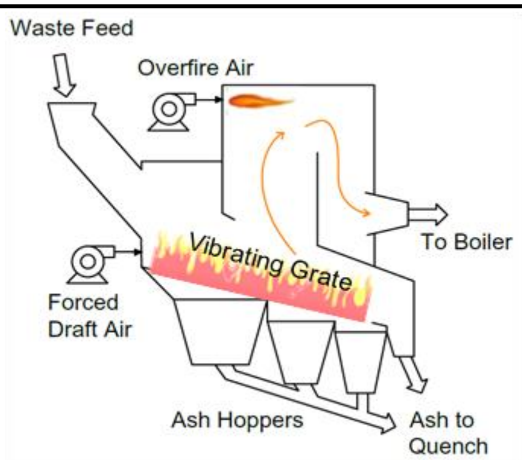
Compared to incineration for thermal treatment of MSW, gasification is inherently:

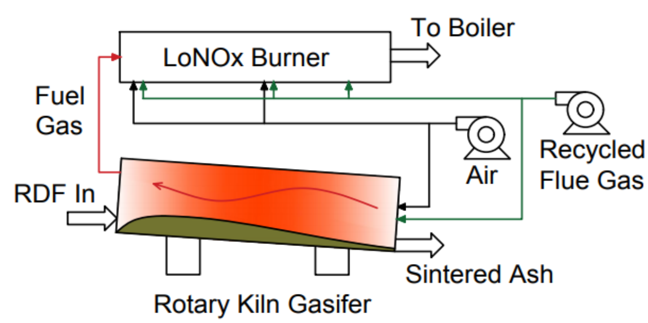
- **more thermally efficient** than incineration;
- **cleaner** than incineration, with fewer air emissions including less entrained particulate, and lower emissions of nitrogen oxides (NOx), as well as lower concentrations of other pollutants in the flue gas;
- **less expensive** than incineration to build and operate;
- **capable of producing commercially beneficial by products**. In addition, MSW gasifiers can be designed to produce a low carbon, inert and non-leachable slag or vitreous frit instead of a leachable bottom ash (as is produced by incinerators). Residual sintered material can be beneficially used in cement making, or as an aggregate for cement blocks or for fill materials.

Proprietary EPR flue gas recycle and LoNOx burner further enhance the advantages of gasification as compared to incineration. Flue gas recirculation is commonly used to reduce NOx emissions from several types of thermal plants, and was adapted for use on countercurrent rotary kilns by EPR.

Modern air fed gasifiers can operate on various forms of combustible solid waste and biomass. Gasification, steam power generation, and flue gas cleaning equipment of the type used by EPR have been in successful commercial operation for decades, and much of it for more than a century. **Figure 3.1** below illustrates the main differences between incineration and gasification in terms of gas phase and solid phase emissions. As indicated in **Figure 3.1**, benefits achieved with gasification as compared to incineration include:

1. Less oxidation of fuel bound nitrogen to form NOx,
2. Reduction in fuel borne NOx emissions from flue gas recycle,
3. Little or no "thermal NOx" is generated by properly operated gasifiers,
4. Reforming used in EPR gasification systems results in a relatively cleaner fuel gas.





Incineration:	**Gasification:**
- Operates with excess air - Generates more PM, NOx VOC, etc. - Equipment larger and more expensive - Ash is generally special or hazardous waste	- Operates sub-stoichiometricly with much lower gas flow through the main reactor - Less particulate generated - and what is formed is removed prior to combustion of the clean fuel gas, generating less PM, NOx, CO_2 VOC s, and no Ozone - Gasification systems are smaller and less expensive - EPR ash is a clean, inert , non-leachable product

Figure 3.1. Conventional incineration compared to EPR LoNOx gasification system

3.1 Gasification vs. Landfill and Incineration for Treatment of Solid Waste

Several studies have compared the relative environmental and economic impacts of landfill placement, incineration and gasification for treatment and disposal of MSW. Such studies, including those carried out by the USEPA (*1996*) and USDOE (*2002*) and Amec Environmental UK *(2011),* as well as reports from Los Angeles (*URS, 2005*), Victoria, BC (*Stantec, 2011*), BPA (*2009*), and a large study from Europe (*Munster, 2009*), show that properly designed and operated air fed gasification systems are, by far, the most efficient and cleanest thermal technology for converting solid waste to energy.

Banes *(2003) and* Zaman *(2009) have* provided life cycle assessments comparing landfill, incineration and gasification as primary technologies for treatment and disposal of MSW. Again, gasification ranked highest, overall, when considering the combined characteristics of conversion efficiency, cost per unit of power generated, and favorable environmental impact. Environmental advantages of thermal treatment of combustible waste, as compared to landfill, have been confirmed by the USEPA, which has concluded that landfills are an important source of fugitive methane gas (*Thorneloe, 2012*), which gas is some 25-fold more effective as a greenhouse gas than carbon dioxide (CO_2).

Thermal treatment of MSW is a well proven technology for producing renewable energy, while greatly reducing the emission of methane and other greenhouse gases per unit mass of fuel, as well as a reducing the amount of waste going to landfills. As shown in **Figure 3.2**, this comparative advantage of gasification is maintained when compared to landfills with gas capture systems, with gasification producing only about 1 kg of CO_2 equivalent (CO_2e) per kWh of generated power, while landfill produces approximately 2.75 kg/kWh, and incineration releases approximately 1.6 kg/kWh of power generated. Air emissions from gasification are inherently lower than from incineration, whether calculated per ton of waste treated, or per MWh of energy generated. Gasification technology offers greater flexibility in facility design and layout and requires less heavy construction and civil work onsite than incineration, resulting in shorter construction times (and lower costs).

Figure 3.2 (a) below compares the carbon dioxide equivalent emissions per unit of electrical power generated from MSW by gasification, incineration, and landfill gas recovery. Landfill gas generation releases more than 2.5 times as much greenhouse gas equivalents per kWh of energy generated as gasification does. Likewise, **Figure 3.2 (b**) shows that gasification generates far less NOx and SOx and particulate matter than incineration, and far less SOx and NOx than landfill gas, per kWh of energy generated.

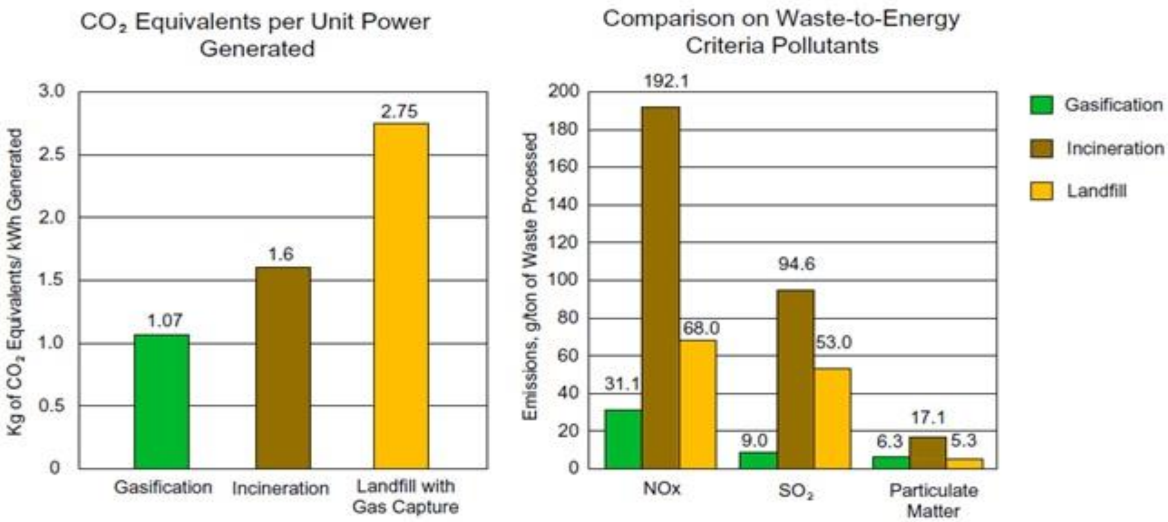


Figure 3.2 (a,b) Relative greenhouse gas equivalent emissions (a) and the relative emissions of NOx, SOx and particulate matter (b) per kWh or energy generated from conversion of MSW by gasification, incineration and landfill.

3.2 Environmental Advantages of Gasification-Based Waste to Energy Conversion

As a source of electrical power, gasification of combustible waste is more effective in reducing greenhouse gas equivalent (GHGe) emissions than pulverized coal combustion, coal biomass co-firing, or natural gas fired combustion turbine combined cycle. **Figure 3.3** shows that direct firing MSW biomass has the net effect of reducing GHGe emissions compared to landfilling where anaerobic decomposition would produce methane (some 25 times as harmful as CO_2).

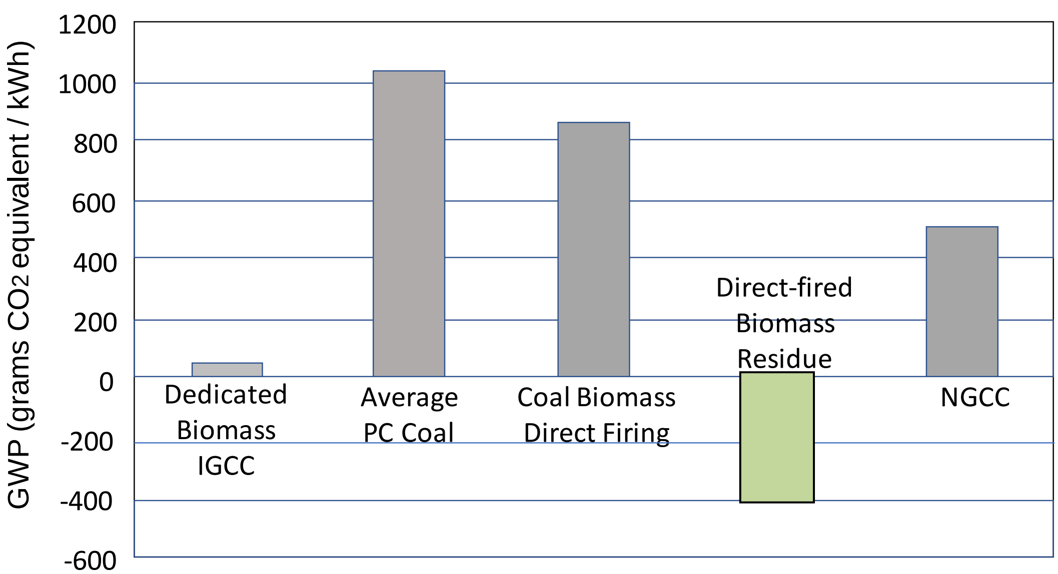


Figure 3.3 Comparison of the GHGe contribution of power plants using different fuels

An important issue in regulation of air emissions is to control the ground level particulate concentrations that result from plant operations. On a comparative basis, **Figure 3.4** shows the calculated ground level concentrations of particulate matter from a 48 MW EPR designed plant in Ireland as compared Republic of Ireland EPA Lower Assessment Threshold Values for PM_{10} and $PM_{2.5}$ concentrations. These are compared to ground level concentrations measured adjacent to a roadway along which diesel trucks occasionally travel. Specifically, the graph compares PM_{10} highway background values to ground concentrations from a 48 MW gasification plant operating on MSW. Maximum and annual average PM_{10} values are shown as determined 500 m downwind from the gasification facility.

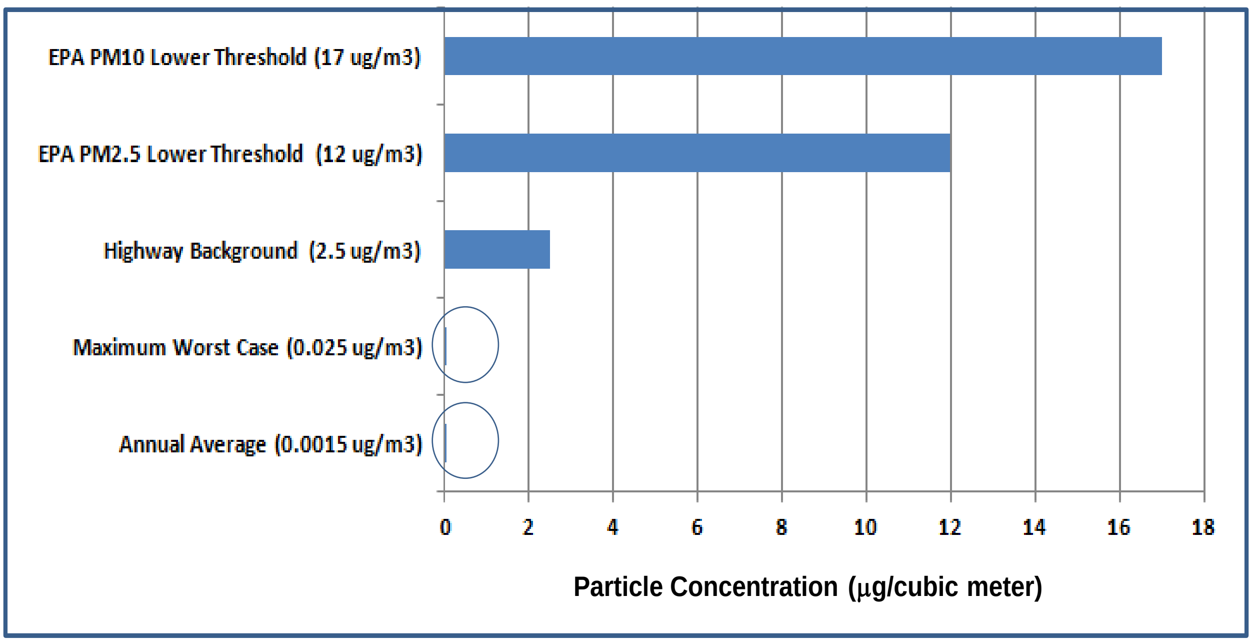


Figure 3.4. Comparison of Irish EPA Lower Assessment Threshold Values for PM_{10} and $PM_{2.5}$ as compared to PM_{10} highway background concentrations and maximum and annual average PM_{10} values from a 48 MW gasification facility

The outstanding environmental performance of the EPR LoNOx gasification system design allows EPR gasification power plants facilities (up to 60 MWe, or more), to be permitted by the USEPA as synthetic minor air emission sources, while processing up to 1,400 tons per day of biomass RDF. The EPR 50 MW gasification power plant under development in North Las Vegas, NV, for example, has been permitted as a synthetic minor stationary emission source by the Clark County Nevada Department of Air Quality.

4.0 EPR Gasification Technology

EPR gasifier designs use proven off-the-shelf equipment in a proprietary process to economically generate electricity from waste with the minimum environmental impact. The use of proven equipment allows for a high level of reliability, while simultaneously providing clean, renewable base load power. Here we discuss the general features of EPR gasification systems.

EPR designed facilities use air-fed gasification for conversion of solid waste. Since these facilities are paid to process their fuel, thermodynamic efficiency becomes relatively less important as compared to thermal power plants that pay for fuel. This allows greater design emphasis to be placed on system reliability and environmental performance.

Systems are individually designed based on the type of waste available, local altitude and climactic conditions, and the availability of sufficient cooling water for a water-cooled condenser. The process flow diagram shown below is included mainly to identify the main equipment components of the thermal and power island sections of the plant and is not intended to be enabling.

The EPR approach to gasification system design has been to start with commercially proven equipment and then reconfigure that equipment by adding proprietary and industry standard upgrades to improve the reliability, environmental performance, and efficiency. Such innovations include:

- reforming at high temperatures to crack any tars present in the raw fuel gas and convert fuel born nitrogen into N_2, greatly reducing NOx formation during combustion;
- staged fuel gas combustion to control flame temperature to eliminate formation of thermal NOx;
- Increased residence time at temperature to allow for the increased reduction of NOx species to inert molecular nitrogen, and destruction of dioxins and furans;
- use of a high temperature final stage of gasification for the elimination of carbon from the bottom ash and consolidation of the ash;
- recycling a large portion of the flue gas for controlling temperature instead of quenching with air, resulting in a much lower volume of gas passing through the flue gas cleanup systems.

These designs are well suited for highly variable fuels such as minimally separated MSW, especially material that may have high moisture content or low average calorific value. EPR gasifiers use flue gas recycling, combined with a reformer and a LoNOx burner, for temperature control and improved thermal efficiency **(Figures 4.1** and **4.6).** In the reformer, the temperature of the fuel gas is increased by the addition of air and recycled flue gas to destroy ammonia and other NOx precursors and to crack any tars in the flue gas. Exiting the reformer, the fuel gas is further mixed with recycle flue gas to limit flame temperature (so as not to form thermal NOx) as it enters the fuel gas burner.

Exiting the burner, the hot combusted gasses are quenched with recycle flue gas prior to entering the heat recovery steam generator (boiler). The reduced temperature of the gas prevents fouling of the boiler tubes. Exiting the boiler, a portion of the flue gas is recycled back to the pre-combustion components. The remainder is sent on to the flue gas clean up system for removal of residual criteria pollutants prior to release to the atmosphere. Steam raised in the boiler is used to power a standard Rankine cycle steam turbine system to generate electricity.

The power island uses well proven equipment that is highly reliable and requires no special modifications. This eliminates the risk found in some gasification systems that use combustion turbines or reciprocating engines as prime movers for power generation. **Figure 4.1** shows a simplified process flow diagram for a rotary kiln-based gasification waste to energy system.

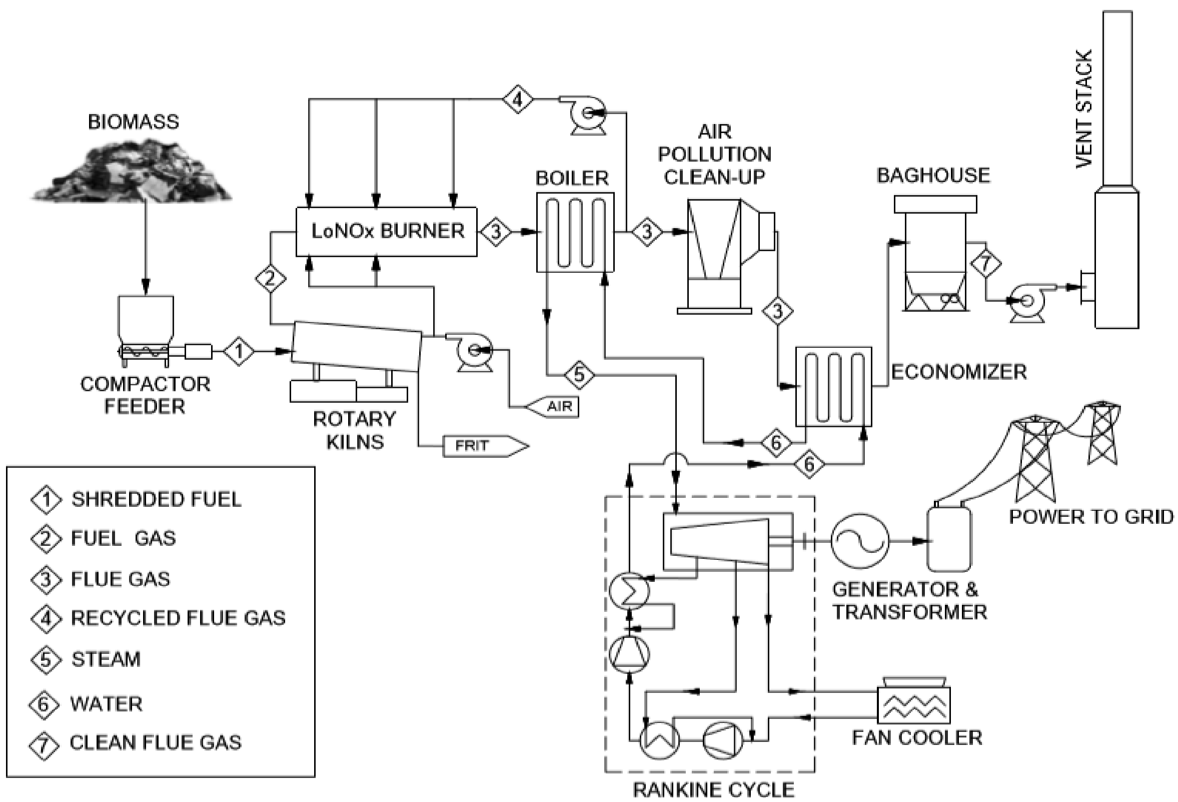


Figure 4.1. Simplified diagram of a LoNOx gasification line with the major process streams

Main steps in the overall process depicted in **Figure 4.1** include:

- Sorting and processing of waste to make into Refuse Derived Fuel;
- Gasification of the Refuse Derived Fuel;
- Reforming of the resulting fuel gas to destroy pollutants;
- Combustion of the cleaned fuel gas controlled by recycled flue gas;
- Production of steam in a heat recovery boiler
- Production of electricity from one or more Steam Turbine Generators; and
- Treatment of flue gas from the Heat Recovery Boilers
- Sintering of the bottom ash residue to produce an inert, carbon free, solid residue

Figure 4.2 shows a block process flow diagram of the overall EPR LoNOx gasification power plant design. The plant is comprised of a **Thermal Island**, which includes rotary kiln gasifiers, a fuel gas reformer and burner, a heat recovery steam generator (HRSG) type steam boiler, and the exhaust gas clean up system.

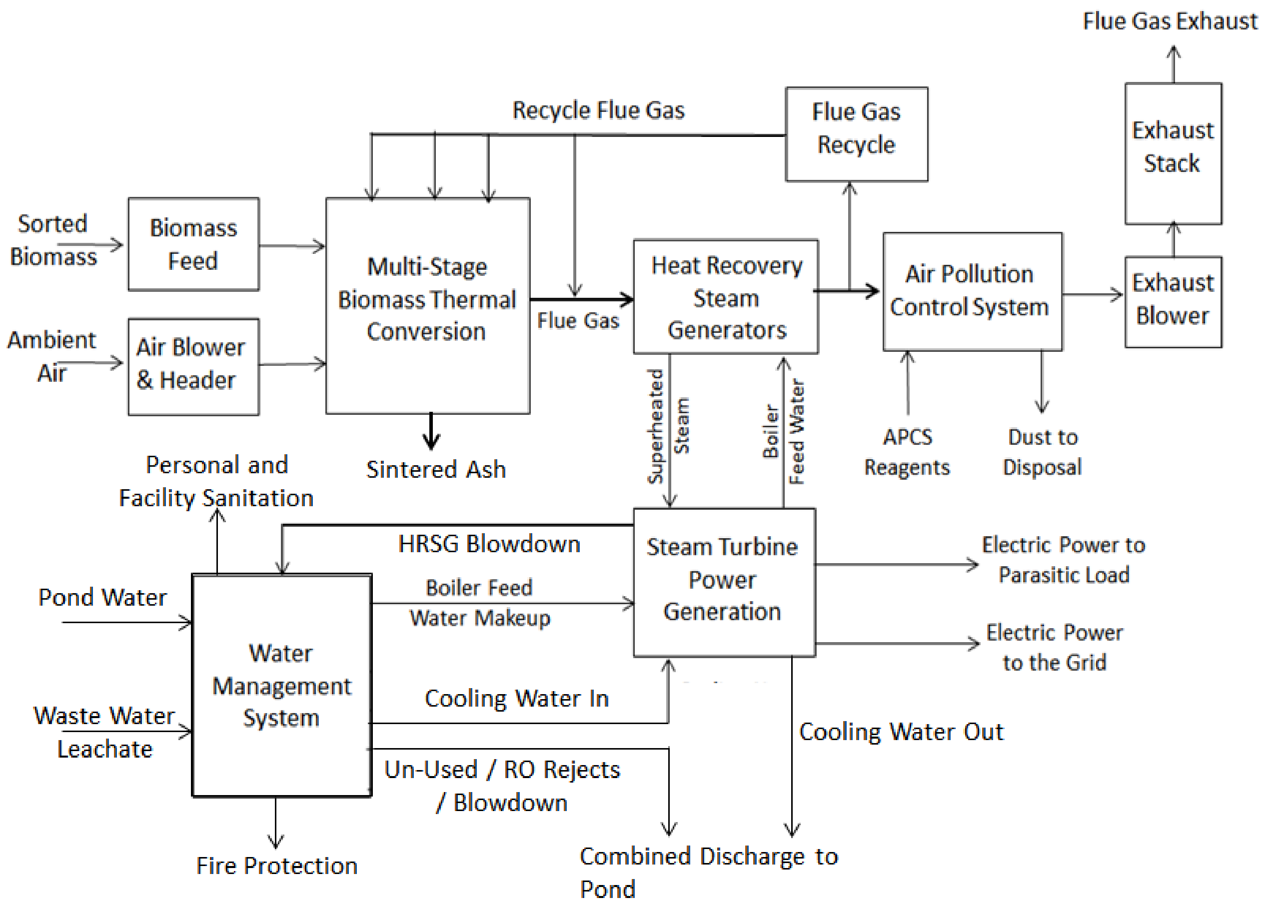


Figure 4.2 Block diagram of a gasification power plant using once through waste cooling

The **Power Island** in **Figure 2** consists of a conventional turbine generator that uses steam from the HRSG boiler to produce electrical power, clean running air exchange cooling towers and a boiler water make-up system. Components of the steam Rankine cycle system are shown inside the dashed lines in **Figure 4.1.**

4.1 Steam Rankine Cycle Power Generation

The steam Rankine cycle is the industry standard for power production from thermal energy. Heat from hot exhaust gases from the boiler generates super-heated steam in a heat recovery steam generator (HRSG). This steam is then used to power a steam turbine, which drives a generator, producing electrical power. This system has been widely used since the invention of the steam turbine over 100 years ago. The steam Rankine cycle equipment currently produces around 90% of the world's electricity.

The power generation system used by EPR is custom designed for each project. The HRSG used is designed to handle the unique exhaust gases that come from waste to energy systems. In this case, the HRSGs will generate steam at 400°C at a rate of approximately 47 tons of steam per hour. This steam is piped to a turbine which, in the case of the Hamilton plant described below, is designed to generate up to 28 MW of electricity. The steam-water mixture leaving the turbine is converted back to water in a surface condenser. This condenser is normally cooled using water. However, air exchange cooling can be used in cooler climates. The condenser is important for maintaining a low back pressure at the turbine exhaust, allowing it to run as efficiently as possible. The water is then re-pressurized with a pump and returned to the HRSG to generate more steam.

Superheated steam, generated in the HRSG system, is piped for the two main uses in the plant. The minor use is for process control steam, with a line providing steam to control the thermal conversion of the fuel and the fuel gas generated, as needed. This is achieved by direct injection of de-superheated steam into the rotating kiln gasifiers and the reformer. The major use of steam in the plant is for power generation. Steam is expanded in a turbine that is outfitted with two distinct extraction pressure level side-streams. The turbine exhaust pressure is maintained by cooling the expanded, wet steam in an air-cooled condenser. The steam cycle includes a de-aerator, which is used with extracted steam to preheat, and strip air from, the boiler feed water.

4.2 Heat and Material Balance

Determination of heat and material (H&M) balance is a foundational calculation in the design of thermal power plants. EPR conducts this critical design process using proprietary in-house engineering software that essentially tracks each chemical component of the inflowing fuel, air, water and reagents through the entire gasification and power generation process. Since H&M balance calculations account for all the mass and energy entering and leaving the process, they are important in designing plant to operate efficiently with a wide variety of fuels.

Table 4.1 is an image from one sheet of the heat and material balance results for 8 of approximately 66 process streams in the design if a typical EPR plant. These calculations are used for everything from equipment sizing to air emissions estimates. Stream number 206 shows the composition of the air entering the gasifier, the amount of which is insufficient to allow complete combustion of the RDF. Stream 207 gives the composition of the fuel gas leaving the rotary kiln gasifier and entering the reformer. Pressures and temperatures associated with each process stream are calculated. More detail on the process streams is shown in **Appendix I.**

Table 4.1 Heat and material balance for 8 of more than 60 process streams in the design for the St. Maarten renewable energy power plant

Stream number		201	202	203	204	205	206	207	208
		Waste Into Fuel Prep	Tires Into Fuel Prep	Debeading Discards	Leachate	RDF to Gasifier	Air Into Kiln	Fuel Gas To Reformer	Kiln Bottom Ash
Pressure	"wcg	0	0	0	0	0	3	-1	0
Pressure	psia								
Temperature	F	81	81	81	81	81	81	1900	1200
Component	Formula	PPH	PPH	PPH	PPH	PPH	PPH	PPH	PPH
Carbon	C	10,861.21	-	-	-	10,861.21	-	-	-
Hydrogen	H	1,425.73	-	-	-	1,425.73	-	-	-
Oxygen	O	9,507.63	-	-	-	9,507.63	-	-	-
Nitrogen	N	171.43	-	-	-	171.43	-	-	-
Sulfur	S	54.91	-	-	-	54.91	-	-	-
Chlorine	Cl	11.68	-	-	-	11.68	-	-	-
Methane	CH4	-	-	-	-	-	-	1,313.35	-
Carbon Monoxide	CO	-	-	-	-	-	-	4,654.40	-
Carbon Dioxide	CO2	-	-	-	-	-	-	27,918.51	-
Water Vapor	H2O(g)	-	-	-	-	-	1,093.19	23,680.52	-
Hydrogen	H2	-	-	-	-	-	-	388.41	-
Nitrogen	N2	-	-	-	-	-	51,644.18	60,753.36	-
Oxygen	O2	-	-	-	-	-	15,689.37	-	-
Hydrochloric Acid	HCl	-	-	-	-	-	-	12.01	-
NO x	NO2	-	-	-	-	-	-	-	-
SO x	SO2	-	-	-	-	-	-	-	-
Ammonia	NH3	-	-	-	-	-	-	208.62	-
Hydrogen Sulfide	H2S	-	-	-	-	-	-	58.35	-
Ash	na	6,609.11	-	-	-	6,609.11	-	66.09	6,543.02
Water	H2O(l)	16,320.46	-	-	1,188.88	15,421.26	-	-	-
Total (PPH)		44,962.15	-	-	1,188.88	44,062.95	68,426.74	119,053.62	6,543.02
Energy (MMBTU/hr)		185.79	-	-	-	185.79	1.88	187.84	1.91
Flow Rate (SCFM or GPM)		18.75	-	-	2.38	18.75	15,125.41	28,883.01	1.76

4.3 Rotary Kiln Gasifiers

Rotary kilns (**Figure 4.3**) can serve as versatile and robust gasification reactors with various designs for biomass and MSW being introduced over the last 40 years. The patented and patent pending EPR countercurrent gasifier designs feature flue gas recycle and optical sensors for tight control of gasifier function over a wide range of fuel quantities, qualities, particle sizes and moisture content. These simply designed gasifiers can operate on a wide range of fuels and are easily maintained. Their horizontal orientation means they can be readily installed in sheds or buildings.

Figure 4.3 Indoor installation of a rotary kiln

Figure 4.4 shows a proprietary (patented and patent pending) EPR rotary kiln gasifier with onboard fan for improved control of the gasification process. The mean gas residence time in the kiln is approximately 8 seconds. The mean transit time for the fuel is approximately 45 minutes**.** Transit time can be controlled by adjusting the rotational speed. **Figure 4.5** shows temperature profiles for the gas, wall and bed temperature for the kiln during operation. **Figure 4.6** shows the layout of a 4 kiln thermal island with color coded operational components.

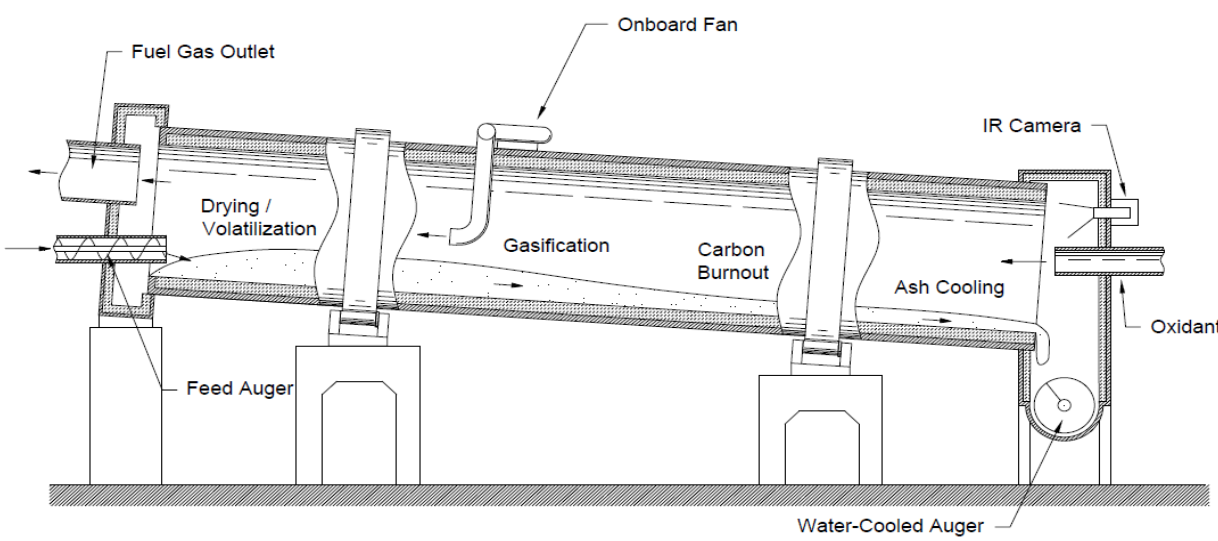


Figure 4.4 EPR rotary kiln elevation view showing reactions zones

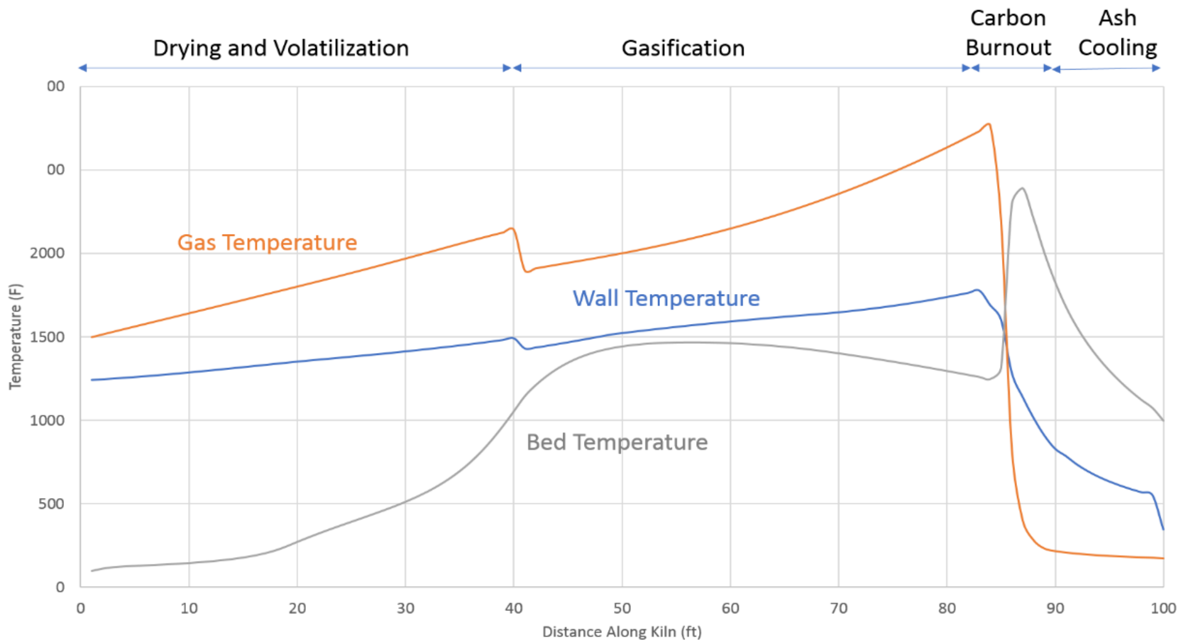


Figure 4.5 Temperature profiles for kiln gas, wall, and bed along in the four main reaction zones

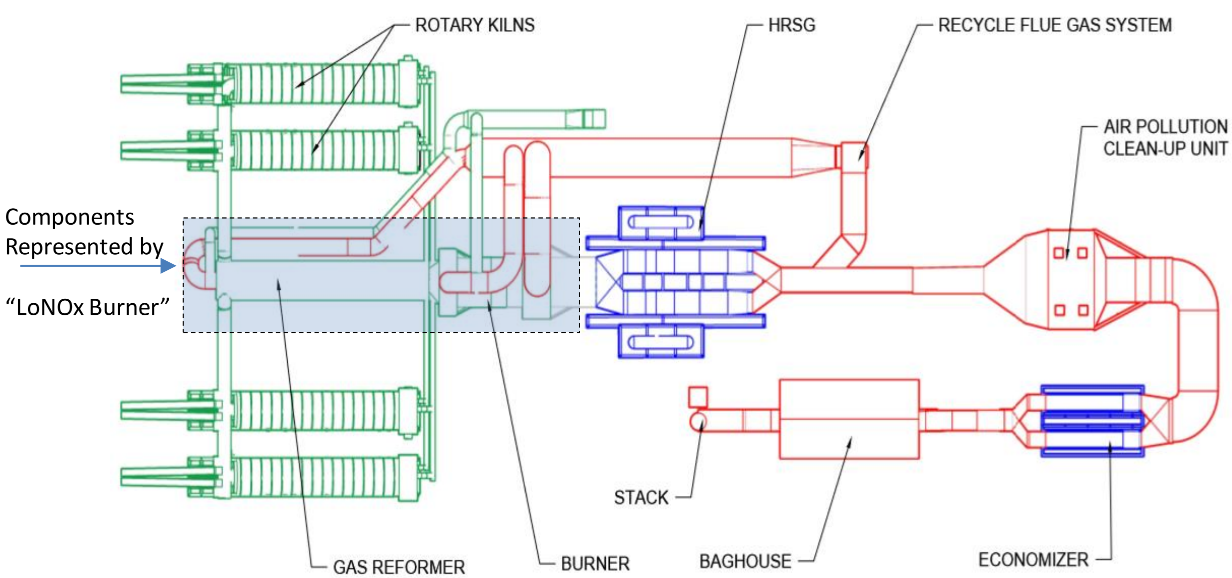


Figure 4.6. Layout of EPR LoNOx gasification line showing the gasifiers reformer and burners (Green), heat exchangers (Blue) and air pollution control components (Red)

Designs based on rotary kilns cost less to build and are robust with the ability to process a wide variety of fuel materials in terms of composition, moisture content and particle size. **Figure 4.7** below is an isometric view of an EPR LoNOx gasification line showing tandem reactor gasification units, steam generation boilers, heat exchangers, flue gas recycle, and flue gas cleaning systems.

These gasification lines are modular. **Figure 4.7** shows the thermal island only. The fuel preparation area, air cooled condenser, and power island are not shown here. As shown, rotary kiln gasifiers can be combined in modules comprised of up to 4 four kilns each. These are connected to a single reformer, burner, boiler, and air pollution control system. These systems can be designed as LoNOx units with the capability to generate up to 50 MW or more depending on fuel quality.

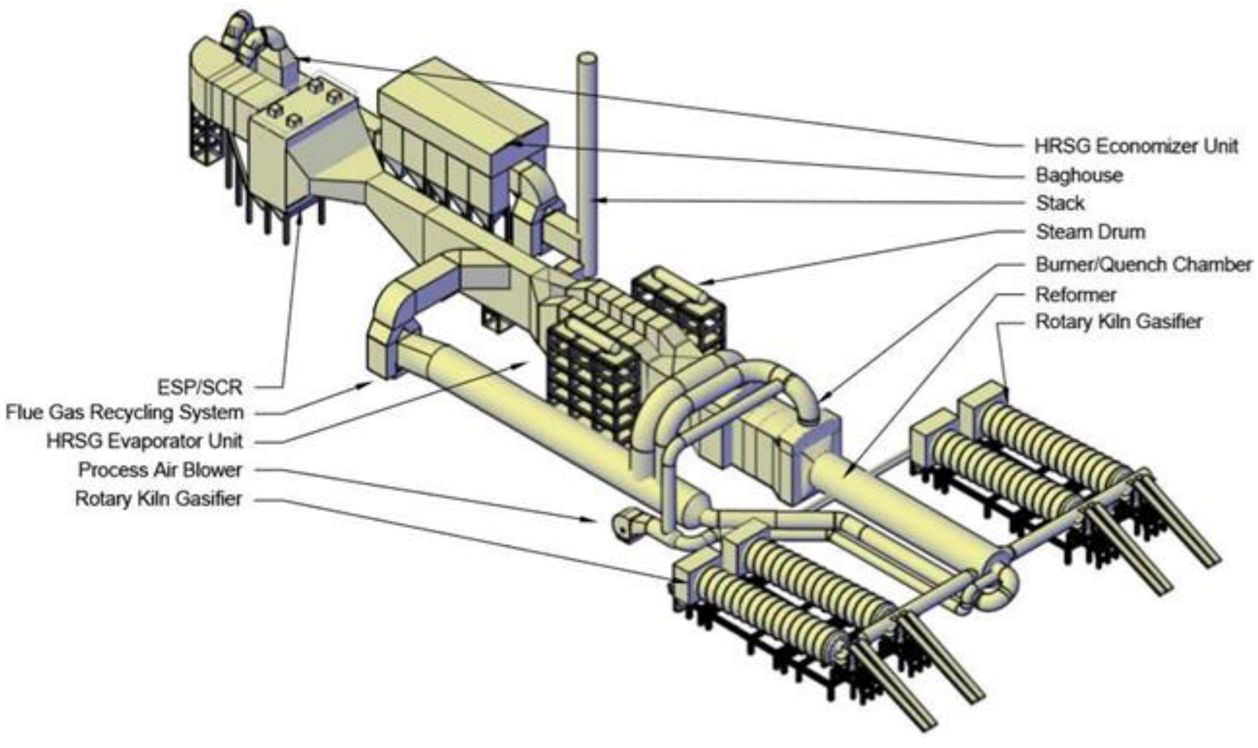


Figure 4.7. Isometric view of EPR LoNOx gasification thermal island

Flue Gas Clean-up and Solid Residue Emissions: Because of lower mass flow through a gasification reactor as compared to a conventional incinerator, flue gas from a gasifier carries less particulate than that from an incinerator. Likewise, with flue gas recycle, NOx emissions are inherently lower as well. The process units used in flue gas clean-up in gasification are the same as those used in other carbon fuel plants. These include acid gas removal, selective catalytic or non-catalytic reduction, electrostatic precipitator, and a bag house. These units are selected for use, as needed, depending on fuel, client preferences and local emission regulations. Using industry proven commercial air pollution abatement equipment, an EPR 50 MW power plant qualifies as a synthetic minor source under USEPA guidelines.

Solid by products of gasification, such as bottom ash and fly ash, have less environmental impact than those from incinerators. There are several reasons for this. First, gasification systems generally use sorted waste, as opposed to the mass burning of raw unsorted waste in mass burn incinerators. This reduces the amount of heavy metals and chlorides that enter the system, and reduces the amount found in the bottom ash and fly ash. Secondly, gasification volatizes many of the water-soluble compounds found in bottom ash. Incinerator bottom ash can contain up to 20% chlorides and 12% sulfates. These same compounds in a gasification system are largely converted to gaseous HCl or H_2S and removed in the flue gas cleanup system. These higher concentrations of water-soluble compounds in incinerator ash make it highly leachable and render it useless for most commercial applications.

Emissions from an EPR LoNOX Gasifier compared to a conventional gasifier are shown below. **Table 4.2** lists the permitted emissions for a conventional gasifier operating in Plainview, CT, as well as for the EPR LoNOx system in Las Vegas, for the same amount and type of waste material. The EPR system processes 1,300 t/d and generates 42.5 MW (net), while the EPI system generates 37.5 MW from 1,300 t/d. Note the reduced NOx and PM_{10} and lead emissions per MW of generating capacity for the EPR system compared to the EPI system.

Table 4.2 Comparison of permitted emissions from a conventional waste to energy gasification system to those from an EPR LoNOX system processing the same amount and type of waste

Criteria Pollutant	Permitted Tons per Year per MWe of Generating Capacity	
	Plainville (EPI)	Las Vegas (EPR)
PM_{10}	1.2	0.4
NOx	4.6	1.8
SOx	2.2	2.0
VOC	0.7	0.3
CO	6.4	0.8
Pb	0.009	0.00018

4.4 Examples of EPR Gasification Power Plant Specifications and Capacities

Hamilton Scotland 27.5 MW: Figure 4.8 below shows an oblique view rendering of the Hamilton Energy Center 27.5 MW power plant superimposed on a satellite image of the site property in Hamilton Scotland.

Figure 4.8 Oblique rendering of an in-building a 27.5 MW Lo NOx gasification power plant

To reduce the elevation profile, of this plant, the thermal island will be installed below grade. The plant will process approximately 297,500 tonnes of RDF per year and produce 27.5 MW of renewable energy (nameplate) using a conventional steam turbine generator. Due to the inherently low NOx production of the rotary kiln gasifiers fitted with flue gas recycle, this smaller plant will rely on non-catalytic selective reduction for NOx abatement and will not require an ESP. The baghouse will have carbon and lime injection for polishing the system effluent prior to release.

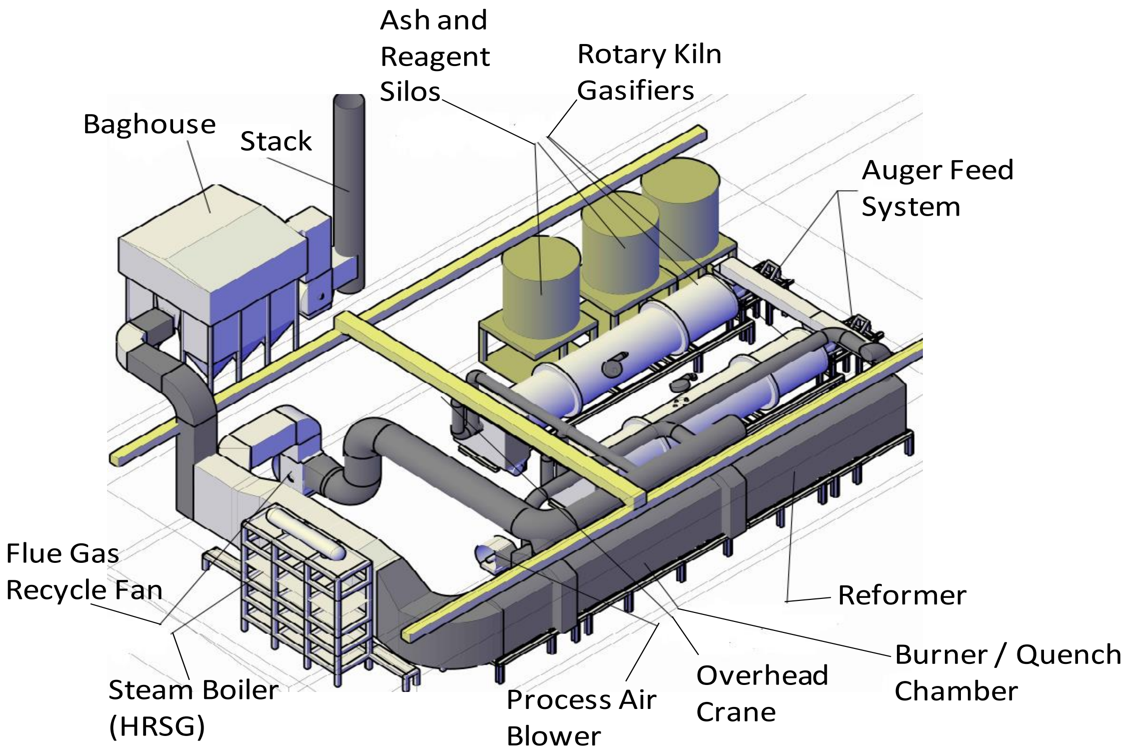


Figure 4.9. Oblique view of the below grade installation of a two kiln 27.5 MW gasification plant

North Las Vegas 100 MW: Figure 4.10 shows an elevation view rendering of the plant superimposed on a ground level image of the property in North Las Vegas, NV. The overall site layout provides space for two 50 MW gasification lines to be constructed. Plant capacities and specifications are shown in the **Table 4.3**. The renewable energy generation plant in Las Vegas will be comprised of two 50 MW gasification lines, as described above, each capable of autonomous operation.

Figure 4.10 Ground level elevation rendering of Phase I (50 MW) of the 100 MW EPR biomass gasification facility in North Las Vegas

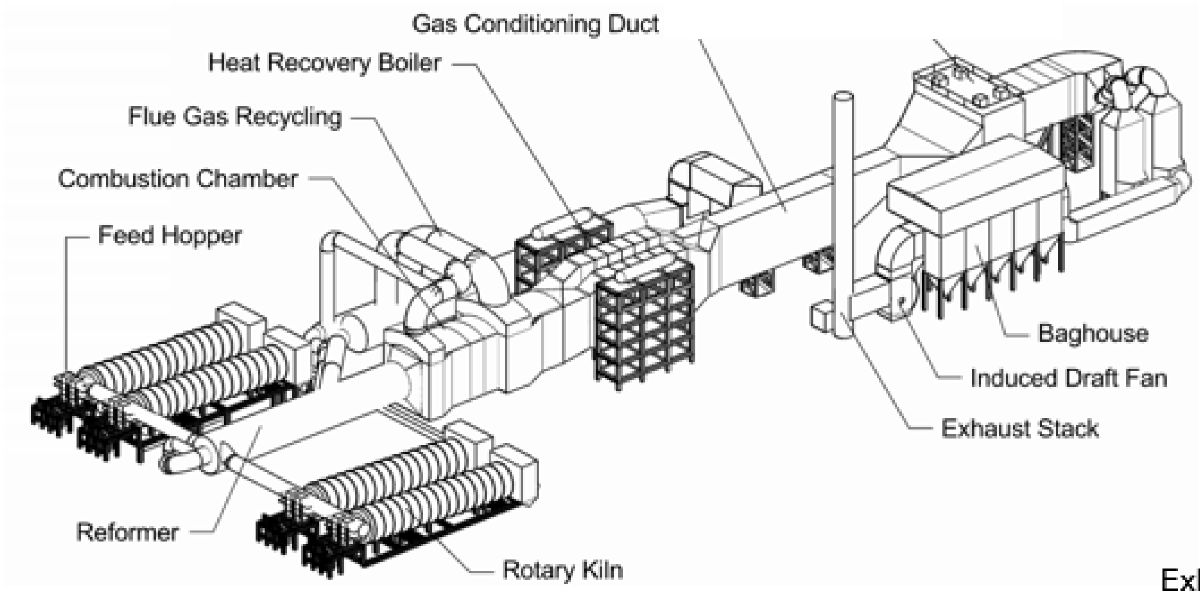
These Rankine cycle power plants will be backed up with 42 MW of natural gas fired combustion gas turbines generation capacity. The gas turbine generators will also be available for peaking power operation when not in use for back-up power generation. As shown, the plant will also have Black Start capability provided by a natural gas fired, battery started, reciprocating engine genset that will have the capability to crank the combustion gas turbines. Key plant specifications and capacities for the 100 MW gasification line module described above are shown in **Table 4.3.**

Table 4.3. Selected power plant design specifications and capacities

Specification	Value
Gasifiers for 100 MW (nameplate) Gasification Line	Two 4 x Rotary Kilns with Flue Gas Recycle
Gasification Line (nameplate) Generating Capacity	50 MW per line / 100MW total
Back-up and Demand Power Capacity (Total)	42 MW
Start-up / Black Start / Demand Power Fuel	Natural Gas
Biomass Processing Capacity	Up to 3000 Tpd
Feeder Line Output Voltage	138 kV
Permitted Net Power to the Grid	87 MW
Average Net Power to the Grid	83.2 MW

4.5 Manufacturing Partners

Metso is a leading international manufacturer of rotary kilns for mineral processing, cement manufacture, coke production and waste incineration based in Finland. **Figure 4.11** on the following page shows a line drawing of an EPR four Kiln LoNOx gasification thermal island. This is compared to a commercially deployed Metso dual kiln waste to energy power plant of the same basic scale and design using similar components. Comparison of the two-line drawings reveals similar gas paths, and similar types of process units on both. Notable differences include horizontal configuration of the reformer on the EPR system as compared to the vertical mounting of the secondary combustion chambers on the Metso plant. The EPR design includes a proprietary flue gas recycle and LoNOx burner feature that is not present on the Metso system. The Metso plant shown is one example of several such rotary kiln plants that are used to convert a wide variety of wastes to energy.



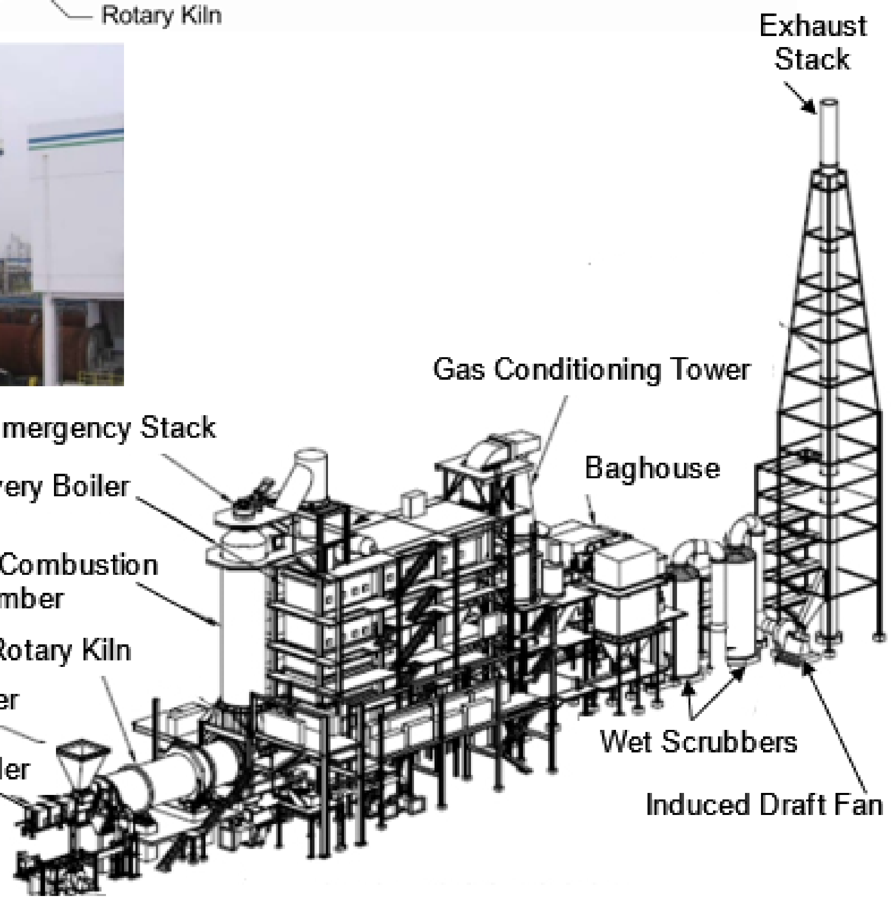


Figure 4.11. (Top) Line drawing of EPR 50 MW Gasification Thermal Island (Inset) Image of Metso dual kiln waste incineration plant near Shanghai, China. (Bottom) Line drawing of one unit of the Metso two kiln waste to energy power plant shown in the inset comprised of the same basic process units and the EPR thermal island shown at the top

Metso has indicated that they can manufacture the EPR design and that Metso can provide a performance guarantee for the rotary kiln, reformer, and LoNOx burner. After reviewing the EPR design. Metso has stated that their rotary kiln waste to energy plant in China (**Figure 4.11)** is essentially the same as the EPR design (but in a horizontal configuration to cut steel costs and without flue gas recycle, steam reforming and a LoNOx burner) and can be used to demonstrate EPR design function at a commercial scale.

4.6 Technology and Intellectual Property Status

EPR is in control of all rights to the technology used at Hamilton through in-house patenting and an exclusive licensing arrangeent with the inventors, all of whom are in-house to EPR. EPR holds exclusive worldwide rights to the technology described here, which is protected by five issued or pending patents with national case filings in Western Europe, the UK and Ireland. The EPR intellectual property suite related to this technology includes issued and pending patents, trade secrets, engineering, construction and operational experience. and proprietary knowhow based on more than 150 man-years of professional experience from research to operations. The patents will not inhibit the ability of the manufacturer and EPC firm to fully wrap the construction schedule and commissioned output. These patents will also serve as barrier to entry for competing technologies since the patents result in cleaner emissions and improve the efficiency of the plant (more MWh output per tonne of feedstock). Licenses to these patents will be granted to SWPH.

4.7 Comparison of Integrated Gasification and HTL vs Mass Burn Incineration

Table 4.4 shows the total capital cost and annual revenues for a mass burn incineration power plant generating 30 MW by consuming 1000 t/d of MSW and 20 t/d of sewage sludge. For comparison, the same data are shown for cleaner and more efficient LoNOx rotary kiln gasifier integrated with a hydrothermal liquefaction plant operating on the same amount of MSW and sewage sludge, with the plastics in the MSW being converted to liquid fuels by HTL.

Table 4.4 Comparison of Capex and Revenue for Incineration vs Gasification and HTL

MSW Conversion Technology	Total Capex	Annual Revenue
Mass Burn Incinerator (30 MW)	$322, 697,000	$38,360,000
Integrated Lo NOx Gasifier (35 MW) and HTL for Plastics	$287,900,000	$51,380,000

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