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PLASMA GASIFICATION: LESSONS LEARNED AT ECOVALLEY WTE FACILITY

Ken P. Willis
VP Project Development,
Alter NRG Corp.
Calgary, Alberta, Canada

Mr. Shinichi Osada
Former General Manager, Environmental
Services Division, Hitachi Metals
Tokyo, Japan

Kevin L. Willerton
VP Strategic Alliances & BD,
Alter NRG Corp.
Calgary, Alberta, Canada

ABSTRACT

In 2003 Eco-Valley became one of the first waste-to-energy facilities in the world to utilize Plasma Gasification technology on a commercial basis. Eco-Valley is located in Japan and has been successfully processing MSW with plasma for over seven years.

The facility processes up to 220 tonnes-per day of MSW or up to 165 tonnes per day of a 50/50 mixture of MSW and auto shredder residue. The technology used at Eco-Valley is a result of a successful collaboration between Westinghouse Plasma Corp. and Hitachi Metals.

With a first of kind facility like Eco-Valley, several operational challenges had to be overcome during and after commissioning. The objective of this paper is to share these operational experiences and learnings.

1. INTRODUCTION

The EcoValley plasma gasification facility is located in Utashinai, Japan on the island of Hokkaido. The plant was constructed in 2002 and has been fully operational since 2003.

The facility was originally designed to process a 50/50 mixture of ASR and MSW, with a design capacity of 165 tonnes per day (tpd).

The purpose of this paper is to explain:

- The operational challenges faced by the facility during its first seven years of operation,
- How those operational challenges were overcome,
- The impact of those operational challenges on the commercial operation of the facility and
- How the lessons learned at EcoValley have been incorporated into Alter NRG's next generation gasifier design.

2. NOMENCLATURE

ASR – auto shredder residue
MSW – municipal solid waste
Syngas – synthesis gas
CO – carbon monoxide
H_2 – hydrogen
CH_4 methane
$C0_2$ – carbon dioxide
N_2 – nitrogen
tpd – tons per day
Al_2O_3 – Aluminum Oxide
SiO_2 – silicon dioxide
MgO – magnesium oxide

3. DEVELOPMENT HISTORY OF ECOVALLEY AND THE UNDERLYING GASIFICATION TECHNOLOGY

The origins of the EcoValley facility can be traced back to a collaborative effort between Hitachi Metals and Westinghouse Electric Corporation in the early 1990s. The two companies jointly developed the plasma gasification technology to process municipal solid waste. The

Westinghouse plasma center, which has a 12 tpd test reactor, located at Westinghouse Electric Corporation's Madison, Pennsylvania facility was the center of activities.

The R&D efforts spanned 5 years and culminated in Hitachi Metals deciding to build a demonstration facility in Yoshi, Japan. The 24 tpd facility was completed in 1999 and operated for one year at which time it was awarded a process certification by the Japan Waste Research Foundation. Among other things the certificate[1] noted:

> It is judged that this technology is appropriate for waste management.
>
> (1) It is approved that this technology can safely operate coping with a wide variety of wastes by plasma power control.
>
> (2) It is recognized that this slag satisfied the Recycle and Soil Standard.
>
> (3) It is recognized that exhaust gas density at stack is below 0.1 ng-TEQ/Nm^3 (02, 12% conversion value)

Hitachi Metals went on to develop two energy-from-waste projects. EcoValley is one of those facilities. The other facility, which is located near the two cities of Mihama and Mikata, processes 17.2 tpd of municipal solid waste and 4.8 tpd of sewage sludge and became operational in December of 2002. The syngas produced at the facility is converted to heat to dry the sewage sludge prior to gasification.

FIGURE 1 - MIHAMA MIKATA MSW AND SEWAGE SLUDGE GASIFICATION FACILITY

4. ECOVALLEY FACILITY

The process flow Figure for EcoValley is shown in Figure 2. The plant produces electricity via steam (Rankine) cycle. The major steps in the process are:

(1) Waste Pit: MSW and ASR are deposited in the waste pit. An overhead crane grabs waste and drops it into a shredder to reduce the size of the feedstock to 2.5 inches. The shredded material is returned to the waste pit where it is mixed with ASR, which arrives in shredded form.

(2) Gasifier: Waste material is conveyed to the gasifier and enters at the top of the vessel. Organic material in the waste is converted into synthesis gas (ie. syngas) which consists primarily of CO, H_2, and CH_4 combustible gases as well as CO_2 and N_2 non-combustible gases. The syngas exits at the top of the gasifier. Inorganic materials are melted and exit the gasifier at the bottom of the gasifier as a molten slag, which forms vitreous granules as it is water quenched.

(3) The syngas travels to the afterburner, a refractory lined cylindrical vessel, in which it is immediately combusted.

(4) The hot gas leaves the afterburner and travels to the heat recovery steam boiler where it is cooled to produce steam.

(5) The steam is used to drive a steam turbine generator.

(6) The flue gas exits the heat recovery steam boiler and is cleaned in a bag house system before being vented to the atmosphere.

The EcoValley facility was designed to process 165 tpd of a 50/50 mixture of MSW and ASR. The facility has two trains for all major pieces of equipment except for the steam turbine.

The capacity of the facility is dictated by the amount of syngas that is produced and subsequently processed downstream of the gasifier. Generally speaking, a plasma gasification facility can process more tonnage of lower calorific value feedstocks than higher value feedstocks. The EcoValley facility can process up to 220 tpd if it is processing only MSW which has a lower calorific value than ASR.

[1] Japan Waste Research Foundation , Technology Development Support Certificate – *English Translation*

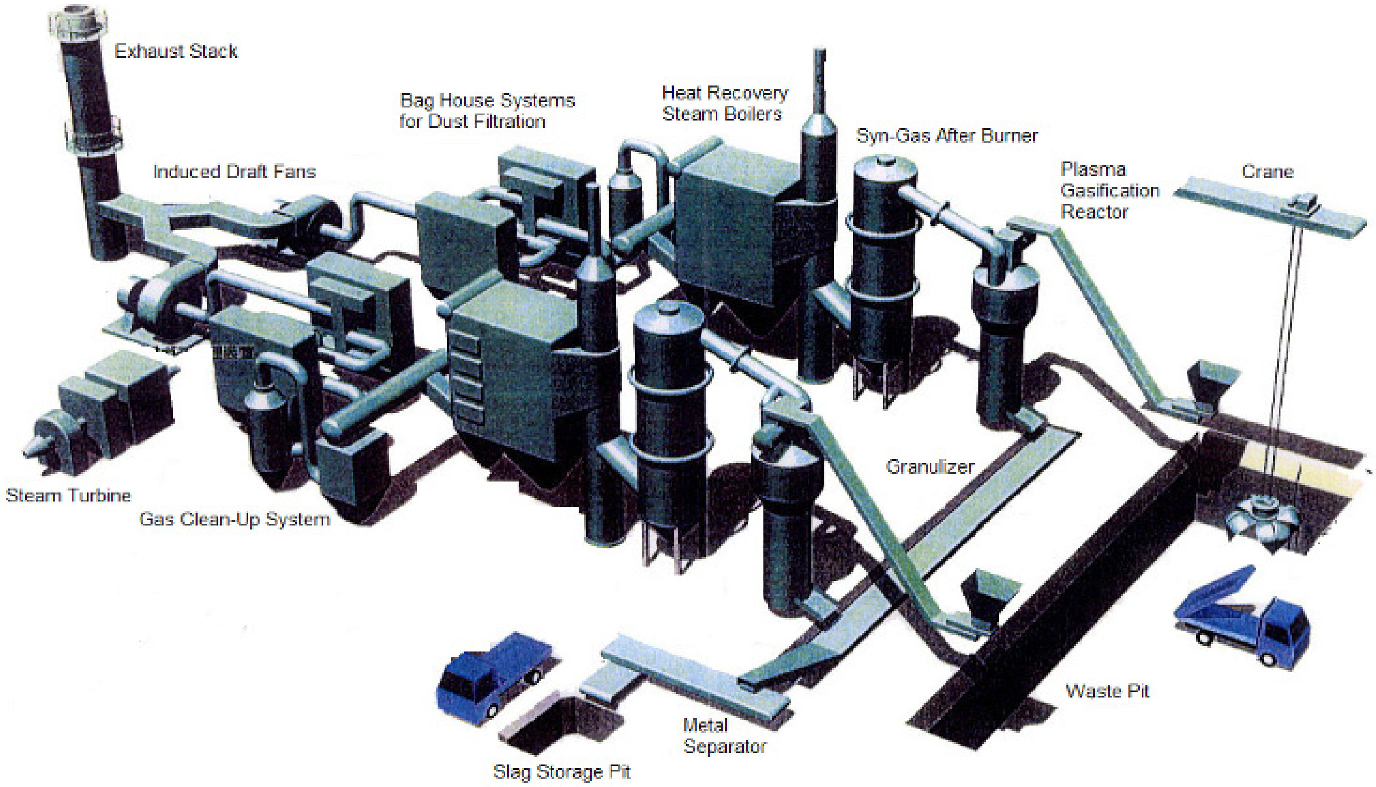


FIGURE 2 - PROCESS FLOW FIGURE FOR ECOVALLEY MSW AND ASR GASIFICATION FACILITY

The facility was designed primarily as a waste destruction facility and secondarily as an electricity production facility. EcoValley was not optimized for electricity production and employs a used steam turbine generator. When operating at capacity, the facility exports 1.5 MW of electricity to the grid.

The EcoValley facility consistently meets the strict emissions requirements set out by the Japanese government. In fact, Hitachi Metals voluntarily agreed, before starting construction on the facility, to meet a dioxins emission limit 10 times lower than is legislated in Japan. EcoValley has consistently met those stricter voluntary limits. The EcoValley facility continues to enjoy a very positive relationship with the local community.

The EcoValley facility is jointly owned by Hitachi Metals, Hitachi Limited, Hokkaido Prefecture, and the City of Utashinai. The commercial operation date was April 2003.

FIGURE 3 - ECOVALLEY MSW AND ASR GASIFICATION FACILITY

4.1 Operational Performance of EcoValley

The EcoValley facility was the first plasma gasification facility created to process MSW and/or ASR. Since it was a first of a kind facility, both Hitachi Metals and Westinghouse Plasma Corporation expected to experience commissioning issues. Three specific issues caused the most downtime and expense to rectify.

(1) The internal diameter of the bottom of the gasifier was initially too large. Cold spots formed which rendered the gasifier inoperable

(2) The refractory that was initially specified for the gasifier did not achieve an acceptable lifespan.

(3) Fine particulate that is entrained in the syngas that exits the gasifier attacked the refractory in the afterburner and accumulated on the walls of the afterburner.

Each of the three commissioning issues is discussed in detail later in the paper. In order to better articulate the issues, the operation of the plasma gasifier at the EcoValley plant is explained in the next section.

4.2 EcoValley Plasma Gasifier

A schematic of the gasifier at the EcoValley facility is shown in Figure 4.

In general terms, the feedstock enters through the feed port at the top of the reactor. The carbonaceous material in the feedstock is gasified and exits the top of the gasifier as syngas. The inorganic portion of the feedstock material (metals and ash) progresses downward through the reactor, melts and exits as a molten slag through the taphole at the bottom of the reactor. This slag is vitrified and granulated as it is quench cooled in water.

The feed material is mixed with metallurgical coke (coke), and flux before it enters the gasifier. Coke is metered in with the feedstock at a ratio of approximately 1:20 on a mass basis. The coke, which is consumed in the reactor but at a much lower rate than the waste material due to its low reactivity, forms a bed onto which the waste falls and is quickly gasified. The coke bed also provides voids for the molten flux, slag and metals to flow downward and for gas to flow upward. The coke also reacts with the incoming oxygen to provide heat for the gasification of the feed material. The purpose of the flux is to control the melting temperature and molten flow properties (rheology) of the inert material of the feedstock. Flux ensures a reasonably low melting point, reducing both coke utilization and plasma torch power requirement. EcoValley uses waste scallop shells from a local seafood processing facility for its flux material

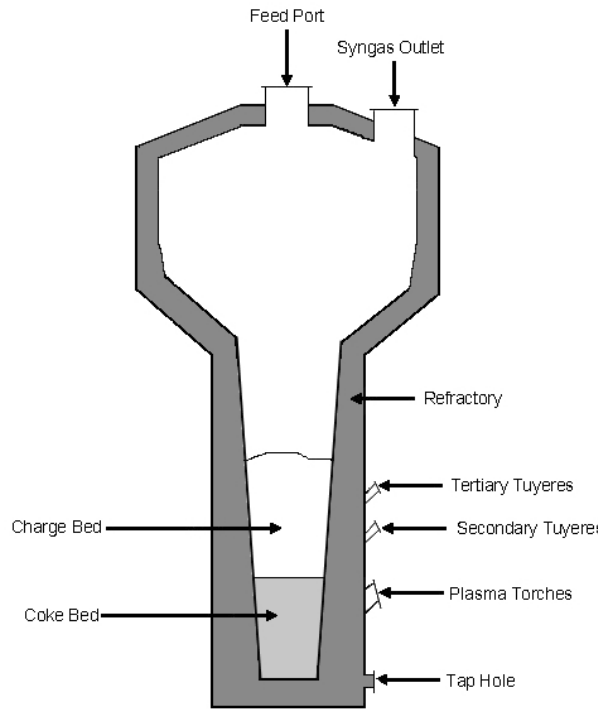


FIGURE 4 - SCHEMATIC OF ECOVALLEY PLASMA GASIFICATION REACTOR

The syngas exiting the gasifier is typically composed of carbon monoxide, carbon dioxide, hydrogen, light hydrocarbons, nitrogen, trace chemicals, trace metals and particulate matter.

4.2.a Oxidation/Gasification Zone

There are three levels of tuyeres (air nozzles) in the gasifier, each corresponding to an oxidation/gasification zone in the reactor. Plasma heated air enters the reactor through the primary (lowest) tuyere level. The hot gas contacts the coke and reacts with the carbon content of the coke to form carbon monoxide and carbon dioxide. This reaction is exothermic and adds additional heat to the coke bed.

The secondary and tertiary tuyeres are focused on the charge bed. Carbon within the feedstock reacts with oxygen to produce carbon monoxide and carbon dioxide, while hydrogen within the feedstock reacts with oxygen to produce water vapour. The water vapour that is produced in this region, as well as any of the feedstock's inherent moisture that has not dried off, is free to react with the carbon monoxide to produce hydrogen via the water-gas-shift reaction.

Adjusting the syngas temperature is done primarily by adjusting oxidant flows to the secondary and tertiary tuyeres. Maintaining a high syngas temperature ensures that aromatic hydrocarbons / tars are destroyed.

4.2.b Preheat/ Drying Zone

The preheat zone constitutes the top portion of the charge bed. Hot gases that are a product of gasification deeper down in the charge bed ascend and heat the colder charge material that rests on top of the charge bed. As this material is heated, moisture is dried off and exits the reactor with the syngas. Volatile components of the feedstock are released once a sufficient de-volatilisation temperature is reached. Due to the high syngas temperature and freeboard residence time, the volatiles are further cracked and converted into carbon monoxide, carbon dioxide, and hydrogen. Calcium carbonate, the flux material, is converted to lime and carbon dioxide in this zone via calcination (an endothermic reaction).

4.2.c Melting Zone

The melting zone is an area at the top section of the coke bed at which the temperature is sufficient to melt the inorganic components of the feedstock. As the inorganic material melts, liquid slag and metals are produced. These two liquids flow through the coke bed and are heated as they descend to the well zone.

4.2.d Reduction Zone

As the slag and metals descend through the coke bed, they flow through a reduction zone. In this zone, carbon dioxide present within the coke bed reacts with carbon to form carbon monoxide (via the endothermic Boudouard reaction). Due to the high concentration of carbon monoxide formed, some metal oxides are reduced into metals. Plasma torch power is adjusted to address changes in ash concentration and composition ensuring the metals and slag continue to flow properly through the zone and through the taphole. Plasma torch power is also used to ensure that this zone is well above the melting temperature of the ash and metals.

4.2.e Well Zone

The well zone at the base of the reactor is the location where all of the molten slag and metals collect prior to discharge through a taphole. The metals will concentrate on the bottom of the well while the slag will float on top due to the density difference between the metals and the slag. The molten material exits the reactor through a taphole, either intermittently or continuously depending on the amount of inorganic matter in the charge. When operating on ASR, continuous tapping is employed due to high ash content (30-50% as received basis). When operating on MSW, intermittent tapping is employed because the ash content is much lower (6-8% as received basis).

4.2.f Refractory

The entire gasifier is lined with refractory. Different refractory materials are used in the different sections of the reactor and the refractory thickness is higher at the bottom and lower at the top. The bottom section of the gasifier endures the highest exposure to heat and slag erosion / corrosion, while the top gasification and freeboard sections of the reactor are exposed to some corrosive gases.

4.2.g Plasma Torch System

The gasifier is fitted with four plasma torches located around the perimeter near the bottom of the reactor. The torches, which provide super heated air to the gasifier, allow the operator to control the gasification process within the gasifier independently of chemical reaction kinetics.

The Westinghouse Plasma Corporation plasma torches used at EcoValley are high temperature heating devices used to impart heat to the process and are capable of superheating the process gas (air) to temperatures in excess of 5,500 ºC. The plasma torch system is capable of increasing the specific energy of the process gas to between two and ten times higher than conventional combustion equipment. It has the capability of greatly increasing the temperature of the gas coupled with the ability to maintain control over process variables, gas operating temperature, and amount of energy supplied to the system.

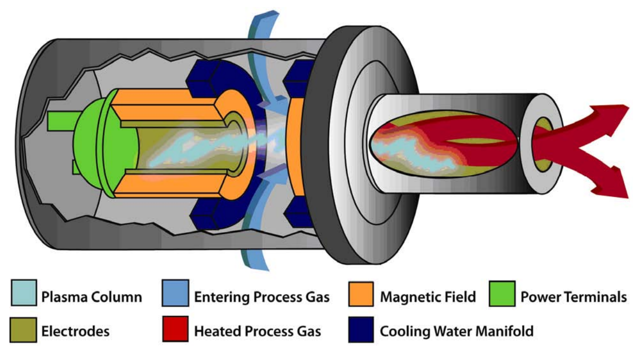


FIGURE 5 - WESTINGHOUSE PLASMA CORP PLASMA TORCH

5. OPERATIONAL ISSUES

5.1 Operational Issue #1 – Internal Diameter of Bottom of Reactor

While commissioning the reactor at EcoValley, Hitachi Metals discovered that the internal diameter in the coke bed portion of the reactor, which was determined through a direct scale up of the reactor at the Yoshi demonstration plant, was too large. Determining the correct dimensions of reactors during scale up can be difficult because gas flows and heat flows are difficult to predict.

The excessively large diameter caused inadequate blast air penetration and dispersion and plasma plume penetration. The four plasma torches could not adequately heat up the entire coke bed so cold spots formed in the coke bed. Slag solidified in the cold spots and both coke and feedstock were observed to stick in these areas.

EcoValley was forced to reduce the internal diameter of the bottom portion of the reactor. The thickness of the refractory was increased to decrease the internal diameter. However, this potential solution did not work because the extra refractory provided too much insulation and it is thought that the melting point of the refractory was exceeded which caused rapid refractory erosion.

This problem was solved by decreasing the diameter of the outer steel shell.

The internal diameter issue was resolved within eighteen months of start-up.

5.2 Operation Issue #2 – Type of Refractory

The refractory initially installed in the melting zone of the reactor had an unacceptably short lifespan. EcoValley experienced excessive corrosion soon after start-up of the reactor. In the first few years of operation, Hitachi Metals experimented with various combinations of refractory and eventually found one the worked well.

The initial refractory in the melting zone of the reactor was composed of two layers. The internal layer (closest to the coke bed) was a high Alumina refractory consisting mostly of Al_2O_3. The outer layer was Silicon Carbide. The combination that Hitachi finally settled on was exactly the opposite: Silicon Carbide for the internal layer and high Alumina for the outer layer.

When Hitachi Metals switched to the Silicon Carbide they found that a thin layer of slag would freeze to the Silicon Carbide, effectively forming a protective layer. The reason the layer of slag forms is because Silicon Carbide is highly thermally conductive and using it as the inside layer caused a lower face temperature of the refractory.

It is thought that Silicon Carbide’s high thermal conductivity made this material highly effective as the hotface layer. Its ability to draw heat away from the coke bed allows the hotface to remain at a lower temperature than that of alumina (as used previously), and if steady state operation is attained with a hotface temperature that is below that of the slag solidus temperature, a protective layer of slag can be formed and continuously regenerated on the surface of the hotface.

Those portions of the reactor that are not part of the melting zone have three layers of refractory. The inner layer is a high alumina refractory composed of approximately 90% Al_2O_3, 7-8% SiO_2, and 1% MgO. The second layer is a porous refractory. The third layer is Silica board.

The refractory in the melting zone has been in place for almost four years now and EcoValley does not expect to replace it for at least one more year. The refractory in the other portions of the reactor has not been changed out since the reactor was commissioned and Hitachi expects to achieve at least a ten year life span.

5.3 Operational Issue #3 – Particulate Carry-Over

Excessive particulate carry-over and the resultant issues was the most difficult to solve of the three major commissioning issues. The following factors all contributed:

(1) There is a very short distance between the feedport entrance into the gasifier and the syngas exit

(2) The ASR arrives at EcoValley in a finely shredded state. There is a high percentage of fine dust particles in the ASR.

(3) The ASR has a high percentage of plastics and therefore contains many corrosive components,

(4) The high design temperature (1200 ºC) for the syngas exiting the gasifier.

The combination of the short distance between the feedport and the syngas exit duct plus the high dust content in the ASR led to significant amounts of particulate carryover into the afterburner. Hitachi tested a feedpipe concept using stainless steel. The feedpipe extended into the reactor from the feedport shown in Figure 6 and increased the distance between where the feedstock entered the reactor and the syngas exit thus increasing residence times. The test was successful and ash carry-over was reduced by approximately 50%. As expected, the stainless steel “test” feedpipe had a very short life due to the high temperatures within the reactor.

The original design temperature for the syngas exiting the reactor was 1200 ºC. At that temperature the particulate in the syngas was carried over into the afterburner in a molten state which aggressively attacked the refractory in the afterburner, in part due to the ash chemistry of the ASR, causing frequent shutdowns.

Hitachi lowered the syngas exit temperature to 1000 ºC, a temperature where the particulate in the syngas was neither molten nor ash. It was, however, quite “sticky” and accumulated inside the duct between the reactor and the afterburner. These slag deposits caused shutdowns and were very difficult to remove. In some cases, the slag deposits within the afterburner would build up and then fall off, dropping to the bottom of the afterburner causing further refractory damage.

Hitachi then further reduced the syngas exit temperature to 750 ºC, a point at which the particulate that is carried over in the syngas is in the form of ash. This last change has virtually eliminated the slag build up and refractory issues downstream of the gasifier.

Lowering the syngas exit temperature has come at the expense of efficiency for the facility. The lower temperature results in a lower temperature in the afterburner and the heat recovery steam boiler which was designed to operate at 1200 ºC now operates at 900 ºC.

5.4 Commercial Implications of Operational Issues

The first two issues caused major downtime during the first two years of operation. The plant was not able to operate at capacity. The particulate carry-over issue persisted for more than five years, impacting the availability in all those years. As a result, EcoValley was not able to process the ASR it has contracted to process and several of the companies that were contracted to deliver ASR found disposal alternatives.

EcoValley now finds itself in the situation where it has resolved its operational issues but cannot source enough feedstock from the local area to run the plant at capacity. EcoValley, which is located in a rural area of the island of Hokkaido, has tried to source additional MSW from the local area but most of the resource is already under long term contract. As a result, the plant runs at about half capacity and is losing money. Hitachi has decided to cease operations at EcoValley in 2013.

The Mihama Mikata facility has not experienced the same issues as EcoValley and continues to run at capacity. There are no plans to cease or modify operations at Mihama Mikata.

6. NEXT GENERATION PLASMA GASIFIER DESIGN

Alter NRG purchased Westinghouse Plasma Corporation in 2007 along with all its plasma and gasification intellectual property. The next generation gasifiers incorporate many improvements including the learnings from EcoValley's operational experience. Alter NRG and Hitachi signed an agreement in 2007 in which Hitachi agreed to provide Alter NRG access to the staff and the operational records of the facility.

Alter NRG produces two standard size reactors. The W15 has a slightly larger processing capacity than the gasifiers employed at EcoValley. The G65 can process about seven times the amount of feedstock as each gasifier at EcoValley.

The new gasifier design is shown in Figure 6.

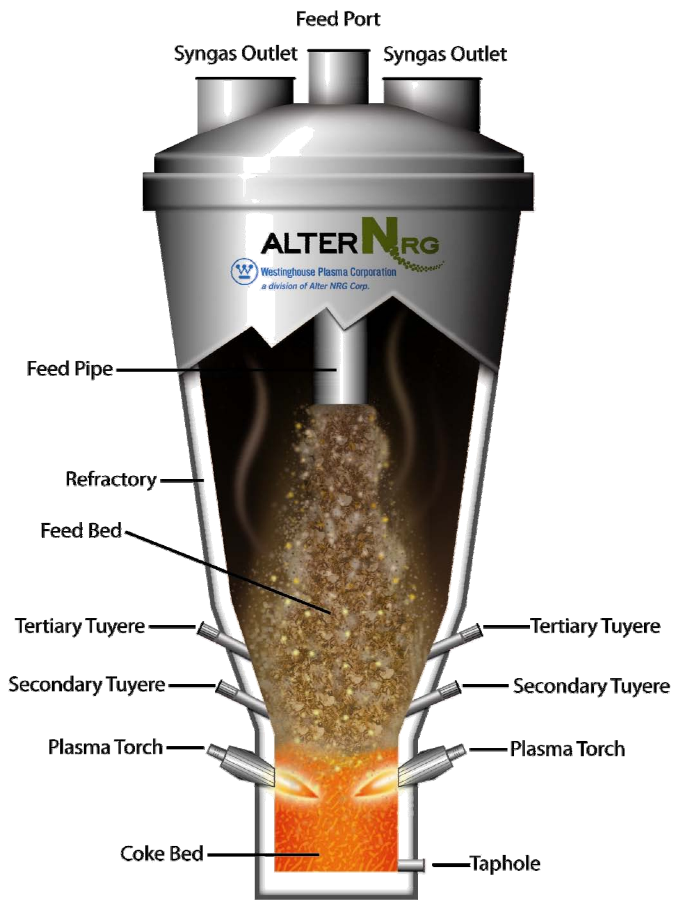


FIGURE 6 - ALTER NRG GASIFICATION REACTOR

The size of the bottom directly reflects Hitachi's experience. The refractory Alter NRG specifies for its gasifiers is very similar to the refractory now used at EcoValley. The standard design also features a partial water quench at the syngas exit so that any particulate carry-over does not move downstream in a molten or sticky form.

The new design includes a water cooled feed pipe that ensures the feedstock enters the gasifier a significant distance away from the syngas exit ducts. This new feature will reduce the amount of carryover.

The shape of the freeboard section of the gasifier has been modified to reduce the gas velocities and increase the residence time in the gasifier, further reducing particulate carryover.

6.1 Energy Balance

A sample heat & material energy balance diagram is included in Annex A, providing typical operating conditions, material inputs and energy and syngas outputs of a G65 size gasifier operating on MSW.

ANNEX A

SAMPLE HEAT & MATERIAL BALANCE

Heat and Material Balance

MSW and Tires

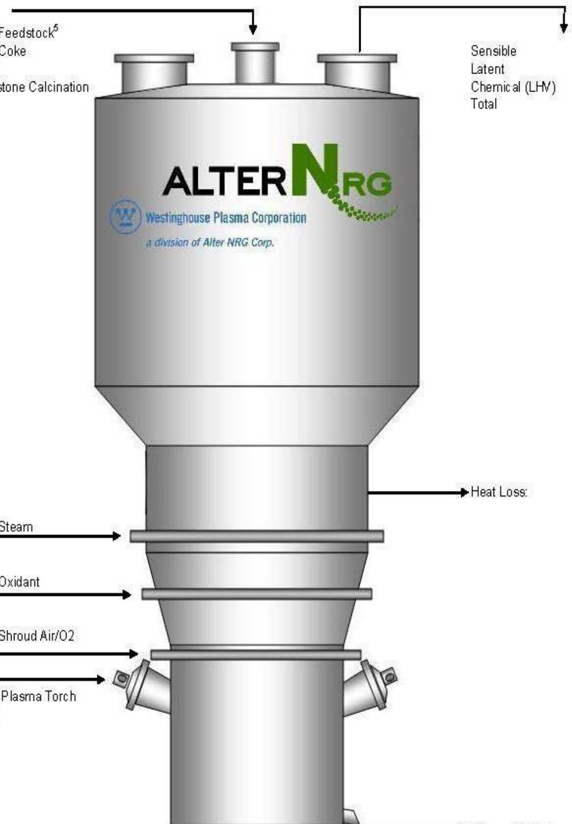
Oxygen-blown Case

Westinghouse Plasma Corporation
a division of Alter NRG Corp.

ALTER NRG

Inputs

FEED in	kg/h	kcal/kg	
*1007MSW USA	29,583	3,294	
*6002Tires with Steel Belts	1,667	7,928	
		-	
		-	
		-	
		-	
Total (kg/h // kcal/kg)	31,250	3,335	LHV
		3,542	HHV
Total (lbs/h // Btu/lb)	68,894	6,003	LHV
		6,375	HHV
OTHER in			
Coke	1,250 kg/hr		
Coke LHV	7,017 kcal/kg		
	12,629 Btu/lb		
Flux	2,309 kg/hr		
Flux Material	Limestone		
STEAM in			
LP Steam	0 kg/hr		
Pressure	308 kPa		
Temperature	450 °C		
Shroud Steam	0 kg/hr		
OXIDANT in			
Oxidant	9,008 kg/h		
Oxygen Purity	95% mass basis		
Pressure	136 kPa		
Temperature	25 °C		
Shroud Air	1,161 kg/hr		
Shroud Oxygen	1,161 kg/hr		
Oxygen Purity	95% mass basis		
Pressure	136 kPa		
Temperature	25 °C		
Plasma Torch Air	1,184 kg/hr		
Pressure	1,136 kPa		
Temp	25 °C		
PLASMA Torch Energy			
Electric Energy Use	3,217 kW_e		
Thermal Energy Transferred	2,735 kW_t		
Simulation Indicators			
Cold Gas Efficiency:	79%		
Coke Usage	4.0% of feed		
Torch Power	2.4% of input energy		



Outputs

Raw Gas		
Volumetric Flow	41,534 Nm^3/hr	
Mass Flow	37,629 Kg/hr	
Temperature	900 °C	
Pressure	101 kPa	
Composition	Wt.%	Vol.%
CO	55.454%	40.460%
CO2	9.999%	4.643%
O2	0.000%	0.000%
N2	5.736%	4.185%
Ar	0.756%	0.387%
H2	2.231%	22.616%
CH4	0.924%	1.177%
C2H6	0.693%	0.471%
C2H4	0.323%	0.235%
C3H8	0.508%	0.235%
C4H10	0.669%	0.235%
HCl	0.498%	0.279%
H2S	0.179%	0.108%
COS	0.035%	0.012%
SO2	0.000%	0.000%
NH3	0.145%	0.174%
HCN	0.009%	0.007%
H2O	21.840%	24.775%
Total	100.000%	100.000%
H2/CO	0.56	
UNREACTED CARBON	Solids, kg/h	Raw Gas, mol%
	142.6	0.64%
Carbon Chemical Energy	1.3 MW	
ENERGY DENSITY	HHV	LHV
kcal/kg *	3,219	3,023
kcal/Nm³ *	3,030	2,846
Btu/scf *	322	303
Syngas Chemical Energy (MW)	109.3	102.7
* dry basis		
SLAG & METAL OUT		
Slag & Metal Combined	9,550 kg/h	
Pressure	101 kPa	
Temp	1,650 °C	
Overall Energy Balance on LHV Basis [MW]		
	In	Out
Feedstock	130.15	
Torch	3.22	
Oxidant Streams	0.00	
Steam	0.00	0.00 *
Feedstock Moisture/Steam		4.22 *
Chemical		103.96
Sensible		15.54
Heat Loss		4.52
Slag		5.17
Metals		0.00
Solubility Adjustment	0.04	
Total	133.41	133.41

* Heat of Vaporization Adjustment for LHV balance

Notes:
1. All values are illustrative in nature and are provided for discussion purpose only.
2. Heat balance is provided on lower heating value (LHV) basis.
3. Unreacted carbon excludes feedstock carry-over.
4. Energy balance computed by VMG on a heat of formation basis. LHV balance provided for display purposes only.