INDEPENDENT WASTE TECHNOLOGY REPORT

Subject: THE ALTER NRG / WESTINGHOUSE PLASMA GASIFICATION PROCESS

Process Type: PLASMA ASSISTED GASIFICATION

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The Alter NRG / Westinghouse Plasma Gasification Technology

CATEGORY OF PROCESS	Plasma Gasification to produce power and other added value products.
FEEDSTOCK COMPATIBILITY	MSW (municipal solid waste), MSW + tyres, coal + wood, petcoke, hazardous wastes
PROCESS CONCEPT	The process concept combines the Westinghouse updraft gasification reactor (that uses plasma torches to provide part of the energy input) with syngas cleaning in a variety of configurations to offer syngas to energy and syngas to added value products, such as ethanol.

Juniper ratings

Supplier Rating	MSW, coal + wood, petcoke and haz wastes to energy	***	Canadian company with its own plasma gasification technology acquired from Westinghouse Plasma, considered to be a world leader in plasma torch systems. The combined team has significant experience in both gasification and plasma technologies.
	MSW to liquids	**	
Provenness	MSW, RDF and ASR to electricity	(●)	2 reference plants in Japan built by Hitachi Metals. WPC supplied plasma torches and basic design. Alter NRG has full access to data from these facilities.
	Coal + wood to syngas for use in coal-fired boilers	(◖)	Gasification island and syngas cleaning will be supplied. Clean syngas used in coal-fired utility boiler.
	MSW to ethanol	?	Formed strategic alliance with Coskata. Will produce syngas at Waltz Mill pilot plant for use in novel bioreactor. Financial support from GM.
	Haz waste processing	◖	2 small commercial plants currently under construction in India.
	Petcoke to power	(◖)	Plasma gasification of petcoke demonstrated at pilot scale. Project announced in Alberta, Canada to produce electrical power.

LEGEND:
Supplier ratings are from ***** (= world class leader) to * (= new entrant with no track record as yet). Provenness: ✓ = fully proven; ● = proven in commercial operation; ◖ = demonstrated at a pilot or company owned facility, typically in a time-limited trial; ? = a process concept for which there is very limited performance data available as yet. An ↑ indicates that we are hopeful of increasing the rating in the near future, and a (bracket) is used to signify that a rating has been qualified for a particular reason.

SCALE	Largest commercial reference plant:	Utashinai: 180 tpd (55,000 tpa)
	Smallest commercial reference plant:	Mihama-Mikata: 22 tpd (7,000 tpa)
	Scale at which process is offered:	MSW + tyres: 100, 300 and 750 tpd (30,000, 90,000 and 220,000 tpa) and multiples thereof.

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DATE PREPARED

November 2008

The report is based on analysis conducted during 2008. Juniper also visited the Utashinai and Mihama-Mikata plasma gasification plants in Japan and the Waltz Mill pilot facility in the USA during May 2008.

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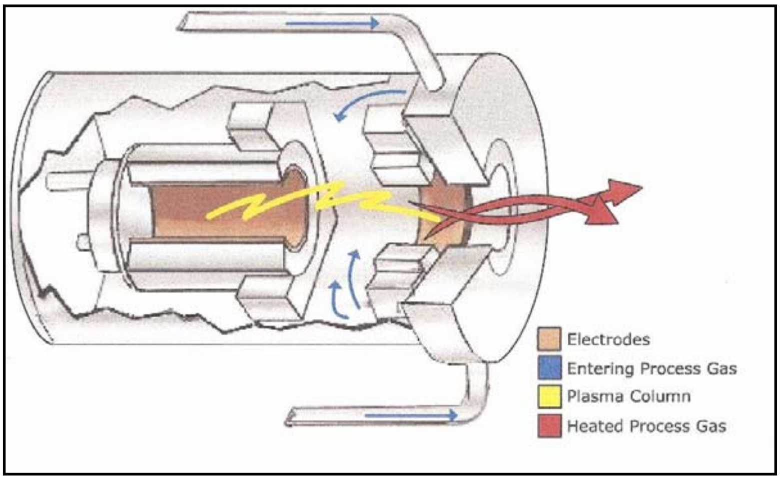
OVERVIEW

Alter NRG, incorporated in March 2006, is a relative newcomer to plasma gasification and the waste management sector. They emerged onto the international scene in 2007 with their acquisition of Westinghouse Plasma Corporation (WPC). At that time WPC was regarded by many as a leader in MSW plasma gasification. Buying WPC immediately positioned Alter NRG as one of several key contenders in the potentially large embryonic market for plasma processing of household waste.

Plasma[1] is generated when gaseous molecules are forced into high energy collisions with charged electrons resulting in the generation of charged particles. This occurs when a gas (many types can be used and are sometimes referred to as 'carrier gases') is exposed to high energy fields such as an electrical discharge[2] that can occur between two electrodes. When the quantity of charged particles (both negative and positive) is sufficiently high, the gas conducts electricity. Collisions between charged particles also occur giving off heat and an arc of light (similar to lightning) called Plasma. The ionised carrier gas is projected at high velocity beyond the end of the electrodes as a result of the high density electric fields, giving rise to the term 'plasma jet' or 'plasma plume'.

Figure 1: Illustration of the operation of a plasma torch



Source: Alter NRG

In the WPC design energy from the plasma arc is transferred to the plasma gas which is controlled by a magnetic field. The superheated plasma plume is directed at a bed of metallurgical coke (met coke) in the base of the gasification reactor (cupola). There are different types of plasma gasification process, including processes using electrodes to create the plasma as well as processes where plasma torches are used in a different configuration. These are discussed in a review of plasma based waste treatment processes that has been published by Juniper[3].

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[1] *Depending on the energy source and the conditions under which the plasma is generated, the arc discharge itself can be between 5,000°C and 7,000°C (9,000°F to 12,600°F) and such a configuration is known as Thermal Plasma. Also, the presence of the charged gaseous species makes the plasma gas highly reactive and is the reason why plasmas are referred to as the 4th state of matter: the charge that particles carry makes their behaviour significantly different from other gases, solids or liquids. Thermal plasmas are further subdivided into two categories – 'transferred' and 'non-transferred' types. These refer to the way in which the electric discharge is produced. In 'non-transferred' plasma, both electrodes (cathode and anode) used to produce the high energy electric discharge are part of the plasma torch assembly. The torch therefore has the sole function of producing hot plasma gases. In 'transferred' plasma systems, the electricity discharge occurs between the plasma torch (the cathode) and the conductive lining of the reactor wall (the anode) or in some cases a metal bath and the reaction vessel is itself part of plasma generation. The WPC plasma torch is a non-transferred thermal plasma technology.*

[2] *The electrical discharge for plasma generation can be provided by DC (direct current) or AC (alternating current) sources.*

[3] *"Plasma, its role in waste processing – a decision makers guide", September 2006, available from www.WasteReports.com*

Figure 2: A Westinghouse plasma torch being test fired in air

Source: Alter NRG

Since the acquisition of WPC, Alter NRG has announced projects and alliances which together allow them to target a broad range of market opportunities:

- a full-scale commercial project for co-firing of biomass/coal-derived syngas in coal fired power plants;
- a large petcoke to power project linked to the exploitation of oil sands in Canada;
- an integrated higher energy efficiency combination of plasma gasification and IGCC[1] for a variety of waste projects with more than one partner;
- production of ethanol from waste via a combination of plasma gasification and microbial syngas fermentation;
- two hazardous waste processing facilities in India (Pune and Nagpur).

Thus, in two years they have emerged from being a relatively unknown start-up company in Canada to a company that has attracted considerable interest from the investment community. However, at the time of writing, they have not themselves delivered a waste-to-energy project.

Against this background this review provides information and analysis to allow the reader to form a view on four broad topics:

- how strong is their core technology?
- how good is its performance in technical, environmental and economic terms relative to alternatives?

[1] *Integrated Gasification Combined Cycle – process in which the syngas is converted to electricity via a gas turbine and the hot exhaust gases from the gas turbine pass to a Heat Recovery Steam Generator (HRSG) and the steam is used in a steam turbine to produce additional electricity.*

- how proven or risky is it?
- how well positioned is the company to capitalise on growth in demand?

We report our overall conclusions in the final section of this review after having first described the various configurations that Alter NRG are developing; reporting on performance data and describing the current status of their commercial initiatives; but we start by providing the historical context.

HISTORICAL CONTEXT

Alter NRG's origins date back to 2001 when the current Chairman began exploring the potential for opportunities to use gasification to convert coal and/or organic materials (biomass and waste) into power or added value products. It was formed as a private income trust in 2006 and the company's research identified WPC as a leader in the design and supply of plasma torches and plasma cupola reactors. In June 2006 they licensed the Westinghouse Plasma Corporation (WPC) technology for the Canadian market for a period of five years. In April 2007 the company completed a $35 million IPO (its shares are listed on the TSX Venture Exchange under the symbol "NRG"). In the same month the acquisition of WPC was completed at a cost of US$29 million, giving Alter NRG ownership of the core technology around which the company intends to build corporate and market strategies.

Alter NRG has its headquarters in Calgary, Canada and has built a relatively strong, though small, technical, engineering and corporate management team. Interestingly, the company also owns a large asset base of coal reserves (468 million tonnes) and is therefore extremely interested in using gasification technology for coal applications.

WPC was a management buy-out of from the former plasma development activities of Westinghouse Electric Corporation (WEC). It has more than 30 years of plasma experience and we understand that the Intellectual Property (IP) of the WPC torch and cupola technologies is protected by 22 patents currently in force and there are a further 100 expired patents that define the 'prior art' which should protect the technologies from new entrants. Plasma technology was initially developed by WEC to provide an electrically-generated energy source in the form of high temperature gas plasma. Numerous applications were pursued including material processing and resource recovery from waste streams. The Westinghouse Science & Technology Centre in Pittsburgh, Pennsylvania has developed and commercialised other material processing applications in the iron and steel industry. This broad base of development activity has allowed the WPC team to gain a strong understanding in the core technologies capabilities and limitations. According to WPC their plasma torches have achieved more than 500,000 hours of operation in various industrial applications since 1989.

WPC's plasma cupola technology was developed by WEC, under Electric Power Research Institute (EPRI) sponsorship, during the period 1983-1990. It was demonstrated to be a viable technology for producing hot metal from fragmented scrap and low cost charge material. After this programme, WEC embarked on another multi-million dollar test programme (1988 – 1990) to extend the plasma cupola technology to the treatment of hazardous waste materials. Various waste feeds were evaluated including: contaminated landfill material; PCB-contaminated electrical hardware; transformers and capacitors; and steel industry wastes. Shredded computer hardware has also been processed to recover valuable metallic by-products. These tests demonstrated the ability of plasma cupolas to vitrify a wide range of materials with varying degrees of moisture and inorganic content.

Juniper considers WPC to be one of the world leaders in the design and supply of plasma torch technology. In 1990 the construction of the Waltz Mill pilot facility in Madison, Pennsylvania (see Figure 4) led to further research with various waste streams.

Waltz Mill Pilot Plant

WPC's Plasma Centre, including the Waltz Mill plasma gasification pilot plant, provides complete testing, development and evaluations using high temperature plasma heating. Gasification pilot tests can be conducted at Waltz Mill as a means to determine:

- Product gas composition;
- Energy content;
- Emissions;
- Optimal design parameters.

Using the data from more than 100 pilot tests in WPC's pilot plant, Alter NRG and WPC have developed a plasma gasification simulation computer program which is used as the template for the design and performance modelling of the gasification systems.

Figure 3: The Waltz Mill plasma gasification pilot plant

Source: Alter NRG

We understand that in 2007 Alter NRG upgraded the pilot facility at Waltz Mill and the modifications included:

- an automatic lock hopper type feed system;
- sealing of the reactor to prevent the ingress of oxygen;

- a new spectrometer gas analyser with capability to monitor more than 200 compounds;
- a new steam generator;
- an upgraded computer control system;
- new software to control the plasma torches and feed system.

Alter NRG informed Juniper that the project was completed in February 2008 at a cost of approximately US$1.5 million and since then a number of pilot tests have been conducted to improve predictions for particulate carryover, fines recycle, oxygen enriched operation, torch power control, and feed modifications. Alter NRG has stated these upgrades to the pilot plant and the testing programme have led to improvements to the reactor design.

In our opinion, the Waltz Mill pilot plant is an impressive facility and, because it can be used to test the performance of the plasma gasifier with waste streams from a potential client it conveys a significant commercial advantage relative to some of their direct competitors

Figure 4: The Waltz Mill plasma gasification test facility

Source: Alter NRG

Development of the Commercial Plants in Japan

In 1997, Hitachi Metals and Hitachi Ltd started the development of a plasma assisted gasification waste treatment process and discussed the licensing of a technical design from WPC. Hitachi Ltd had previously supplied stoker type incineration technology and also licensed a pyrolysis process from Thide of France; installing three relatively small plants using that technology, two processing industrial waste and the third Municipal Solid Waste (MSW).

They first built and operated a small pilot plasma gasification plant and then constructed a one tonne per hour demonstration plant at Yoshii; which, as required by the Japanese government, operated for one year and continuously for 30 days and produced the necessary data to secure the Technical Development Support Certificate from the government in 2000. Hitachi could then market the technology commercially.

Subsequently, two projects were developed: Utashinai and Mihama-Mikata. We had been given to understand that the Mihama-Mikata facility was constructed first and then Utashinai. However, discussions with Hitachi Metals indicates that the two projects were probably run in parallel with the construction of Utashinai commencing in July 2000, commissioning in July 2002 and commercial operation beginning in April 2003. The company stated that Mihama-Mikata began commercial operation in March 2003 (see Operating Plants, page 30).

It was already known by Juniper, and confirmed during the visit to Utashinai, that Hitachi Metals has decided to withdraw from the Environmental business, as it is not seen by the senior management as being part of their core business activities. Consequently, Hitachi Metals no longer offers the technology although they will continue to operate the Utashinai plant and their relationship with Alter NRG appears to be unchanged.

THE PROCESS CONCEPT BEING PROMOTED BY ALTER NRG

The process concepts being developed by Alter NRG are based around a gasification island incorporating the Westinghouse (WPC) Plasma Cupola Furnace and plasma torches. This core technology is well proven in several industrial applications, including:

- General Motors: foundry application for engine block manufacture;
- ALCAN, Canada: aluminium dross recovery furnace;
- IHI, Japan: incinerator ash vitrification.

Having originally developed the plasma cupola furnace for industrial melting applications, WPC went on to use the Waltz Mill pilot facility to conduct research on the plasma gasification of wastes:

- Hitachi Metals, Japan: three plasma gasification plants processing MSW and ASR[1].

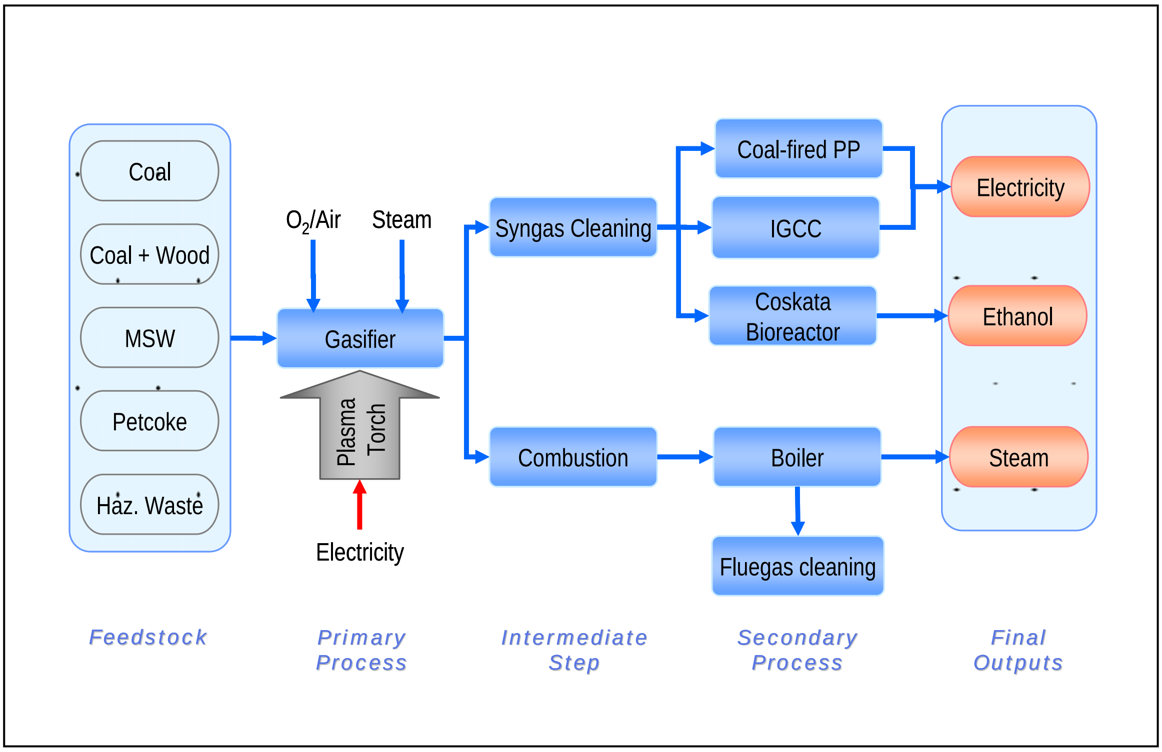
It is this latter development that is directly relevant to the applications considered here, but clearly the others do underpin core elements of the design, engineering and process control.

The process concepts currently being offered by Alter NRG include:

- Gasification of MSW (with co-feed of 5% scrap tyres) to electrical power (ultimately via IGCC);
- Gasification to 'over-the-fence' steam;
- Co-gasification of coal with wood (biomass) to produce a synthesis gas (syngas) that is used as a co-fuel in a coal-fired utility boiler;
- Gasification of petcoke to power;
- Gasification to syngas as a substitute for natural gas;
- Gasification of MSW to ethanol;
- Sale of the core elements of the gasifier to third parties.

[1] *Auto Shredder Residue*

Figure 5: Schematic describing Alter NRG's current process offerings



Source: Juniper interpretation of Alter NRG information

Of these, the primary application being pursued by Alter NRG is the processing of MSW with a 5% co-feed of shredded scrap automotive tyres. The main reason for including the tyres is to boost the average CV[1] of the input. However, in our view, this also increases the complexity and risk profile of the overall system.

The processing of 100% MSW is also of interest. The current design is focused on the integration of a gas turbine in an IGCC configuration. Alter NRG has informed Juniper that the IGCC option is considered to be the long-term goal and that the first project would probably utilise a conventional steam cycle to lower risk or simply sell steam over-the-fence. They would then possibly progress to using gas engines before an IGCC plant (see Figure 12, page 27).

The cupola forms the base of the plasma gasification reactor and, as we have said, has been proven at commercial scale for various melting applications. A coke bed is created within the cupola using metallurgical coke (met coke) to absorb and retain the heat energy from the plasma torches and provide the environment for melting inorganics (metal and mineral content of the waste).

This coke bed is gradually consumed during operation and make-up met coke is required. As met coke is both relatively expensive and obviously derives from fossil carbon, its use within the process has implications for the overall carbon footprint of the process and its economics.

In this design the waste does not pass through the plasma torch. Indeed the plasma torches do not impinge directly on the input waste. Instead, the torches are used to provide the high temperatures required by the cupola. Juniper refers to this design concept as Plasma Assisted Gasification. In this concept, the role of the

[1] *Calorific Value, the chemical energy contained within the feed*

plasma torches is to create a stream of very hot air (the plasma plume) which provides an intense input of heat energy into the reactor, supplemented by heat released by the met coke which is slowly consumed.

It should also be noted that a number of other proponents of plasma-assisted gasification waste processes claim that the MSW 'sees' a temperature of 20,000ºC (~ 36,000ºF) and is therefore completely destroyed by being 'zapped' into simple molecules. In fact within the Alter NRG/WPC design the temperature of the plasma plume would be between 5,000 and 7,000ºC (~ 9,000 to 12,600ºF) and the bulk temperature within the base of the reactor (cupola) about 2,000ºC (3,630ºF) – far lower than the 20,000ºC referred to earlier. The actual operating temperatures are sufficient to drive the gasification reactions and break down tars and higher molecular weight compounds into CO and H_2 and it is unfortunate that these claims that are made by other developers create a false impression of how plasma assisted gasification processes work.

The molten slag leaves the reactor at about 1,650ºC (3,000ºF) and the syngas at between 890ºC (1,650ºF) – 1100ºC (2012ºF).

The plasma torches therefore are energy input devices and the plasma assists the gasification reactions to take place. The electrical energy input to the plasma torches is also used as a control parameter to accommodate and counteract the expected variations in waste CV.

Figure 6: Westinghouse plasma torch (internal and external assemblies)

Marc 3a

Source: Alter NRG

Alter NRG offers two sizes of Westinghouse plasma torch:

- the Marc 3a[1]

This torch has a power rating of the 80 – 300 kW. There are 16 units using these torches in commercial operation including 2 plasma gasification plants operating in Japan.

- and Marc 11

[1] *this is a branded product*

This torch has power ratings of 300 – 800 kW and 800 – 2400 kW. There are 8 units in commercial operation at metal melting facilities (since 1987) and it will be the torch used for the proposed large scale MSW plasma gasification projects.

Alter NRG has developed a standard process design concept for MSW applications by using outside engineering consultants BDR[1]. This design is encapsulated in the Design Basis Memorandum (DBM) which has been reviewed by Juniper and is discussed in the following sections. The standard design includes syngas cleaning and conversion to power via a gas turbine in an IGCC configuration. However, we understand from discussion with Alter NRG that the company will use syngas combustion followed by the conventional steam cycle for their first waste gasification project. Juniper fully supports this decision because to implement what we consider to be the 'home run' technology of IGCC first would be an excessively risky undertaking.

Waste Handling and Pre-treatment

MSW delivered to the plant will be discharged into a covered concrete bunker and tyres will be stockpiled in a separate outdoor receiving area. The receiving bunker will be used as the feed handling, preparation and mixing area to create batch feeds for the gasification reactor. The current design allows for a MSW feed of 710 tpd and 40 tpd of scrap tyre pieces.

From the storage bunker the MSW will be handled by front-end loaders and will be delivered to a heavy-duty shredder to reduce it to the required size and the tyres will be fed through a tyre cutting process that will produce pieces of a manageable size to enable uniform mixing with the MSW prior to the gasification process.

The intention of the standard design (as described in the DBM) is to co-gasify MSW with scrap tyres (5% by weight of the total feed). The use of a 5% by weight co-feed of scrap automotive tyres may create technical challenges downstream of the plasma gasifier which could far outweigh the potential benefits of extra energy input from the high CV of the rubber.

Metallurgical coke (met coke) and limestone are both required as feeds to the gasification process. The met coke is used in the gasification process to provide a bed which absorbs the heat energy from the plasma plumes and helps to maintain this heat input in the gasification zone of the reactor by additional heat release as the met coke slowly combusts. Limestone is used to control the melting properties of the slag to ensure it maintains satisfactory flow characteristics to allow it to be 'tapped' and flow from the reactor into the slag quench tank. Limestone addition also ensures that the slag is fully vitrified, making this property less sensitive to input waste composition.

Front-end loaders will place appropriate amounts of shredded MSW, cut tyre pieces, met coke and limestone onto a conveyor which will transport the feed to a hopper attached to the gasification reactor. Once the hopper is filled a valve will open allowing the material to enter the vessel. The design includes a double hopper system with the intention that while one hopper is emptying into the reactor the other is being filled. The hoppers will feed through two gate valves which act as an air lock to minimise air ingress to the gasifier.

The current design includes one heavy duty shredder and one tyre cutter. It is not clear whether these devices will operate continuously or via campaigns to produce sufficient feed material for the gasifier to operate for more than 24 hours. Experience from other Energy-from-Waste facilities has shown that the shredder is a critical plant item which can suffer unexpected downtime when processing MSW. It may be advisable to include for a second shredder to build some contingent redundancy into the design.

[1] *Bower Damberger Rolseth Engineering – a division of AMEC*

Ensuring that the feed materials are evenly mixed will also pose an operational challenge to ensure that the gasification reactor does not see wide variations in energy release as the tyre scrap has a much higher energy content (CV) than MSW.

Juniper has concluded, from our experience of carrying out many due diligence reviews of gasification processes, that the front-end solid waste handling and pre-treatment elements of the process are critical to the successful performance of the complete gasification process. It is imperative that the characteristics and idiosyncrasies of these activities are fully understood and the technical challenges experienced by plants in the past are avoided. Discussions with Alter NRG engineers have indicated that they are aware of these challenges and they will take account of the experience, both good and bad, from other examples of gasification process to optimise their design.

Plasma Gasification Reactor

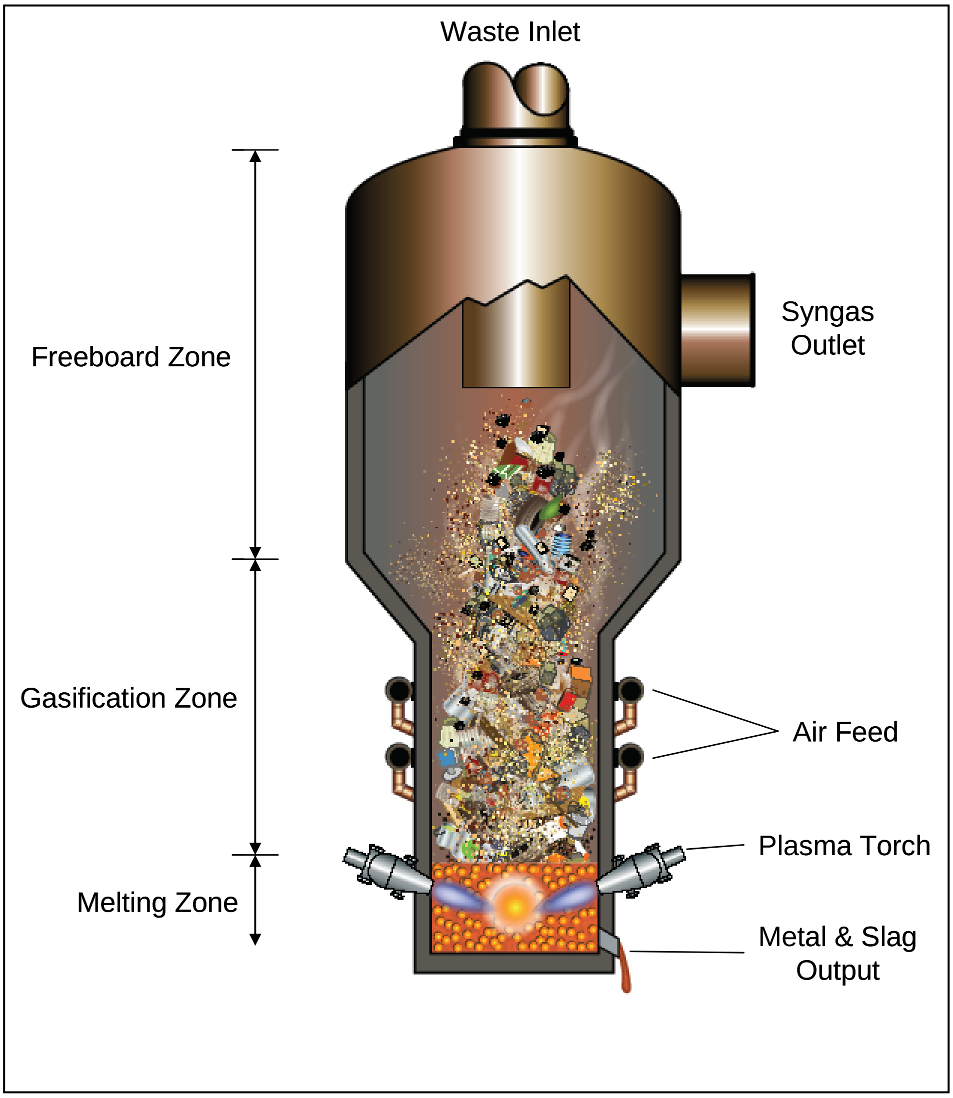
The Plasma Gasification Reactor (PGR) is based on the WPC cupola, which is a vertical shaft furnace of a type conventionally used in the foundry industry for the re-melting of scrap iron and steel. It is internally lined with the appropriate refractory to withstand high internal temperatures and the corrosive operating conditions within the reactor. The preliminary size of the standard PGR is 9.7 metres (32 ft.) outer diameter at its widest point and 19 metres (63 ft.) overall height.

The gasification reactions will convert the organic component of the MSW/tyre feedstock into a syngas which exits at the top of the PGR while the inorganic components are converted into a molten slag that exits at the bottom. The PGR operates with very high temperatures in the lower portion of the reactor and both oxygen and steam will be injected into the process. The high temperatures also significantly increase the kinetic rates of the various chemical gasification reactions.

The syngas will exit the PGR at 890°C (1650°F) – 1100°C (2012°F) at near atmospheric pressure. It will be quenched and cleaned for various downstream uses.

The molten slag is a mixture of non-combustible inorganics and recoverable metals which will be sent to the slag handling system for further processing.

Figure 7: Schematic of the Plasma Gasification Reactor



Source: Alter NRG

For the new standard design, the PGR will be fitted with six (6) Marc 11 plasma torches at the bottom of the reactor vessel, each with a power range of 300 to 800 kW. They will each operate at 600 kW under normal conditions to provide a total of approximately 3.6 MW of energy to the gasification process. The excess torch capacity provides the PGR with the ability to handle upset conditions, start-up and the required maintenance events without adversely affecting the operation of the gasification reactor. This energy consumption acts as a debit on the overall energy balance (relative to conventional processes, such as incineration, that derive all their energy from the input waste). However, when compared with other slagging type gasification processes this energy debit corresponds to the energy required to produce and use high purity oxygen in the process.

Alter NRG (via WPC) has access to a large body of empirical and operational data related to the processing of various waste streams and coal. Many test runs were conducted at the Waltz Mill pilot facility on MSW and the Utashinai and Mihama-Mikata plants in Japan have both operated for several years. This body of data gives Alter NRG a competitive advantage over many other suppliers who have yet to test their designs. In effect, this means that while others are struggling to run that first demonstration of their process, Alter NRG has moved on to design a *“2nd generation”* reactor that has learned from and builds on the experience in the Japanese plants and the Waltz Mill pilot facility. Alter NRG is aware of shortcomings with the existing design that caused technical challenges downstream of the gasification reactor, particularly at Utashinai. They have conducted a third party review (by Hatch Engineering) of the design aspects of the gasification reactor using CFD[1] modelling techniques, which is a more cost effective method of exploring design changes than making modifications to the pilot reactor and running tests to develop a modified design for the PGR. Juniper has seen the outputs from this CFD modelling work. Based on this modelling the objectives of the design changes were to:

- minimise the amount of particulate carryover from the gasification reactor;
- respond to the adverse operational experiences from the Japanese plants;
- improve the overall performance of the reactor.

However, the fact that the design has been changed means that the findings of the CFD modelling work will need to be validated in the pilot plant. Nevertheless, only the optimised design from the CFD work will have to be tested and not the many other variants that the CFD work has shown to be sub-optimal, saving cost and time.

The company has therefore decided to make some modifications to the reactor design, based on the results of the CFD modelling, and we consider the reasons for these modifications, explained to us by the company's engineers, are justified. Because these proposed modifications have not been tested at full scale there are technical risks to consider when making such major modifications to a design that is proven and operating in the two Japanese plants. It should be borne in mind that during the commissioning of the new reactor design technical challenges may occur which will require resolution and could create delays to the overall project programme.

Owning the Waltz Mill pilot plant and having access to all of the empirical data produced there is a significant market advantage for Alter NRG because many of their competitors do not have access to such a facility.

Air Separation Unit

The PGR requires its own supply of oxygen and a cryogenic air separation unit (ASU) will be used to produce a 95% O_2 rich liquid stream. A cryogenic ASU is required because vacuum PSA[2] systems, which are used in Japan, would not have sufficient capacity to supply the volume of O_2 required. Oxygen purity is not critical to gasifier operation but a lower purity of O_2 would increase the amount of nitrogen in the syngas, which would in turn adversely impact on the sizing of downstream equipment and hence also the capital cost.

Liquid O_2 will be stored in tanks and vaporised when required to produce a stream of gaseous oxygen which would be injected into the gasifier. Additionally, N_2 is a by-product from the ASU. This will be stored and used for purging and blanketing of the equipment. Alter NRG has also stated that a portion of the nitrogen would be used for NOx control in the gas turbine of the IGCC variant of the design.

Syngas Cleaning

The syngas leaving the top of the PGR will contain many contaminant species that must be removed prior to utilisation of the syngas. The IGCC variant will require considerable cleaning and, indeed, successfully implementing that element of the design would be regarded (when processing a heterogeneous feed like MSW) by many outside experts as challenging. For the process variant that uses a secondary combustor and the steam cycle less contamination would need to be removed upstream, but downstream gas cleaning systems would still be needed (following the combustor) to meet the required regulatory emission limits to air. The extent to which the syngas would need to be cleaned for other applications is not covered in this review.

[1] *CFD = Computational Fluid Dynamics*

[2] *PSA = Pressure Swing Adsorption*

Typically, from an MSW feed and from an updraft gasification reactor the raw syngas could contain:

- particulate matter; including carbon dust, alkali metal salts and heavy metal compounds;
- liquid tar droplets[1] and sub-micron aerosols, including volatile heavy metals such as mercury and cadmium;
- metal carbonyls;
- gas phase halogen species; including HCl, HF, HBr and possibly elemental bromine;
- sulphur species; including H_2S, COS and SO_2;
- nitrogen species; including NH_3, HCN.

When scrap tyres are co-gasified then additional contaminants will occur in the syngas:

- increased levels of sulphur producing more H_2S and COS;
- ZnO (zinc oxide)[2] used in the rubber vulcanisation process will form sub-micron particulates which will increase the loading of the downstream particulate removal processes.

The syngas will be cleaned in a multi-stage process, the number of stages being dependent on how clean the syngas needs to be for the particular utilisation and conversion process specified in each specific project. These multi-stage elements can add considerably to the capital costs and incur significant operating costs for the disposal of secondary residues. They can also reduce the overall plant operational availability and, in some circumstances, lower revenues from energy sales.

The DBM describes the syngas cleaning and conditioning processes prior to utilisation in a gas turbine which, as we have pointed out, requires one of the most stringent syngas cleaning requirements. This is the combination of processes we will discuss here.

Quenching, particulate and HCl removal

The hot syngas exiting the PGR passes immediately to a water quench and spray tower system. A venturi scrubber is specified as the quench device and is designed to remove a high percentage of the particulate loading and some of the HCl. A further advantage of quenching the syngas is that the temperature is reduced rapidly and dioxin/furans are not able to reform via the *de-novo* synthesis reactions and therefore the levels of dioxin/furans in the syngas would be very low.

The cooled syngas saturated with water droplets flows from the venturi to the spray tower which is a vertical vessel in two sections. The lower section serves as a separator and is where the liquid disengages from the syngas and is pumped back as recycle liquid to the venturi scrubber. The syngas flows upwards through a chimney tray to enter the absorber section where it passes through a number of water sprays arranged in series. The topmost spray header injects sodium hydroxide so that the syngas sees the highest pH at the top of the absorber section, resulting in the removal of all but traces of the remaining HCl.

Experience of complex syngas cleaning processes (for MSW applications) prior to energy conversion systems, such as gas engines, exists in Japan and Juniper considers such systems as moderately well proven. However, their operation has not been troublefree. There are four such plants in Japan that employ a direct quench and they have experienced problems with carbon dust carryover from the gasification reactor and slag formation as hot

[1] *Typically an updraft gasification reactor will produce a syngas containing a significant amount of tar droplets. Alter NRG has informed Juniper that tests conducted at the Waltz Mill pilot plant has shown that the syngas produced from MSW does not contain tar*

[2] *a typical automotive tyre contains between 1 and 1.9 wt% of ZnO. Fly ash formed by combustion of tyres and captured in the bag filter can form more than 50 wt% of the fly ash*

particulates, such as alkali salts, are cooled rapidly. We are aware that modifications to the original design had to be made and this carbon dust would have to be removed to protect the downstream gas turbine. It would appear from discussions with Alter NRG engineers that they are also aware of these potential issues and they understand that the performance of this part of the process is critical and it should be monitored and controlled very carefully. However, they themselves do not have directly relevant experience to draw on.

Wet Electrostatic Precipitator

The syngas passes from the top of the spray tower and flows to the inlet of the Wet Electrostatic Precipitator (WESP) in order to remove small particulate matter, particularly sub-micron particles (including ZnO) and aerosols. On entering the WESP, the syngas is evenly distributed across the tube bundle. In the collecting tubes, incoming particles are given a strong negative charge by the high intensity ionizing corona produced by the high voltage electrodes. As the syngas flows through the collector tubes, the action of the electric field on the charged particles causes them to migrate to the tube walls and accumulate. A water film flows down the tube walls and removes the solid material to the discharge point.

The syngas, which is still saturated with water, passes to a cooling stage which comprises an aerial cooler and a chilled water heat exchange system. Water is condensed from the syngas and sent to the water treatment plant.

The four Japanese plants that convert syngas from MSW into electricity via gas engines all employ a WESP, so this combination is reasonably well proven in such applications. However there is no significant commercial experience of using a WESP in front of a gas turbine on an MSW feed.

Co-processing of scrap tyres is not undertaken at any of these facilities. It will increase the loading of sub-micron particulates and will therefore, in our view, increase the technology risk associated with the design which must be considered very carefully to ensure that the majority of these small particles are removed prior to a gas turbine.

Mercury removal

The process design includes a mercury removal stage. An activated carbon bed filter is proposed to ensure that trace quantities of mercury and mercuric compounds are removed. Typically, sulphur impregnated activated carbon is used and the mercury is converted to mercuric sulphide (HgS), which is a stable compound. A single filter is said by Alter NRG to remove 95% of the mercury; if a greater degree of removal is required to meet a specific legislative limit then a second filter could be placed in series to achieve a total removal efficiency of 99.5%. This would increase the pressure drop through the system, requiring greater fan power with the associated increase in operating cost.

Ultimately, the carbon beds will become saturated, their performance will deteriorate and the bed charges will need to be replaced. The spent bed material will require disposal as a hazardous waste, also incurring additional operating cost. This does not appear to have been taken into account in the DBM and cost model submitted for our review.

Syngas compression

If the cleaned syngas is to be used in a high efficiency boiler or spark-ignition gas engines then compression is not necessary. The DBM describes a power train design incorporating a gas turbine and therefore the syngas would be compressed to 350 psig (24 barg, 2.4 MPa). The compression, storage and handling of a flammable gas is an everyday activity in the chemical and power generation industries but is not a typical activity in the waste industry. Consequently, there is an increased technical and operational risk that would need to be carefully managed.

Carbonyl sulphide hydrolysis

A hydrolysis process to convert COS to H_2S has been specified in the DBM. This is a catalytic process where steam is reacted with the syngas over the catalyst bed and the COS is converted to H_2S and CO_2. This process has been used extensively in coal and refinery gasification processes and the primary technical challenge relates to potential poisoning of the catalyst by chlorides and metal carbonyls, both of which could be present in the syngas from MSW. Typically, this technical issue is resolved by placing an activated carbon guard bed ahead of the COS hydrolysis reactor. In the standard Alter NRG design an activated carbon filter is used for mercury removal and would be placed ahead of the COS hydrolysis process. This activated carbon bed would also act as a guard bed and should remove the potential contaminants to the required level. In having to perform two duties the bed may become saturated with contaminants more quickly and the bed material may need to be replaced more often.

Desulphurisation

There are various desulphurisation technologies that have been developed by the natural gas industry and three have been used in gasification plants which have operated in Europe and Japan. The Thermoselect plant at Karlsruhe in Germany used the Sulferox process; the Isahaya, Tokushima and Yorii plants built by JFE in Japan (employing the Thermoselect gasification process under licence) use the Lo-Cat process supplied by Merichem Inc. and the Mutsu plant built in Japan by Mitsubishi Materials (under sub-licence from JFE) used a proprietary process supplied by Tokyo Gas.

Alter NRG has selected the Crystasulf technology available from Crystatech Inc., a US based company. The reasons given by Alter NRG for this selection are that the process preferentially removes H_2S over CO_2, CO and H_2 and that it is a single stage process that produces a solid elemental sulphur product.

Sour syngas enters the absorber reactor where it contacts the clean Crystasulf solvent (liquid SO_2) and reacts with the H_2S to form sulphur which remains dissolved in the liquid SO_2 solution. The sweetened syngas exits the absorber and is cooled prior to utilisation.

The used Crystasulf solution passes from the absorber into a crystalliser where elemental sulphur crystals form. The material discharged from the crystalliser passes to a filter to remove water to produce approximately 1.7 tpd of sulphur (90+% by weight on a wet basis). SO_2 lost during the reactions is replenished by injecting fresh liquid SO_2 into the solvent stream prior to injection into the Crystasulf reactor. A small portion of the inlet H_2S is converted to salt by-products which are removed for disposal.

Of the four Japanese gasification plants processing MSW and cleaning the syngas for gas engine use; three use the Lo-Cat process. Juniper therefore considers that process to be moderately well proven in waste applications, whereas we are not aware that Crystasulf has been used with syngas produced from waste gasification. This therefore poses some degree of technical risk. Notwithstanding this, we understand the reasons why Alter NRG selected this process.

Energy Production and Utilisation

With respect to the generation of electrical power from the produced syngas, Alter NRG's ultimate goal is to employ a gas turbine in an IGCC[1] configuration. We understand from the DBM that a GE Frame 6581B gas turbine is proposed and, from discussions with Alter NRG engineers, that GE has confirmed the estimated CV of the syngas is high enough for that gas turbine to operate satisfactorily. However, the 750 tpd standard

[1] *Integrated Gasification Combined Cycle – the hot exhaust gases pass through a Heat Recovery Steam Generator (HRSG) and the steam is converted to power via a steam turbine.*

gasification plant will produce an insufficient quantity of syngas for this size of turbine and therefore an amount of natural gas will be required as an auxiliary fuel supply. In our view, this is a disadvantage of Alter NRG's process concept. Apart from the obvious cost implications, many decision makers will be concerned by the potential greenhouse gas emissions. Use of a fossil fired co-feed to the gas turbine would also impact adversely on the environmental performance and sustainability of the system. Moreover, its use could affect revenues significantly, particularly in the UK where the Renewable Energy legislation sets a maximum level of 10% for the use of fossil fuels in a thermal process for wastes and biomass. Exceeding this limit could reduce electricity revenues by up to 75%, greatly impacting on project economics.

Juniper considers the proposed coupling to a gas turbine as a potentially high risk endeavour. There is no plant processing solely MSW or RDF that has integrated a gas turbine. Large scale coal gasification plants and gasifiers on oil refineries processing distillation column bottoms have done so and the Schwarze Pumpe facility (near Dresden in Germany), which operated five large gasifiers processing a mixture of coal and wastes, also used a gas turbine and produced methanol. This plant has recently been closed due, we understand, to economic reasons and it was not directly comparable with the proposed Alter NRG design concept.

For satisfactory operation of high efficiency prime movers it is essential to have a stable flow of syngas which contains minimal contamination from particulate matter and chemical compounds such as acid gases and alkali metal salts. Alter NRG has informed Juniper that they intend to focus their efforts for the first plant on producing a stable flow of syngas and use of a combustor and steam boiler to minimise the technical risks associated with energy conversion. In our view, this is a sensible and pragmatic approach to risk mitigation. The utilisation of the syngas in a boiler to produce steam and then electricity via a steam turbine is the least problematical method for energy and power recovery. This has been demonstrated at several gasification plants in Europe and Japan. This method was initially selected by a number of other gasification process suppliers prior to advancing to more complex techniques such as using gas engines (e.g. JFE).

Alter NRG is also considering options to use gas engines; an approach that has been commercially proven in Japan. JFE (formerly Kawasaki Steel and NKK, prior to their merger) has constructed four slagging gasification plants (high temperature oxygen blown) that process MSW and convert the cleaned syngas to electrical power via Jenbacher (GE) gas engines:

1. Mutsu (140 tpd MSW) – 2 x 1.2 MW gas engines;
2. Isahaya (300 tpd MSW) – 5 x 1.5 MW gas engines;
3. Tokushima (120 tpd MSW) – 2 x 900 kW gas engines;
4. Yorii (450 tpd industrial wastes) – 2 x 1.5 MW gas engines.

All of these plants have operated for more than one year.

Slag Handling & Utilisation

The inorganic metal and mineral content of the input MSW are converted into a molten slag by the intense temperatures at the base of the PGR. Limestone is also added with the waste feed to affect the eutectics of the slag and control the viscosity. The molten slag exits the PGR continuously through a tap hole at a temperature of 1650°C (3000°F). A refractory lined channel (launder) delivers the slag to the slag extraction pipe where it encounters high pressure water sprays which cause the slag to break apart to form small granules. The granulated slag drops into the water bath and is collected by a drag chain conveyor. This material then passes under a magnetic separator which separates the ferrous metal granules from the mineral slag granules. The quench water is cooled in an air-cooled heat exchanger before being recirculated into the slag quench system.

Alter NRG's intention would be to recycle the vitrified slag material into construction applications as an aggregate. During our visit to the two Japanese reference plants we observed the slag that was produced at each plant and

Hitachi Metals informed us that the slag from Mihama-Mikata was sold as an aggregate and used locally in the construction of roads and car parks, but that the slag produced at Utashinai was not suitable for these applications due to an increased level of porosity which is thought to be caused by the amount of ASR in the feed blend. Alter NRG has conducted slag leaching tests on a sample of the Mihama-Mikata product material (see Solid Residues, page 45) and has informed Juniper that they are currently undertaking further leach testing.

Waste Water Treatment

All effluent streams will pass to the waste water treatment plant and will be cleaned to a level to allow the treated water to be recycled back as process water. Excess waste water (approximately 25 m^3/day) will require disposal.

Because the syngas cleaning system will use a water quench and other wet scrubbing processes, a significant quantity of liquid effluent will require to be treated prior to recycling as process water. The process water streams from the venturi quench, spray tower, separators, HRSG blowdown, filter press recycle and reverse osmosis reject flow to the waste water collection tank for treatment. The DBM explains that the waste water treatment system is a physical/chemical process. The wastewater is fed into a flash mixing tank with a number of treatment chemicals and remains there for about 5 – 10 minutes. The precipitated products and water flow by gravity to a lamella clarifier/thickener. Thickened solids then flow to a filter press for final dewatering prior to landfill disposal. Clarifier overflow passes through a charcoal filter to remove any remaining mercury or organic contaminants and is then recycled for re-use as process water.

The processes involved in handling, cleaning and recirculating the liquid effluents are all well established. We do not therefore see these as adding to the overall risk profile of the process, but they will add to both the capital and operating costs of the facility.

Material & Energy Balance

The mass and energy balance data provided to Juniper by Alter NRG is based on their design for a typical US MSW (710 tpd) + tyre (40 tpd) feed. The balances have been made around the gasification island and include all inputs to and outputs from the gasification reactor.

Figure 8: Mass & energy balance (design basis) for Alter NRG's core design (with IGCC)

MASS BALANCE				ENERGY BALANCE			
INPUTS	% (by WT)	OUTPUTS	% (by WT)	INPUTS	% (by MW)	OUTPUTS	% (by MW)
MSW	62.3	Syngas	82.1	Feed	92.7	Syngas (sensible)	15.1
Tyres	3.5	Metal	5.5	Met coke	4.2	Syngas (latent)	0.7
Steam	3.4	Slag	12.4	$CaCO_3$	-0.1	Syngas (chemical)	80.3
Met coke	2.7			Pre-heated air	1.2	Slag	0.2
$CaCO_3$	4.8			Plasma torch power	2.0	Heat losses	3.7
Air	20.0						
Plasma air	3.3						
TOTAL	**100%**		**100%**		**100%**		**100%**

Source: Juniper interpretation of Alter NRG data

We understand that the mass and energy balance data have been derived from design simulations and estimates of assumed waste compositions. It is not taken from an actual operating plant. However it should be noted that, we have been provided with a much greater level of detail, particularly for the energy balance, than Juniper has ever been provided with by any other plasma gasification supplier.

23.3% of the input to the gasifier by weight is air which, of course, contains 75.47 wt% of nitrogen diluting the syngas and reducing the CV. Met coke requirement is 2.7 wt% meaning a 750 Tpd plant would require about 6,300 Tpa of met coke, which would incur a significant operating cost. We understand Alter NRG has tested anthracite as a substitute for met coke and is confident met coke usage can be substantially reduced or eliminated. Further testing is ongoing.

One aspect of the energy balance that may be surprising is that the plasma torch power, in MW of energy input to the gasifier, is relatively low at 2%.

The chemical energy of the syngas available for conversion to power is about 80% of the MW leaving the gasifier. The sensible and latent heat content of the syngas (15.8% in terms of MW) would be lost if the syngas is immediately quenched as per the current design. This is a techno-economic trade-off between recovering an additional amount of heat energy and the technical challenges and complexities that would be faced in trying to recover this energy via conventional heat exchange techniques. Quenching of the syngas also brings the added benefits of minimising the reformation potential of dioxins/furans.

Thermal Efficiency of the Process

When producing electrical power, which is the primary product required by most markets, the efficiency of the thermal process comes under scrutiny. Typically the thermal efficiency of a conventional Waste-to-Energy (WTE) plant, based on the ratio of 'energy out' to 'energy in', has been in the range of 18 to 22%. CEWEP[1] has suggested that the relevant criteria for energy recovery should be based on environmental aspects, particularly carbon emissions. In essence, they argue that the more usable energy produced by a WTE plant, the more fossil fuel is displaced from power generation and the greater the net saving of CO_2 emissions. Consequently, the thermal efficiency of the plant becomes more important.

Currently the European Union considers the incineration of MSW in a WTE plant to be a disposal activity and not a recovery (of energy) activity. There are discussions underway in Brussels[2], related to the European policies on climate change, to alter this classification. Proposals have been made to allow a WTE plant to be considered as a recovery operation if it meets a resource recovery efficiency threshold (based on energy values), currently proposed to be 0.65 for new facilities operated after 1 January 2009. This subject has also been considered in a European Court of Justice Judgement[3]. If this is adopted it would be very important for any new proposed WTE plant to show that the proposed process could meet this threshold, since gaining political approval for the project would be more challenging for a low efficiency 'disposal' plant than a high efficiency 'resource recovery' plant.

[1] *Confederation of European Waste-to-Energy Plants*

[2] *It should be noted that the CEWEP calculation methodology has not yet been adopted by the EU and a different approach could give different results.*

[3] *ECJ Judgement "C-458/00" par. 32-34 in the case Strasbourg/Luxembourg C-458/00 dated 13.02.(2003)*

An efficiency calculation methodology has been developed by the EU and published in the draft Waste Framework Directive[1]. The calculation formula proposed in the BREF[2] for the so-called R1 Efficiency Index is based on work undertaken by the EU Best Practice Committee based in Seville, Spain:

$$\eta = \left\{ (E_p - E_i) \big/ 0.97 \times (E_w + E_f) \right\} \times 100$$

where:

η = the R1 Efficiency Index

E_p = annual gross energy produced (combined total of electricity plus heat as equivalents[3])

E_i = annual energy imported that does not contribute to steam production

E_f = annual energy input to the system by fuels with steam production

Ew = annual energy input to the system by waste

0.97 = factor to allow for energy losses (sensible heat losses from the plant walls and in the bottom ash)

Juniper has used its interpretation of the R1 calculation methodology to determine comparative numbers for the plasma gasification to gas turbine design using data supplied by Alter NRG and certain other companies.

It can be seen from Figure 9 that the existing conventional combustion technologies would meet the current proposed EU level of 0.6 for the R1 Efficiency Index but at least two of the leading Japanese slagging gasification plants would not. The Alter NRG IGCC process would easily achieve the required level of resource recovery efficiency of 0.65 for new plants provided that the predicted performance levels are achieved in practice. It should be noted that we have not been able to compare 'apples with apples' as the other four processes all employ the steam cycle and the Japanese plants use a proportion of the energy to melt the inorganics to form a recyclable slag. Alter NRG's process also produces a slag but data for their steam cycle and gas engine process variants is not yet available for review by Juniper.

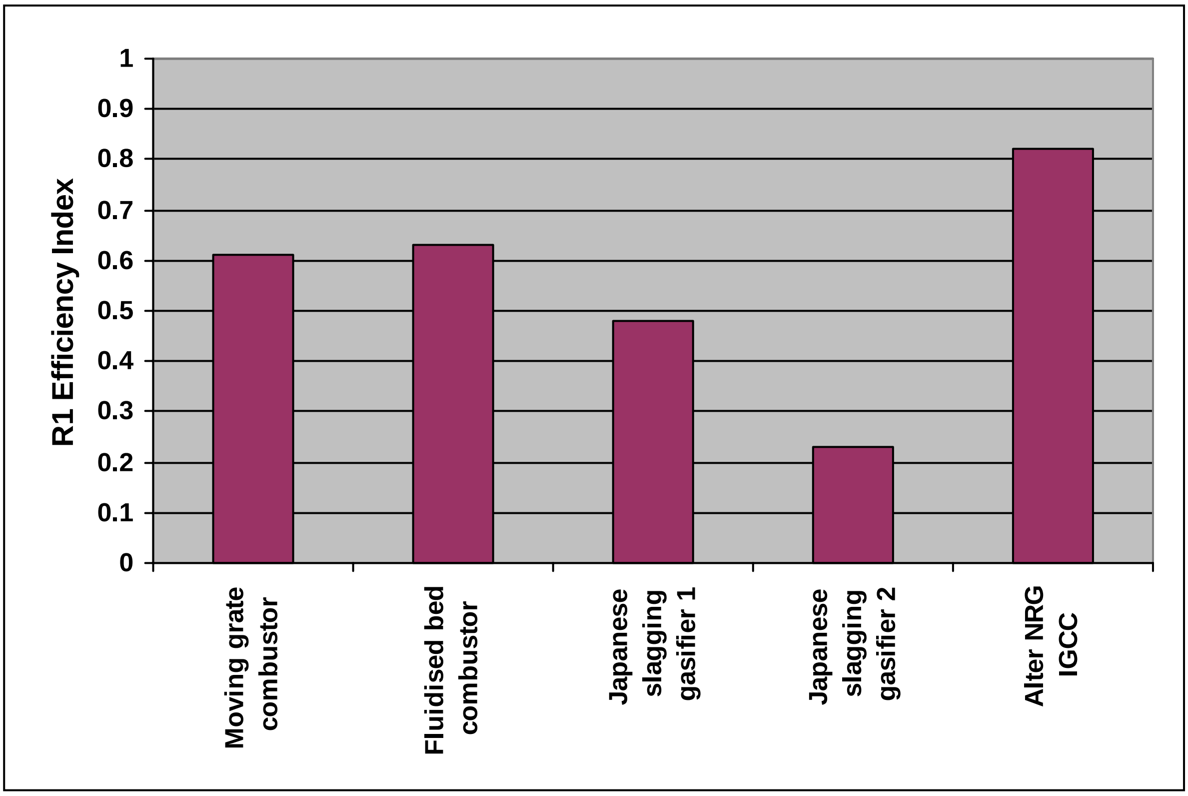
Figure 9 shows that the Alter NRG design concept could achieve high levels of energy recovery provided that it achieves its expected performance. Also the recovery efficiency is significantly greater than a conventional incinerator configured to produce electricity alone. It should however be noted that when used in CHP mode the difference will be much less significant.

[1] *Annex II A and B of Council Directive 75/442/EEC on waste, as amended by Commission Decision 96/350/EC, 15.07.(1975)/24.05.(1996) and in draft of Waste Framework Directive Dec. (2005)*

[2] *BAT (Best Available Techniques) Reference Document (BREF) entitled Waste Incineration (WI) produced as a result of an information exchange carried out under Article 16(2) of Council Directive 96/61/EC (IPPC Directive)*

[3] *This methodology requires the energy flows to be input as equivalents. There are different forms of energy unit; i.e. MWh, MWh_e and MW_{th}, therefore conversion factors are needed. Assuming an overall European average of 38% conversion efficiency for utility electricity generation then 1 MWh = 0.38 MWh_e or 1 MWh_e = 2.6136 MWh and for heat generation an efficiency factor of 91% is applied then 1 MWh = 0.91 MW_{th} or 1 MW_{th} = 1.0989 MWh.*

Figure 9: Comparison of R1 efficiency index for Alter NRG process with other thermal technologies



Source: Juniper analysis

CURRENT COMMERCIAL STATUS

The WPC plasma torch and cupola was originally developed for melting applications and has operated in this mode at three facilities; one each in the USA, Canada and Japan.

Plasma Melting Furnace, General Motors, Defiance, Ohio, USA

This unit was installed in 1989 at the General Motors' Powertrain car plant in Ohio, USA as part of the foundry operation for the production of grey iron for the manufacture of engine blocks and other automotive castings. This was the first commercial scale plasma cupola built in the world, employing 6 x Marc 11 plasma torch systems, each operating at 1,750 kW. The plasma cupola processes a feed charge comprising; sprue[1], steel turnings, iron borings and fragmented steel scrap. GM reported[2] that "*... over five years of operating experience demonstrated that the plasma technology is economically suitable for iron melting. No major changes of traditional industry practices are required to operate plasma cupola systems. The plasma equipment can be operated and maintained by routine plant personnel*".

[1] *in foundry casting, a sprue is the piece of solidified metal that forms in the passage through which molten metal passes into a sand mould. The sprue is cut from the casting and recycled back to the feed melting process.*

[2] *"Plasma Cupola Operations at General Motors Foundry", Gary, Fry, Chaput (GM) and Darr, Dighe (WPC), American Foundrymen's Society, 1998 Casting Congress, May 1998, Atlanta, USA*

Plasma Melting Furnace, ALCAN, Jonquière, Canada

The plant was built in 1992 as an aluminium dross recovery furnace at ALCAN's plant at Jonquière, Canada. It uses 2 x Marc 11 plasma torch systems each operating at 850 kW. As an alternative to the conventional Rotary Salt Furnace (RSF) dross processing technology, the plasma dross processing technique reported an increase in material quality, reduced waste for disposal and excellent electrode life. The plasma process was designed by ALCAN and WPC supplied the plasma torches, the cupola and the basic design of the melting furnace. ALCAN reported[1] that "*... the ALCAN plasma dross treatment process has been demonstrated in full production plants for five years during which more then 150,000 tonnes of dross have been processed. The operation of the plasma torch is safe, reliable and requires minimal maintenance and operator training. The energy cost, thanks to better conversion efficiency, is equivalent to a fossil fuel burner used in the RSF technology*".

Ishikawajima-Harima Heavy Industries (IHI), Ash Vitrification Furnace, Japan

The plasma cupola process was installed in 1995 for IHI at Kinuura, Japan to melt and vitrify ash from a MSW incineration plant. It uses 4 x Marc 3a plasma torch systems each rated at 300 kW. Again the plasma torches were supplied by WPC together with the cupola and basic design of the melting furnace. We understand that the slag produced is recycled as a construction aggregate.

Plasma gasification Plants Processing MSW

Three plants were then built in Japan for waste management applications. The plants at Yoshii, Utashinai and Mihama-Mikata were built by Hitachi Metals under licence from WPC for the processing of MSW and ASR. These three plants are described in more detail in Operating Plants, (Yoshii, page 30; Utashinai, page 31 and Mihama-Mikata, page 36).

The operating plants using the WPC plasma technology are summarised in the table below (Figure 10).

[1] *"Five years of industrial experience with the plasma dross treatment process", Lavoie and Lachance, Proc. 3rd International Symposium on Recycling of Metals and Engineered Materials, November 1995, Alabama, USA*

Figure 10: Selected reference plants using the WPC plasma technology

Location	Duty	Plant capacity	Treatment capacity (Tpa)	Start-up
General Motors, Defiance, Ohio, USA	Plasma melting of iron and steel scrap	50 – 80 Tph*	—	1989
ALCAN, Jonquière, Canada	Plasma melting of aluminium dross	—	36,000	1992
IHI, Kinuura, Japan	Plasma melting of MSW incinerator ash	60 – 80 Tph*	18,000 – 24,000	1995
Yoshii, Japan#	Plasma gasification of MSW	24 Tpd	7,200**	1999
Utashinai, Japan	Plasma gasification of MSW + ASR	180 Tpd***	49,500**	2003
Mihama-Mikata, Japan	Plasma gasification of MSW + dried sewage sludge	22 Tpd****	6,600**	2003

* depending on feed material
** calculated by Juniper assuming 300 days operation per year
*** 50% MSW + 50% ASR
**** 80% MSW + 20% dried sewage sludge
# no longer operating

Source: Juniper analysis of information supplied by Alter NRG

All of these reference plants were constructed prior to the acquisition of WPC.

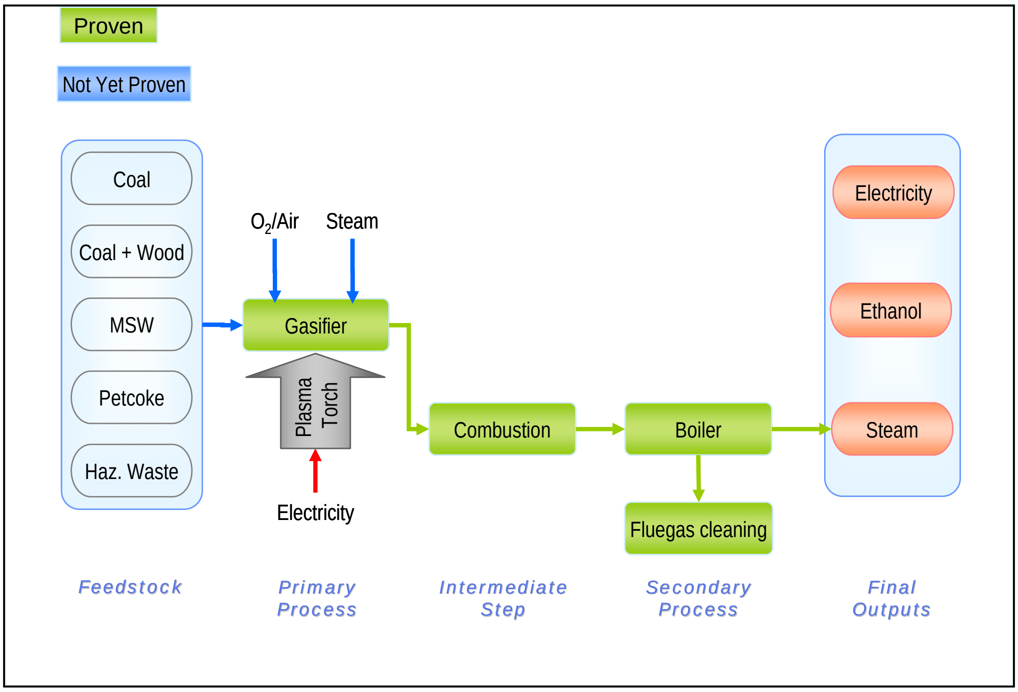
Waste-To-Energy Projects

Alter NRG is intent on supplying a Waste-to-Energy project and the DBM presents the design basis for this market application. They informed Juniper that they and other licensees are pursuing several MSW WTE opportunities. Some projects have been announced, but none has yet started construction. These are summarised below.

Alter NRG's WPC technology has been chosen by Geoplasma for use in a proposed new WTE facility in St Lucie County, Florida, USA. The original proposal by Geoplasma was for a one million tpa plant configured as an IGCC process (see Figure 12) that would have been the largest plasma waste processing plant in the world. Partly because of the scale, this project attracted much attention at the time it was announced. The industry was sceptical that a company with no track record to date could deliver such a large and complex facility, particularly since they claimed it would not require significant public-sector investment or tipping fees to make the project viable. Since the project was announced in 2006 relatively little progress has been made. To accelerate development Alter NRG has recently entered into a joint venture agreement with Jacoby Energy Development, the parent company of Geoplasma. We understand from Alter NRG that, following their input, the proposal is now for a small single line plant (500 Tpd). We also understand that because a major company has been identified as a customer the plant will produce steam for use 'over-the-fence' by Tropicana Inc. The 500 tpd scale has been chosen as appropriate to deliver the steam load required by Tropicana.

The exact status of the project remained unclear at the time of finalising this report.

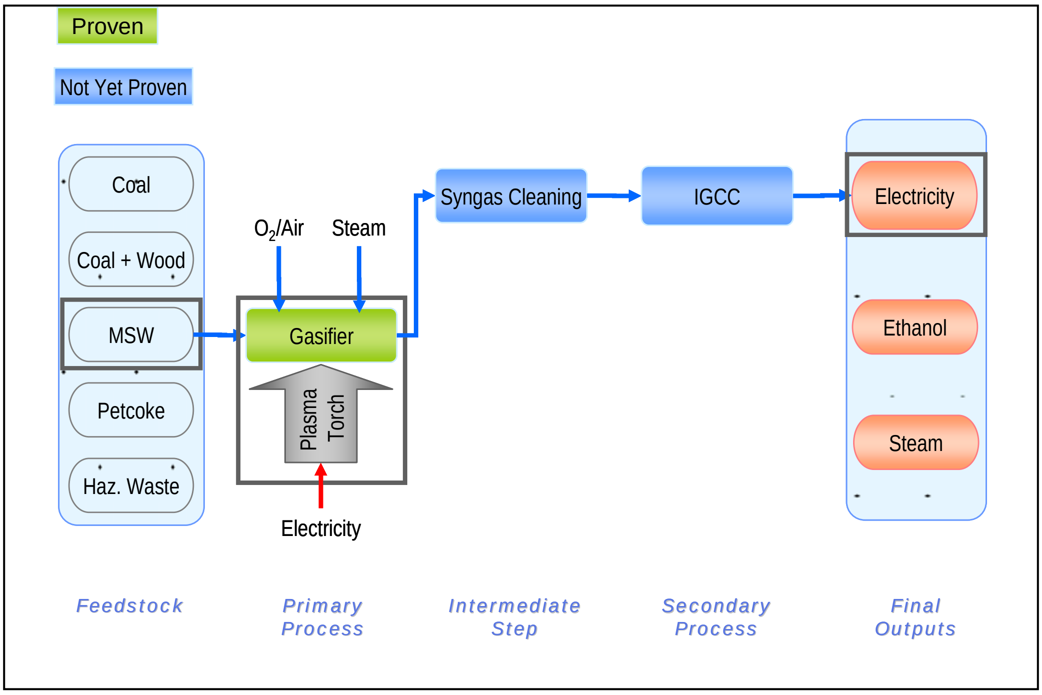
Figure 11: Schematic representation of the configuration proposed for the first WTE project



Source: Juniper interpretation of Alter NRG information

Figure 11 shows the least risk configuration for Alter NRG to pursue for their first WTE project, provided the contractual arrangements for steam off-take by the Tropicana plant are secure.

Figure 12: Schematic representation of the IGCC configuration proposed for future WTE projects



Source: Juniper interpretation of Alter NRG information

In addition to Waste-to-Energy applications for their plasma gasification technology, Alter NRG is pursuing other strategic directions and market applications which will be discussed, later in this report (see Business Focus & Market Strategy, page 47).

Commercial Orders

In addition to directly developing projects, Alter NRG will sell plasma torch technology and design services (for the gasification reactor) to third party clients who would design the balance of plant and build a facility. Alter NRG has announced two orders of this type from SMS Infrastructures, one of India's leading civil engineering firms, for plasma gasification technology to process various hazardous wastes (68 tpd) and produce up to 1.5 MW (net) of electricity. The plants are currently under construction in India in Pune and Nagpur with the Pune project scheduled for commissioning in 4Q 2008 and the Nagpur project in early 2009. WPC has supplied the plasma torches and design of the gasification reactor.

Figure 13: The gasification reactors for the hazardous waste facility at Pune (under construction)

Source: Alter NRG

Kiplasma Industries of Turkey has purchased a gasification reactor design from WPC for a hazardous waste to energy plant for Istanbul to process 144 tpd of various hazardous wastes. If the project goes ahead then Kiplasma will purchase plasma torches from WPC. The plant is estimated to start operation in 2010.

Economics

Alter NRG has shared their economic model with Juniper under confidentiality and has provided a detailed cost model for the IGCC variant and for projects in North America. Juniper reviewed the model on the basis of our experience of having reviewed similar models and our knowledge of the requirements of the waste management industry and the financial community in relation to providing funding for these types of project.

Juniper considers the model to be robust. The assumptions used within the model are, in our opinion, realistic for the current market circumstances in North America. Juniper has reviewed many cost models for MSW gasification processes and several for plasma gasification. We would conclude that the Alter NRG cost model is not overly-optimistic compared with a number of others we have seen. However, many of the assumptions used, although realistic, are based on estimates and are not taken from actual operating plant. Although some economic data from the Utashinai and Mihama-Mikata plants was provided to Juniper under confidentiality constraints we consider that this data is not directly relevant to other projects: because both of those plants are very small; were constructed in the context of Japanese market requirements, which are very different; both use the steam cycle and both process other waste streams in addition to MSW.

Juniper found that the IGCC variant, because it requires to burn natural gas in the gas turbine, is more closely linked to energy prices than many other energy-from-waste models that we have reviewed. Significant changes to the natural gas price can have a major impact on the margin generation of the model.

In countries that incentivise electricity production as ‘green’ electricity, such as the UK where the Renewable Energy legislation uses ROC’s (Renewable Energy Certificates) to pay producers a higher price for the electricity exported into the grid as renewable power, the Alter NRG model would generate higher ‘back-end’ revenues and therefore a higher project margin in such countries.

Conversely, the model is based on a market where the tipping fees are relatively low and therefore the front-end project revenues are projected to be modest. Therefore, a project would become much more lucrative in geographic areas where the tipping fees are much higher, eg. North East US, California, Europe and Japan.

The data in Figure 14 is publically available from Alter NRG’s website and provides some comparison of cost numbers for the WTE offering (both IGCC and steam cycle variants) and the proposed front-end gasification repowering project at NRG Energy’s Somerset plant (see page 50). It should be noted that this data is taken from design estimates and various economic assumptions relating to plant performance and local project parameters.

Figure 14: Cost data for 750 tpd WTE project & the Somerset coal-fired retrofit

	WTE IGCC	WTE Steam Cycle	Somerset Retrofit
Total capital cost (million CAN$)*	290	193	200
Gross Annual EBITDA (million CAN$)	44	25	45
Power export (MW)	56	18	120
Capital cost/MWh	21	43	11
Pre-tax ROE (%)	18	13	18 – 22**

* includes a 20% contingency
** after tax

Source: Alter NRG Corporate Presentation (September 2008) from www.alternrg.ca

Juniper carried out sensitivity analysis on Alter NRG's cost model to determine the impact of changes to the economic and commercial assumptions on the NPV and ROE forecast. The results were confidential to Alter NRG but we can make the following observations:

- for high CV fuels or co-feeds the back-end revenues would be sufficient to give an acceptable financial return even if the market will only allow a relatively modest tipping fee;
- increasing prices for met coke around the world would have an adverse effect on operating costs and Alter NRG is working to find a replacement material. We understand that tests with anthracite are showing promise;
- the impact of plasma torch electrode replacement would appear to have much less of an effect on project economics than might be expected;
- opportunities in the UK would be very interesting because of that government's renewable energy legislation which provides ROC's (premium prices for 'green' electricity) for such projects.

At the time of writing this report we had not been provided with the cost model for the steam cycle or gas engine variants and therefore cannot comment further.

PROCESS PERFORMANCE

The standard Alter NRG gasification plant design has not yet been implemented. The next two sections discuss design information and predicted performance characteristics from the Japanese reference facilities made available to Juniper via Alter NRG.

Operating Plants Processing MSW

Westinghouse's first three plasma cupola plants were designed for industrial companies to carry out melting duties. These examples of the WPC process are not directly relevant to the plasma gasification process being offered by Alter NRG except that they continue to operate and have provided historic data with respect to refractory and torch life in similarly difficult and challenging applications. The design of the melting and slag handling elements of the process have also been optimised over the years of operation of the three facilities (see Historical Context, page 7).

The Waltz Mill pilot facility was also built around this time and allowed WPC to conduct research into plasma gasification, particularly for waste streams (see Waltz Mill Pilot Plant, page 8).

Yoshii

WPC provided Hitachi Metals with the plasma torch systems (2 x Marc 3a torches rated at 300 kW), the cupola and the basic design of the gasification reactor for a demonstration plant built at Yoshii in Japan. The plant was designed to process 24 tpd of MSW and was commissioned in 1999. As is required by the Japanese government for the commercialisation of all novel waste processing technologies, the plant was operated in 2000 for one year with a continuous run of thirty days to obtain the data required to secure the Technical Development Support Certificate from the government. However, very little of this data seems to be still available and so we could not draw on this for this review, which is disappointing, given its status as a demonstrator. We were informed that the plant did process MSW satisfactorily into syngas and a vitrified slag and the dioxin/furan emissions from the plant was reported to be less than 0.01 ng/Nm^3, as measured for the Japanese regulations.

Having demonstrated successful operation and acceptable environmental performance at Yoshii, Hitachi Metals could then market the technology commercially.

Figure 15: The Yoshii facility

Source: Hitachi Metals

Utashinai

The Utashinai plant has a special significance in the context of the processing of household waste (MSW) using plasma-based technologies, since it was the first – and remains the largest – commercial plant anywhere in the world. In the past it has been difficult to gain a clear picture of how well this facility was operating – there was much conflicting 'information' (some of which, with hindsight, seems to have been poorly informed and may have originated from competitors). A key part of this review therefore was to assess at first hand the performance of the plant in the context of other Waste-to-Energy facilities operating in Japan, particularly slagging gasification processes.

Juniper visited the facility at Utashinai on 12 May 2008 in the company of Mr Shinichi Osada (General Manager) who was the Hitachi Metals engineer who had designed the facility (using WPC's basic design package) and who is currently responsible for day-to-day plant operation.

Utashinai is owned by a Joint Venture (JV) company (known as Eco Valley Utashinai Co. Ltd) comprising the Japan Regional Development Corporation, Hokkaido Coal Mining Development Centre, Utashinai City, Hitachi Ltd and Hitachi Metals Ltd. It is operated by Hitachi Metals. The plant construction cost was supported by the Japanese Government via NEDO (National Environmental Development Organisation) which provided a subsidy to Utashinai City who then invested the money into the JV company. The Japan Development Bank also extended loan capital to the project.

Some 35 years ago Utashinai was a coal mining area with a population of 40,000 people but now no coal is mined and the population has shrunk to 4,000. Hitachi claims to have a good relationship with the people of the town that was created by good communication with the residents throughout the entire life of the project. Hitachi agreed to employ local people at Eco Valley to operate the facility and gave a commitment to control dioxin emissions.

Although there appears to be some confusion as to what the plant was designed to process, we conclude from information provided by Hitachi Metals and discussion with Mr Osada that the plant was originally intended to process 100% ASR. It seems that the subsidy was given because NEDO wished to incentivise the gasification of ASR which was considered a very difficult waste stream to treat. The plant was constructed in two lines each designed to process 82.5 tonnes/24 hours providing a total capacity of 165 tonnes/day. The original design CV[1] for the ASR was 4800 kcal/kg (20.1 MJ/kg), but occasional sampling has determined that it varies significantly from 2000 to 4800 kcal/kg (8.4 to 20.1 MJ/kg). The ash content of the ASR has also varied considerably from 30 to 50%. It has become apparent that this variability has posed technical challenges to plant operation.

The Utashinai plant was built at an existing facility which had operated a gas turbine burning natural gas. The original intention was to use this turbine but, we understand, it soon became clear to Hitachi Metals that it would not be suitable for the syngas that would be produced. This idea was shelved and a secondary combustion chamber was installed followed by a waste heat recovery boiler and steam turbine/generator system. The design steam production was 42 tonne/hour, which would generate 7.9 MW of electricity. The parasitic power load requirement for plant operation was 3.2 MW providing a net export potential to the grid of 4.7 MW.

We were informed by Mr Osada that Eco Valley decided to co-gasify MSW with ASR because ASR is not easy to source in such quantities. However, the NEDO subsidy was given to incentivise the processing of ASR so a certain quantity had to be processed. 75 tonnes/day of MSW is delivered to the Utashinai plant from collections at five local cities. We were told that the CV was measured and found to be 3000 kcal/kg (12.6 MJ/kg), which is high versus typical MSW but it should be noted that the local waste excludes kitchen waste that is separately processed in an anaerobic digestion (AD) facility in the area. The feed to the gasifier was originally in the ratio MSW:ASR of 2:1; however, Mr Osada stated that it is now 50:50. The plant is therefore now processing approximately 180 tpd of the blended feed.

Figure 16: The Utashinai facility

Source: Hitachi Metals

[1] *CV = calorific value (heating value or chemical energy content)*

Figure 17: MSW and ASR in the Utashinai bunker

MSW ASR

Source: photographs taken by Juniper during visit

It can be seen from Figure 17 that the MSW and ASR are very different materials in particle size, composition and moisture content. Although the two wastes are delivered into different parts of the storage bunker and are segregated, there is no mixing prior to the crane grab transferring feed material into the feed hopper. Mr Osada explained, in response to a question from Juniper, that a crane grab full of ASR is deposited in the hopper followed by a crane grab full of MSW. The crane operator tries to achieve the 50:50 feeding ratio in this manner but Mr Osada admitted that it was a rather inaccurate procedure which could result in MSW:ASR being fed into the gasifier in the ratio of 60:40 or even 70:30. In our opinion this is not an optimal method of feeding the gasification reactor. The two materials have very different CV's and the plant is effectively being fed in a batchwise manner with the waste passing through the plant in plug flow. The difference in CV between the two wastes also means that the gasifier is being fed with a batch of high energy, high ash content material followed by a batch of lower energy, lower ash content material which, we believe is a potential reason for the process instabilities experienced by the plant from time to time.

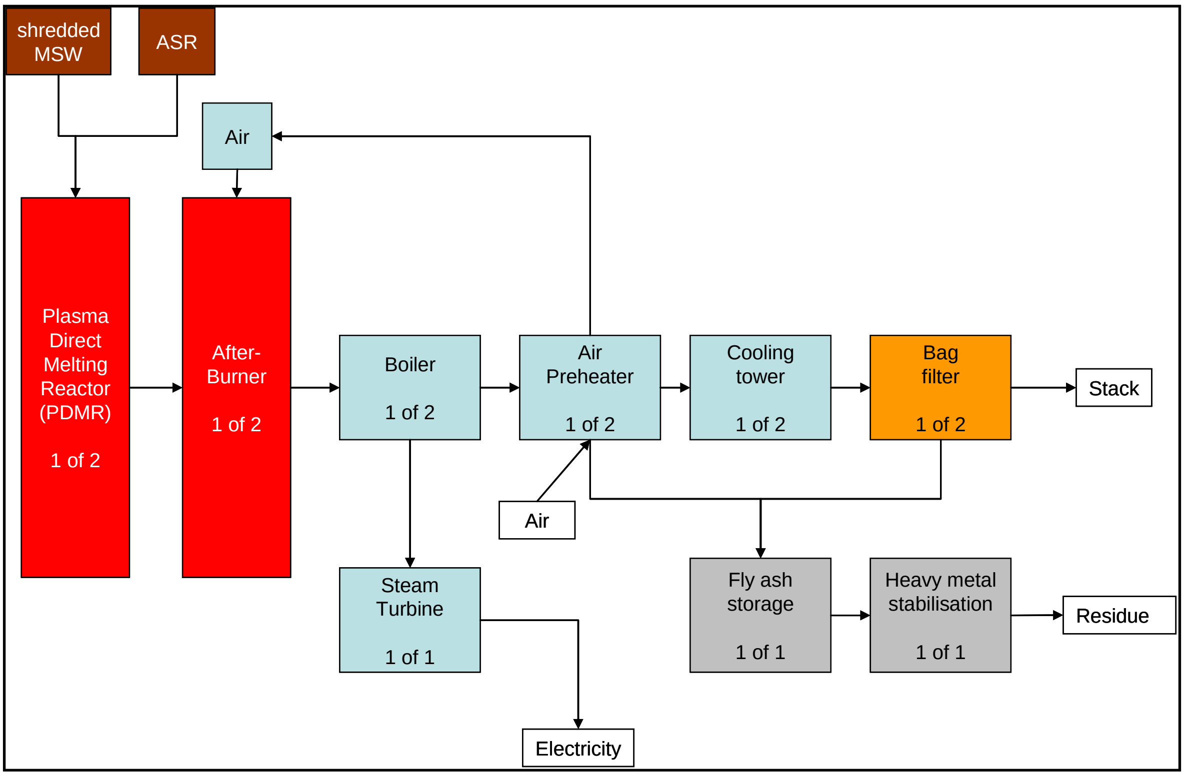
There are two significant differences between the Utashinai reference facility and the two projects being pursued by Alter NRG and its partners in North America. Firstly, Utashinai was designed to process ASR, not MSW and still processes a 50:50 mix of ASR and MSW. Secondly, it is configured to immediately combust the syngas in a conventional combustor/steam boiler.

The Utashinai facility employs two lines and includes two plasma gasification and melting reactors which convert the waste into a syngas while the inorganic content of the waste is melted to produce a slag. The syngas from each gasifier passes to a combustion chamber in a close-coupled configuration. Air is added at this point to produce a hot flue gas stream which passes through a boiler to produce steam.

The steam from both boilers is fed to a single steam turbine/generator to produce electrical power – the majority of the electricity produced is used internally and only a small amount is exported to the grid. The flue gas then flows through a heat exchanger to pre-heat the combustion air, a cooling tower (gas-to-gas heat exchanger) to reduce the temperature of the flue gas prior to injection of lime and thence through two fabric filters (baghouse).

The fabric filters use bags coated with a special catalyst for the removal of dioxin/furans. The flue gas is then discharged to atmosphere via a single stack.

Figure 18: Schematic representation of the Utashinai process flow



Source: Juniper interpretation of Hitachi Metals' information

The plant includes two shredders for MSW processing and size reduction (the ASR is delivered to site in a pre-processed condition). As discussed above, the crane operator picks alternate grabs of MSW and ASR and loads them into the feed hopper. From there a conveyor transfers the waste to the top of the PGR, within which it flows downward under gravity.

The vertical shaft reactor is an updraft gasifier in which the solid waste flows downwards and the produced syngas flows upwards countercurrently. The syngas therefore exits at the top and the ash/char phase flows to the bottom where the intense heat created within the met coke bed by the plasma plumes melts the inorganics to produce a slag. The reactor has a diameter at the bottom (where the met coke bed is formed) of 1.4 metres. This increases to 3.5 metres and then the freeboard section increases again to about 4 metres to lower the syngas velocity and reduce the level of solids entrainment. Each reactor has four WPC Marc 3a plasma torches arranged at 90^{o} intervals around the circumference of the cylindrical reactor. The torches are flush-mounted into the reactor walls and the plasma plumes produced by the torches extend into the met coke bed.

At start-up, the reactor is loaded with met coke (10 cm pieces) to form the coke bed. Additional met coke is added at a rate of 200 – 300 kg/hr. Limestone is also added in the form of seashells, which is a cost effective source of calcium carbonate available locally to the plant.

Figure 19: Metallurgical-grade coke used at Utashinai

Source: photograph taken by Juniper during visit

The fly ash recovered from the boiler, air pre-heater and baghouse is treated with chelating agents to encapsulate and stabilise the ash to negate the potential for heavy metal leaching. The ash is sent to a landfill for disposal.

The slag produced at Utashinai is porous and has a whitish appearance, which appears to be caused by the ASR content of the feed affecting the physical and chemical characteristics of the slag. Hitachi Metals has found that it is not suitable for recycling as an aggregate for construction applications and we were informed that it is sent to a landfill some 40 minutes away from the plant for disposal.

The tour around the plant was very informative and we were able to get quite close to the equipment, which is unusual for Japan where most tours take place behind glass via a specially designed walking route within the building. We could observe the slag outlet and an operator was positioned at this point and frequently used an oxygen lance to break up slag formations and stop them blocking the outlet port. In comparison to other Japanese slagging gasification plants visited by Juniper that have a much greater throughput capacity, the Utashinai plant equipment was quite large and tall relative to the capacity of each line (82.5 tonnes/day of ASR). The equipment was also located very close together without any discernible space between each piece to facilitate easy access and maintenance. Housekeeping standards appeared to be less rigorously maintained than at other Japanese plants we have visited.

We also observed that water extracted from the adjoining river was used to cool the metal shell of the gasification reactor. Water was seen flowing down the outside surface of the gasifier and there was evidence of the build up of mineral scale on this outside wall.

Mihama-Mikata

Mihama-Mikata is the second commercial reference plant – and, indeed, these two facilities are the only such references in the world processing MSW: regarded as "commercial references" by Juniper at the present time (other facilities being 'pilot' or 'semi-commercial' demonstrators). The Mihama-Mikata plant is 100% owned by the local government. Hitachi Metals supplied the plant on a 'turnkey' basis and it is operated by a private company, sub-contracted to the government. We understand that Hitachi Metals gave a process guarantee to the local government which relates to operating costs dictated by the consumption of electricity and coke. If the contracted operating costs increase then Hitachi Metals has to pay the difference. This indicates that Hitachi Metals had a degree of confidence in the technology and was sure that they could manage and operate the plant such that this contractual condition was not invoked by the client.

Juniper visited the Mihama-Mikata plant on 14 May 2008 in the company of Mr Akira Nomura (Sales Manager of Hitachi Metals).

The Mihama-Mikata plant commenced commercial operation in March 2003 and incorporates a 'Recycling Plaza', which processes 8.5 tonnes of delivered MSW in five hours.

The gasification plant is configured as a single line and was designed to process 22 tonnes per day of wastes: 17.2 tonnes per day of MSW and 4.8 tonnes per day of sewage sludge. The MSW is shredded on-site and the sewage sludge is partially dried to 50% moisture content by passing through a rotary kiln dryer where hot flue gases from the secondary combustor flow countercurrently to the sludge flow in the kiln.

As at Utashinai, the plant is configured as a close-coupled gasifier. Consequently, the syngas is immediately combusted in an afterburner and no electricity is generated. This configuration is again significantly different from the core design being considered for St Lucie and other new projects in North America.

Figure 20: The Mihama-Mikata facility

Source: Mihama-Mikata brochure provided by Hitachi Metals

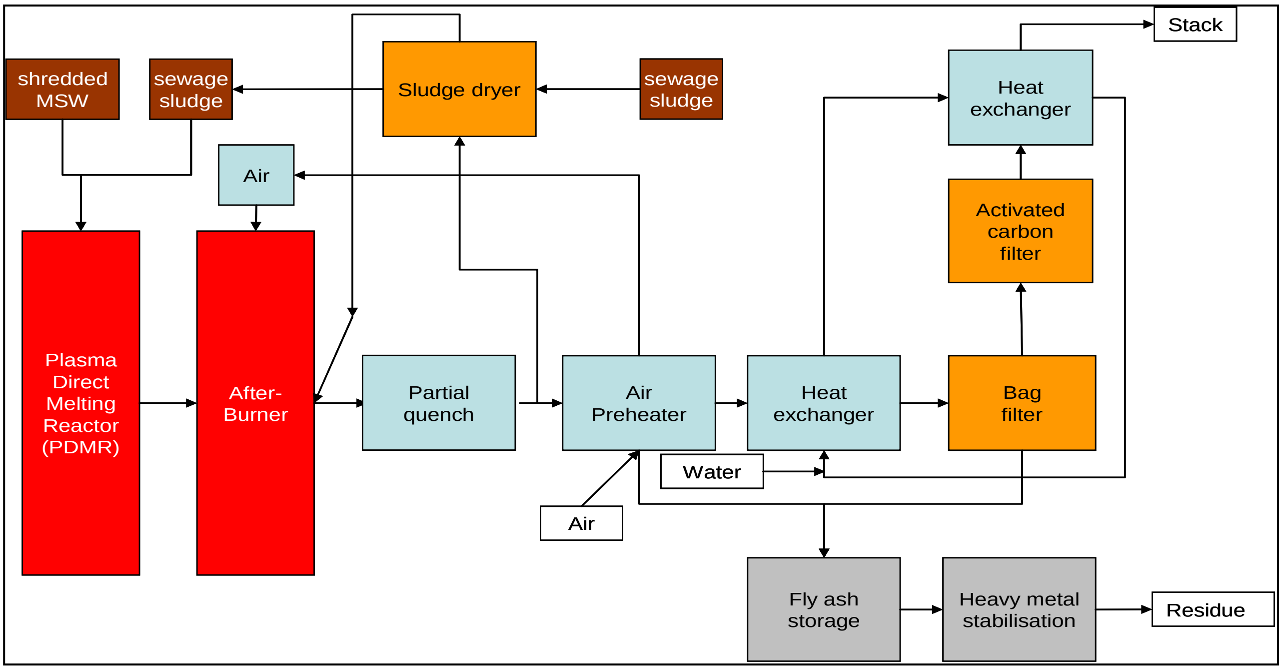
The Mihama-Mikata facility employs one plasma gasification reactor which produces a syngas and the inorganic content of the waste is melted to produce a slag. The syngas from the gasifier passes to a combustion chamber in a close-coupled configuration. Air is added at this point to produce a hot flue gas stream which passes through a bank of heat exchangers and thence through a baghouse and activated carbon adsorption tower before being discharged through the stack to atmosphere.

This area of the design is different from Utashinai because the bags in the baghouse are normal bags (not catalytically coated) and the dioxin/furan removal takes place in a separate adsorption tower. The flue gas passes through the first heat exchanger which preheats air which is used in the gasifier and the secondary combustion chamber. Further heat energy is recovered to provide hot water to heat buildings and to re-heat the flue gases in winter prior to discharge through the stack (to avoid a visible white plume).

A significant degree of materials are removed from the delivered MSW in the Recycling Plaza and the plant operates one shredder for size reduction of the residual MSW. The feed material is transferred from the storage bunker into the feed hopper by the crane operator and sewage sludge is pumped from the rotary kiln dryer into the feed hopper. A screw feeder transfers the MSW and sewage sludge into the gasifier via a side entry.

Other than the feed entry design, the plasma gasification reactor is the same as that used at Utashinai. The syngas exits at the top and the ash/char phase flows to the bottom where the intense heat created within the met coke bed by the plasma plumes melts the inorganics to produce a slag. Because the Mihama-Mikata plant is much smaller the reactor has only two plasma torches arranged opposite each other, in an offset configuration so that the two torches do not point directly at each other. As at Utashinai, the torches are flush-mounted into the reactor walls and the plasma plumes produced by the torches extend into the met coke bed.

Figure 21: Mihama-Mikata Process Flow



Source: Juniper interpretation of Hitachi Metals information

At start-up, the reactor is loaded with met coke (10 cm pieces) to form a bed. Additional met coke is added to the gasifier at a rate of about 200 kg/hr (about 5% of the feed). This met coke looked very similar to that used at Utashinai (see Figure 19). Limestone (rather than seashells) is added as the slag fluxing agent.

The plant produces 1.5 tonnes per day of slag which, we were informed, is used locally in road construction projects. The slag looks much different (more vitreous) to that produced at Utashinai.

The fly ash recovered from the second heat exchanger and baghouse is treated with chelating agents to encapsulate and stabilise the ash to negate the potential for heavy metal leaching. The ash is sent to a landfill for disposal.

The gasifier is operated at 850ºC and the secondary combustor at 900ºC (the hot gases are held in this chamber at that temperature for two seconds). The air used in the gasifier and secondary combustor is pre-heated to 280ºC (the air pre-heater at Utashinai is no longer used due to slag formation causing blockages).

As explained above, at Utashinai an operator was continuously using an oxygen lance to clear slag blockages at the tapping point of the gasifier. At Mihama-Mikata there was no operator present (see Figure 22). It should be recognised that the quantity of slag produced at Utashinai is much greater and that slag tapping at Mihama-Mikata is not continuous as a level of slag needs to build up before it will flow out of the gasifier.

It was reported by Alter NRG that, following a visit to the plant in 2008, Mr Osada stated no appreciable increase in power requirement to the plasma torches was observed if the air was not preheated.

Figure 22: Gasification reactor slag outlet at Mihama-Mikata

Source: photograph taken by Juniper during visit

During our visit, the plant was operating and as we passed through it everything appeared to be running smoothly. This was confirmed in the control room: the TV monitors showed all parts of the process to be operating well and the operators confirmed this when responding to questions. The plant appeared much cleaner than Utashinai and ‘housekeeping’ was excellent.

Operational Performance

The two Japanese references plants are the only ones using the WPC technology and processing MSW that have any performance history of any kind. Juniper has visited both facilities and our observations and findings from the visits are discussed below. Utashinai is considered by many to be the more important reference as it is the largest, but it does not process MSW alone.

Potential Sources of Unreliability and Mitigation Measures

The main areas where these facilities require regular maintenance include:

- shredders

  Shredder downtime is caused primarily by large metal objects jamming the machines and damaging the shredder knives. Utashinai has two shredders so that one is always able to operate if the other is undergoing maintenance. This is a prudent measure.

- gasifier refractory

  We understand that the refractory inside the gasification reactor is inspected during the annual maintenance shutdown and repairs are carried out, if necessary. Mr Osada stated that the gasifier refractory should last five years. Given that refractory lifetime is a key uncertainty for high temperature waste gasification, this track record provides significant risk mitigation for any future plants that use the same design and refractory specification.

- plasma torch electrodes

  The four plasma torches are operated continuously and are designed such that an isolation valve, located between the gasifier shell and the torch assembly, can be closed and that torch extracted from the gasifier while the other three torches continue to operate. It was explained that the torch change out time was very quick and that the torches are removed every 500 hours, inspected and the electrodes replaced if necessary. In our opinion, this is an excellent feature of the design, which offers significant advantages for boosting overall plant availability.

  We understand that the lifetime of the copper cathodes is typically 500 hours but the silver anodes can be rotated and can survive for about 1000 hours.

  Mr Osada explained that the operators hold two complete spare torches per gasifier and they carry out their own repairs.

- secondary combustor refractory

  This area of the process is where the major technical challenges are faced. Severe slagging is experienced at the top of the secondary combustor and in the connection between the gasifier and secondary combustor. 'Sticky' inorganic particulates adhere to the walls of the combustion chamber and either cause a blockage of the syngas outlet and/or adhere to the refractory wall at the top of the secondary combustor. The slagging gradually increases to form large 'stalactites' which eventually become too heavy, break off and damage the refractory at the bottom of the combustion chamber. Mr Osada stated that this part of the process is the major reason for downtime and is, in his view, associated with the processing of ASR.

Utashinai: Technical Challenges

Mr Osada stated that the performance of the gasification reactor and plasma torches was very good, but he also pointed out that the plant had suffered major technical challenges caused by the processing of ASR. Originally the afterburner temperature was maintained at 1200ºC because the chlorine content of the ASR was high, which caused refractory degradation and severe slag build up. With an ASR/MSW blend, the operating temperature has been reduced to 900ºC, which has alleviated the problem to some degree but slag still builds up, albeit over a longer period of time.

Mr Osada explained that the power generation of the plant is now only 4–5 MW because of the change in waste feeding and only a small amount of electricity is exported to the grid. The emphasis of plant operation is on maximising revenues from the tipping fees charged for processing the waste and not maximising revenues from power sales.

Hitachi Metals say that they operate both process lines continuously, but on the day of our visit one line was not operating and had been shutdown for two days prior to our visit. We were informed that this was an unscheduled outage related to an "ongoing technical problem". Since the plant was originally designed to process 100% ASR this has a much greater CV and will release a greater volume of syngas. In order to keep the gas velocity down, and avoid solid entrainment, the volume of the reactor had to be sized accordingly. The plant is now processing MSW and ASR in a 50:50 ratio with a total capacity of about 150 tonnes/day and with the CV of the MSW approximately 50% the value of the ASR. The volume of syngas produced is therefore lower; which, from a heat input standpoint, means that the plant is effectively operating at turndown. Mr Osada said that the plant was operated for a trial period with 100% MSW for one month and a capacity of 110 tonne/day/line was achieved.

Mr Osada reported that the operators experience technical challenges with the shredders because of large pieces of metal and metal objects, which should not be in the waste delivered to site but are occasionally present. He also stated it was essential that Utashinai had two shredders.

The composition of the syngas was not available for review. Mr Osada stated that it is never sampled for analysis because it is extremely difficult and dangerous to withdraw a sample.

Utashinai: Operational Availability

Before we discuss the performance of these facilities in terms of their plant availability it should be stressed that there is a difference between the way availability is viewed in Europe and North America versus how it is viewed in Japan. The drive in Europe and North America is to maximise the on-stream time to 'sweat the asset' and maximise revenue generation. In Japan, the plant is designed to process a particular annual tonnage of waste and will operate for a fixed number of days/year, typically 300 (82.2% availability in Western terms) with the remaining time being used for scheduled maintenance activities. The Japanese report on-line availability as the proportion of the operational days for which the plant is designed to operate. This results in a higher reported availability than would be given according to the Western system. However, renormalisation to take into account the annual shutdown is equally incorrect, because this would give a false, overly pessimistic, indication of the reliability of the facility.

On the above basis Mr Osada claimed an annual availability for the gasification island of 95%. Given the comments he also made about the ongoing technical challenges that are being experienced, it is clear that the overall availability will be lower as a result of unscheduled outages of the downstream equipment.

Mr Osada also explained that the operators try to operate the Utashinai plant for 300 days per year and schedule two planned outages of 30 days each. However, for the preceding 12 months the plant had achieved an operational time of about 270 days with the additional downtime caused by the slagging problems in the secondary combustor.

Mihama-Mikata: Technical Performance

It would appear that Mihama-Mikata has not suffered from the same technical challenges as Utashinai. Excessive slagging was not evident and the floor area of the facility was very clean with excellent housekeeping. Few personnel were observed as we viewed the process and no one was stationed near the slag outlet of the reactor.

During our visit to Utashinai, Mr Osada said that the operability and availability of the Mihama-Mikata plant was better. The secondary combustion chamber does not experience excessive slagging and the process appears to operate more easily with MSW. This was confirmed by Mr Nomura who also informed us that that the Mihama-Mikata plant operates for 2½ months followed by a two week shutdown for maintenance.

We were informed by Alter NRG that the plasma torches operate for 300 hours before they are removed for inspection and electrode replacement and this was confirmed by Hitachi Metals.

Environmental Impact

For any waste-to-energy facility the minimisation of environmental impacts is critical to the achievement of permitting and acceptance of the plant by local people. Alter NRG has not yet supplied a plasma gasification process themselves but the company obtained data from Utashinai and Mihama-Mikata relating to air emissions and slag leach testing. This data was made available to Juniper and our observations and comments are summarised below. The data for Utashinai and Mihama-Mikata are presented alongside each other.

Emissions to Air

Emissions data from the two Japanese plants is very limited. We understand that Alter NRG obtained certain publicly available data for emissions to air from both the Utashinai and Mihama-Mikata facilities and that this limited data, which was acquired over a period of several years, reflects the actual plant operational performance at the time the sampling and analysis took place.

Dioxin/Furans

Figure 23 gives dioxin[24] emissions from Utashinai and Mihama-Mikata sampled and analysed over the period 20 April 2003 to 30 March 2007 (for Utashinai) and 27 June 2006 to 29 November 2007 (for Mihama-Mikata). Samples are taken each year at both facilities but only data from these dates was given to Alter NRG by Hitachi Metals.

[24] *In Japan 'dioxins' are defined as polychlorodibenzo-para-dioxins + polychlorodibenzofurans + co-planar polychlorinated biphenyls (Law No. 105, Environmental Agency of Japan, 16 July 1999)*

Figure 23: Dioxin data for Utashinai and Mihama-Mikata

Date sampled	Total dioxins (ng-TEQ/m^3)[1]	Facility criterion (ng-TEQ/m^3)
UTASHINAI		
2003	0.0032 – 0.0098	
2004	0.0020 – 0.0050	0.01
2005	0.0068	
2006	0.0026 – 0.0094	
2007	0.0032 - >0.01	
MIHAMA-MIKATA		
2006	0.00004 – 0.0017	0.05
2007	0.0024 – 0.0026	
In accordance with Environmental Agency of Japan standards, all data converted to 12% O_2, 101kPa, 273K		

Source: Juniper analysis of data from Hitachi Metals (provided by Alter NRG)

The data excursion reported in January 2007 for dioxin emissions at Utashinai above the required regulatory limit was explained by a failure of bags in the baghouse, which caused the increase in measured emissions. The Utashinai plant employs specially coated bags that adsorb dioxins from the flue gas stream and, we understand, one or more of these bags failed allowing untreated flue gas to pass directly to the stack. It can be concluded that with the exception of this one upset condition at Utashinai the data presented demonstrates that the Utashinai and Mihama-Mikata facilities have operated in compliance with their facility performance criteria with respect to dioxin emissions.

Figure 24: Dioxin emission limit values for different geographies

Country	As promulgated	Converted to Japanese standard conditions[2] (ng-TEQ/m^3)
Ontario MOE A7 (11% O_2, 101 kPa, 298K)	80 pg-TEQ/m^3	0.079
CCME[3] (11% O_2, 101 kPa, 298K)	80 pg-TEQ/m^3	0.079
US EPA 40 CFR Part 60 (7% O_2, 101 kPa, 298K	0.1 to 0.3 ng-TEQ/m^3[4]	0.07
European Union (11% O_2, 101 kPa, 273K)	0.1 ng-TEQ/m^3	0.09

Source: Alter NRG (from a report produced for them by Golder Associates)

To put the emissions data shown in Figure 23 in an international context Figure 24 summarises the regulatory emission limits for Canada[1] (Ontario and Canada generally), the USA[2] and the European Union[3]. In order for

[1] *ng-TEQ/m^3 refers to the definition of dioxins on a Toxicity Equivalence basis*

[2] *12% O_2, 101 kPa, 273K*

[3] *Canadian Council of Ministers of the Environment*

[4] *Lower end of range provided by US EPA used in assessing compliance*

comparisons to be made, the emission limit values were converted and normalised from their national standard reference conditions by Golder Associates.

The dioxin data from Utashinai and Mihama-Mikata is the only example of such data for a plasma gasification process with a MSW feed and therefore this data will be sought by regulators from other jurisdictions to assess whether the process would comply with their limits. Unfortunately, because the Japanese regulatory authorities define what is included in such analysis differently (the Canadian, US and EU regulatory limit values do not include co-planar polychlorinated biphenyls in the definition of dioxins whereas the Japanese do), there are subtle differences in the methodology for calculating the TEQ[4] and the toxicity equivalence factors (TEF's) used for dioxin/furan isomers in those countries compared with Japan. Because the measured concentration values from Utashinai and Mihama-Mikata are at least an order of magnitude below the performance criterion and the differences in TEF's used in Canada, the EU and Japan are small, it can be concluded that for dioxins compliance with the required criteria in other countries would be likely.

Particulate, SO_2, NOx and HCl

Limited data for four other pollutants – dust (fly ash), sulphur dioxide (SO_2), nitrogen oxides (NOx) and hydrogen chloride (HCl) was made available for our review. This data derives from samples analysed over the period 22 February 2005 to 28 November 2005 (for Utashinai) and 24 March 2007 to 29 November 2007 (for Mihama-Mikata). Measurements are taken every year but this was the only data obtained by Alter NRG.

Figure 25: Emissions data for Utashinai and Mihama-Mikata for other pollutants

Date sampled	Particulate (mg/m^3)	SO_2 (ppmv)	HCl (mg/m^3)	NOx (ppmv)	CO (ppmv)
UTASHINAI (Facility criterion)	**40**	**120**	**200**	**150**	**--**
2005	<10	<2 - 2	6 - 31	79 - 130	--
MIHAMA-MIKATA (Facility criterion)	**20**	**60**	**100**	**150**	**30**
2007	<16 – 17	0.09 - <5	86 - 93	69 - 84	10 - 13
In accordance with Environmental Agency of Japan standards, all data converted to 12% O_2, 101kPa, 273K					

Source: Alter NRG

The data in Figure 25 indicates that both the Utashinai and Mihama-Mikata facilities have generally operated in compliance with their Japanese regulatory criteria for the six pollutants measured, which is as one would expect given that Hitachi Metals has had to satisfy the regulatory authorities in Japan on a regular basis that the air emissions are in compliance with these limits.

For particulate, SO_2 and HCl the Utashinai plant met the performance criteria easily but for NOx the emissions ranged from 52.7% to 86.7% of the facility criterion value indicating that NOx levels were sometimes relatively

[1] *Ontario Ministry of the Environment (Guideline A7) and Canadian Council of Ministers of the Environment (Canada Wide Standards and CCME Guidelines for MSW Incinerators)*

[2] *United States Environmental Protection Agency (40 CFR Part 60 Standards of Performance for Large Municipal Waste Combustors)*

[3] *European Union Directive (2000/76/EC)*

[4] *Toxic EQuivalency calculation based on the accepted toxicity value for each isomer of dioxin and furan*

close to the limit. This is a potential concern given that the actual emissions from a facility can vary considerably with time due to the varying composition of the input waste, especially if the average has been derived from a relatively small data set. NOx would appear to be an issue at Utashinai but not at Mihama-Mikata. This is probably due to the ASR containing materials with nitrogen-bound molecules which leads to increased post-combustion NOx production. It is unlikely that Utashinai would achieve compliance in Ontario, the US and the EU without additional downstream de-NOx technology. Based on the two data points available, Mihama-Mikata should meet the required criteria for all countries considered.

From the small number of data points available it would appear that the SO_2 emissions from both Utashinai and Mihama-Mikata would be fully compliant across all the geographies considered.

The measurements for particulate matter (fly ash) seem to be a relatively inaccurate indication of the plants' performance because they are presented as a concentration which is less than a specific value, probably the detection limit of the analytical instrument. For Utashinai, the presented data is below the limit values for Canada and the US but the data is insufficiently accurate and too close to the limit value to conclude that the plant would meet the EU compliance criterion. For Mihama-Mikata, the data is again presented as less than a specific value. There are only two data points available and from this limited information it would appear that the plant could meet the regulatory limit for Canada but would fail to meet those required for the US and the EU.

Figure 26 summarises the number of instances (within the data provided for review to Juniper) when the Japanese plants would have exceeded the emissions limits in North America and the EU.

Figure 26: Data exceedances from regulatory limit values for Utashinai and Mihama-Mikata

Pollutant	Data points	Ontario	CCME	US EPA	EU
		Number of exceedances			
Utashinai					
Particulate	6	0	0	0	Insufficient data
SO_2	6	0	0	0	0
HCl	6	1	0	1	1
NOx	6	2	0	3	5
Mihama-Mikata					
Particulate	2	Insufficient data	0	2	2
SO_2	2	0	0	0	0
HCl	2	2	2	2	2
NOx	2	0	0	0	0
CO	2	Not defined	0	0	0

Source: Juniper analysis

Consequently, for Utashinai (4 data sets of 6 data points), there were exceedances that were above the Ontario limits (3), the US EPA limits (4) and the EU limits (6) with the majority of exceedances (10) relating to NOx emissions.

For Mihama-Mikata (2 data sets of 2 data points) there were exceedances for particulate that were above the US EPA limits (2) and EU limits (2) and, for HCl, 2 exceedances each for all four regulatory regimes.

For future plants, Alter NRG would specify and design the downstream equipment to ensure compliance with the required regulatory regime.

Solid Residues

The plasma gasification process produces a vitrified slag that Alter NRG would like to recycle into construction applications as an aggregate material. The slagging process should encapsulate and immobilise heavy metals within the solid matrix of the slag and therefore the heavy metals should not leach out of the slag.

The Utashinai and Mihama-Mikata plasma gasification plants are located in Japan, as are nearly all of the other 100+ commercially operating slagging gasification plants that are processing MSW. The slag produced from most of these facilities is re-used in the Japanese construction industry; either as an alternative aggregate material for backfilling and in the construction of roads and car parks as a mixture with asphalt; or as a material from which construction products, such as paving slabs, roof tiles and construction blocks, are manufactured. Consequently, this slag must meet the relevant Japanese leaching tests to be acceptable for construction applications.

The relevant regulatory limits for the major heavy metals of interest to the Japanese are shown below and it can be seen that the stricter limits set for soil are the same as the limits set for drinking water quality:

Figure 27: Japanese regulatory limits for leaching

Heavy metal	Japanese regulatory limit for soil (mg/l) [MOE Notification No. 46]	Japanese regulatory limit for waste (mg/l)	Japanese regulatory limit for drinking water (mg/l)
Arsenic (As)	0.01	1.5	0.01
Cadmium (Cd)	0.01	0.005	0.01
Chromium VI (Cr^{6+})	0.05	0.3	0.05
Lead (Pb)	0.01	0.3	0.01
Mercury (total) (Hg)	0.0005	0.3	0.0005
Selenium (Se)	0.01	0.3	0.01

Source: Nippon Steel Eng'ng & Office of Drinking Water Quality Management, Ministry of Health, Japan

Figure 28: Leachate testing limit values for thermal plant residues for the USA, Germany and Switzerland

Heavy metal	US drinking water limit (mg/l)	German DEV S4 (mg/l)	Switzerland TVA (mg/l)
Arsenic (As)	0.01	0.2	0.01
Cadmium (Cd)	0.005	0.05	0.01
Chromium VI (Cr^{6+})	0.1[33]	0.05	0.01
Lead (Pb)	0.015	0.2	0.1
Mercury (total) (Hg)	0.002	0.005	0.005
Selenium (Se)	0.05	--	--

Source: US EPA website & Studies in Environmental Science 67, IAWG, 1997

[33] *This refers to total chromium but the regulation assumes the toxicity characteristics of Cr VI*

It should be noted that the German and Swiss regulatory limits relate to the protection of groundwater from heavy metal contamination produced by material that would be disposed of in a landfill. It can also be seen from Figure 28 that the Swiss TVA is more stringent than the German DEV S4. The Japanese regulations are as stringent (As and Cd) or more stringent (Hg and Pb) than their European counterparts. If the leaching results from Mihama-Mikata slag could be shown to meet the JLT-46 test protocol then it should be acceptable for use in construction applications in Japan and in many other countries. Only the leaching of chromium would need to be rigorously assessed for Switzerland.

Alter NRG commissioned some leachability testing, from ALS Laboratory Group, on slag samples they obtained from Mihama-Mikata, which processes primarily MSW.

ALS reported analytical results from one test for the TCLP[34] protocol for leachable metals, which is based on US EPA SW846 Methods 1311 and 6010. The TCLP test is well known and used widely in the US to assess leachability. It was developed by the US EPA to determine whether a waste is hazardous by its toxicity characteristic (TC). The chemical concentration in the leachate is compared with specified concentrations in the TC list to determine whether a hazardous waste has met the requirements of land disposal restrictions.

Figure 29: Leaching test data for a slag sample from Mihama-Mikata

Heavy metal	Japanese MOE Notification No. 46	Mihama-Mikata data
As	0.01	0.0023
Cd	0.01	< 0.0005
Cr^{6+}	0.05	0.0289
Pb	0.01	0.001
Hg	0.0005	< 0.00001
Se	0.01	< 0.01
All concentration data is mg/l The chromium number reported by ALS for Mihama-Mikata is for total chromium and not Cr^{6+}		

Source: Alter NRG

The TCLP data for Mihama-Mikata slag is 'orders of magnitude' less than the JLT-46 limits. It should be noted that the ALS analytical report only includes one set of results from one sample tested. This limits the value of the data and excludes the possibility of defining any level of statistical confidence.

We understand, however, that Alter NRG is undertaking further leach testing analysis in Japan and intends to subject further samples of slag from Mihama-Mikata to the Japanese leaching test (JLT-46).

Landtake and Visual Impact

The footprint and visual impact of the Alter NRG plasma gasification process would be similar to that for a conventional moving grate incineration process of equivalent capacity. The overall site footprint could be slightly larger because of the need for the more complex water treatment plant which would require a larger land area. The height of the stack would depend on the regulatory rules of the location of the plant. An external photograph of the Utashinai plant can be seen in Figure 16 and of the Mihama-Mikata plant in Figure 20.

[34] *Toxicity Characteristic Leaching Procedure*

The DBM provides a preliminary plot layout for the standard design with a total area of 40,000 m^2 (430,000 ft^2) or 4 hectares. The throughput capacity of the plant is 750 tpd (≡ 234,375 tpa[35]), the required landtake is therefore 0.171 m^2/tpa.

Utashinai has a plot size of 10,000 m^2 (107,600 ft^2) or one hectare. The Mihama-Mikata plant, which is a much smaller plant, has a plot size of 12,000 m^2, but this includes an extensive Recycling Plaza.

BUSINESS FOCUS & MARKET STRATEGY

The focus of this review is the design of the core technology, which Alter NRG considers to be the gasification island, incorporating the know-how of WPC and Waste-to-Energy applications. However, Alter NRG also has a declared strategy to become a meaningful producer of commercial fuels: including syngas; diesel; ethanol; hydrogen; steam and electricity, by leveraging its plasma gasification technology. The company's focus is to position itself to become a leader in the production of these clean energy alternatives.

Market Strategy

Alter NRG has informed Juniper that their growth will be fuelled by three primary business models:

1. one time technology sales – the model used by WPC for the sale of technology to India and Turkey (see Commercial Orders, page 28);
2. development of projects, supply of the core gasification island, project management and possible equity participation – largely in relation to projects being developed in North America;
3. licensing of the WPC core technology – mainly outside North America to leverage their market position and create a revenue stream from royalty payments.

The four target markets for project development currently being pursued by Alter NRG are:

1. Waste-to-Energy (WTE);
2. Coal-fired power plant retrofit;
3. Petcoke to syngas, power or liquid fuels;
4. Coal-to-Liquids (CTL)[36].

The first of these is the focus of this review and is discussed below. The remaining opportunities are referred to later in this report.

The company is also opportunistically generating revenues from sales of torches, conducting customer trials (on a paid basis) and sales of equipment (such as the current orders in India for plasma gasifiers to process hazardous wastes.

[35] *assuming an online availability of 7,500 hours per year*

[36] *We understand that Alter NRG do not intend to use their plasma gasification technology for this market opportunity*

This is a more broadly based range of opportunities than is currently being pursued by competitors. Such diversification is a challenge (in terms of resources and focus) for Alter NRG, in our view, but is also a great opportunity for the company both in terms of accelerating growth and diversifying risk.

The Waste-to-Energy market is very attractive to Alter NRG because the revenues generated from the production of power or ethanol are combined with the tipping fee (gate fee) charged to the owner of the waste for processing.

The company is focussing its attention on areas of North America with high population, high tipping fees and/or high power prices. However, it should be noted that the processing of MSW poses significant technical challenges which, in past projects with other technologies (including conventional gasification and slagging gasification), has caused project delays, sub-optimal performance of the gasification-to-power process and, in some cases, project failure. In our discussions with Alter NRG engineers, they have informed us they are aware of these challenges and are planning accordingly.

Project Delivery

As we have pointed out Alter NRG intends to generate revenue via:

- technology sales, where they will sell the plasma torches and detailed engineering design of the gasification reactor; and
- technology sales, where they will sell the Gasification Island (plasma gasification reactor complete with plasma torches, slag handling system, feed hopper, particulate removal and syngas cooling); and
- developing projects, many in partnership with others, that will utilise the WPC plasma gasification process.

But, they do not anticipate being:

- a turnkey supplier of a fully integrated facility;
- undertaking the detailed engineering of projects;
- providing the overall "wrap"/process guarantee on projects.

This seems to us a potentially difficult position from a commercial perspective given the markets' current prejudice in relation to scope-of-supply.

The Gasification Island will be Alter NRG's core offering and the company will provide this as an engineered package. The upstream waste handling elements and the downstream syngas cleaning and power island would be supplied by others, managed by an EPC[37] partner, who would also provide all of the wrap-around engineering. The partner EPC contractor could vary, depending on the geographical location of the project. At the time of preparing this review Alter NRG did not have an active EPC partnership agreement with any company.

It is not clear to Juniper which corporate entity would provide the total process guarantee for the integrated process and who would be the contractual counter-party to the owner/client. Alter NRG has stated their intention to invest in projects as an equity participant. This will provide a level of comfort to the plant owner because this would provide a disincentive for Alter NRG to walk away from a project where the technology was under-performing.

[37] *Engineer, Procure & Commission*

Strategic Relationships

Alter NRG has entered into strategic alliance agreements with external companies to leverage outside human resources and finance and hence help the company grow faster by developing a broader portfolio of opportunities.

In 2007 Alter NRG announced a technology licence and strategic partnership with NRG Energy Inc., one of the largest IPP's in the US. As already mentioned they have jointly announced a retrofit project at the Somerset power plant in Massachusetts, USA (see Co-gasification of Coal and Biomass, page 50). This may be Alter NRG's first plasma gasification project to commence operation and the first of its kind in the USA. The licence with NRG Energy should also open up the potential market opportunity for more power station retrofits.

The company has an agreement with Coskata to use the Waltz Mill pilot facility to produce syngas from various waste streams (see Gasification of MSW to Ethanol, page 52).

Alter NRG has developed a close working relationship with Bower, Damberger and Rolseth Engineering Ltd. (BDR), a Calgary-based engineering firm, owned by AMEC, with nearly 25 years experience in the design, engineering, procurement and management of oil and gas facilities. BDR is currently conducting engineering studies with respect to the use of the WPC plasma gasification technology in Alter NRG's target markets. Alter NRG will contract with BDR on a project-by-project basis.

We understand that Alter NRG is currently working to identify EPC contractors as potential partners for projects around the world.

Syngas Conversion to Added Value Products

Over the past two decades, there has been a boom in biofuels production and a significant increase in support for R&D within this sector, particularly from the US Department of Energy (DoE). There are several drivers that have triggered this trend, but the most influential seem to have been:

- energy security;
- an unprecedented increase in crude oil and natural gas prices; and
- an increasing concern over climate change.

With predictions from energy experts that:

- crude oil prices are unlikely to ever fall back to the levels observed in the first half of this decade;
- reserves of crude oil are beginning to diminish;
- concerns over the stability of energy supplies over the medium to long term will increase; and
- a new commitment and global determination to address environmental issues will emerge.

Consequently, the prospects for emerging technologies for biofuels production would appear to be very good.

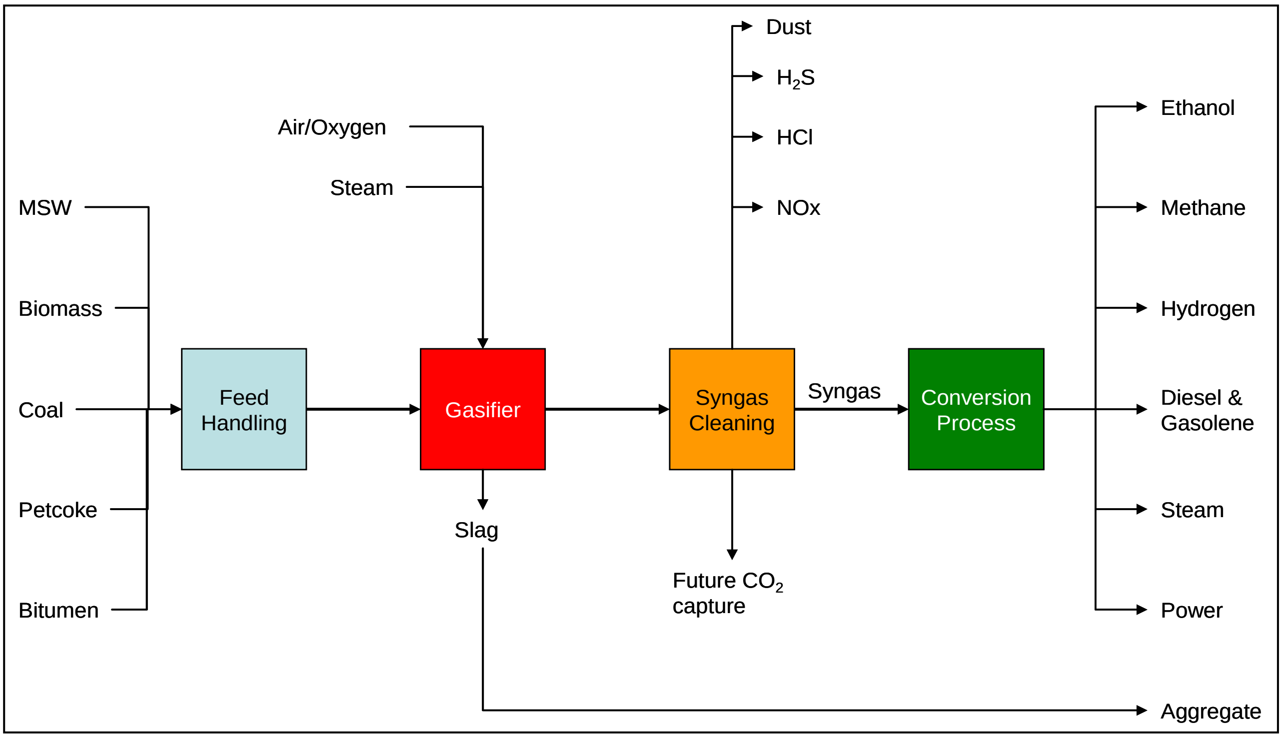
Biofuels are an added value product and they refer to biogenic[38] combustible fuels which provide an alternative to conventional fossil fuels. In principle, they can be used for heat and power, as transport fuels, petrochemical feedstock or pipeline quality gas. The transport fuel market appears to be the area where biofuels, such as gasoline, diesel, jet fuel, compressed natural gas (CNG) and their substitutes or alternatives, can make the most significant contribution to global sustainability. The drive to produce alternative transport fuels using thermal processes, such as gasification, is gaining ground as part of the overall increased activity in this sector because of

[38] *Biogenic: produced by living organisms, as opposed to fossil…*

the concern that agricultural biomass routes to transport fuels potentially divert land suitable for growing food to the production of biofuel pre-cursors like corn with the possible consequence of food shortages.

Alter NRG is pursuing a strategy to address this market need and the way in which the company intends to apply the plasma gasification process is schematically represented in Figure 30. The company's main focus is on diesel and gasoline production from coal to be delivered via their coal-to-liquids opportunity at Fox Creek in Alberta, Canada (see Coal to Liquids (CTL), page 56) where a gasification process will be used to convert coal to syngas which will be converted to diesel via Fischer-Tropsch catalytic technology. This process concept is well proven, particularly in South Africa (Sasol). Alter NRG is also pursuing ethanol production from syngas via their strategic alliance with Coskata (see Gasification of MSW to Ethanol, page 52).

Figure 30: Feedstock to added value product pathways proposed by Alter NRG



Source: Juniper interpretation of Alter NRG information

Co-gasification of Coal and Biomass

The utility power plant retrofit market is, in our view, becoming a very attractive opportunity because of several market drivers related to reducing environmental emissions and improving plant economics. At many US power plants the current environmental permits are expiring and they are required either to retrofit expensive gas cleaning technologies; or completely replace the power plant with a new one; or face compulsory closure (similar opportunities also exist in some other markets). From data provided by Alter NRG, we understand that retrofitting is less costly ($1,500 to $1,800 per kW) versus building a new supercritical coal plant or an IGCC coal plant ($3,000 to $5,000 per kW). Consequently, the retrofitting of a plasma gasification process is a potentially attractive proposition for many IPP's. They would co-gasify coal and wood (or other biomass/waste) to produce a clean syngas which is burned in the coal boiler, displacing coal with renewable biomass thereby reducing non-renewable CO_2 emissions.

NRG has identified 322 coal-fired boilers in North America which would be suitable for retrofitting.

We understand that the Somerset project is just the first of several opportunties that are currently under consideration by NRG. Indeed in April 2007 Alter NRG granted NRG Energy Inc. a five-year US licence to use WPC plasma gasification technology to retrofit coal-fired utility power plants. NRG Energy is one of the leading power generators in the North East US (they also have operating assets on the west cost, in the central south east of the USA and Texas) and produce 23 GW of power from primarily coal and natural gas. NRG Energy is considering a repowering project at their Somerset plant in Massachusetts. This facility must either repower by 1st January 2010[39] or close down and we understand the viability of an APC[40] retrofit upgrade has been determined to be uneconomic. NRG Energy received Massachusetts DEP approval for the project in January 2008 but an environmental group (CLF) has launched two appeals, which were unsuccessful. CLF has launched a third appeal that continues to slow the project down and the Massachusetts DEP has extended the deadline for plant closure to mid-2010. Alter NRG has therefore stated that the timing for commencement of the project is unclear.

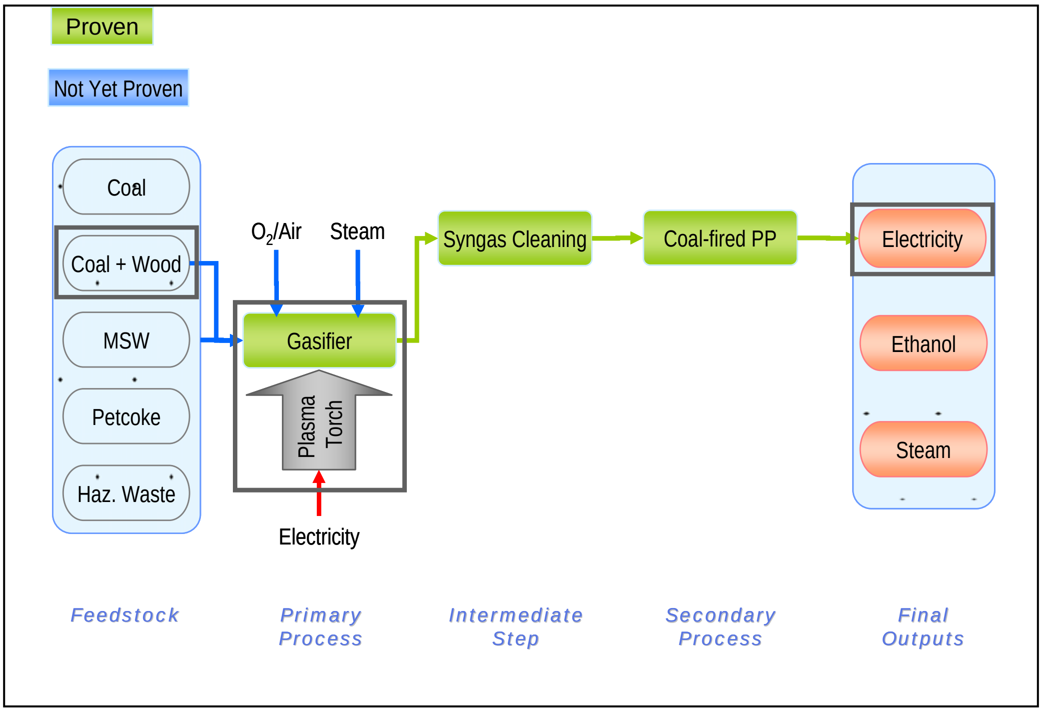
This plant is a pulverised coal station originally producing 380 MW. It was built in 1925 and a number of older units have been retired in place. The repowering project would produce 120 MW from the blend of coal and biomass (wood). Consequently, NRG is looking to install a plasma gasification process to convert a mix of coal and biomass (wood chips) into syngas. The syngas would exit the plasma gasifier at 1093°C (2000°F) and be cooled to 260°C (500°F). It would then pass through three cleaning processes to remove particulate (dust), mercury (95%) and sulphur (95%). A 60% reduction in NOx emissions is also anticipated. An optional carbon capture retrofit will be included in the design for future implementation. The cleaned syngas would be injected through burners into the coal-fired boiler to be burned as 'pseudo' natural gas.

Figure 31 depicts the process configuration that would be used. This design has been applied in Scandinavia with mixtures of coal with biomass and the requirements for syngas cleaning and burner firing are relatively well known.

[39] *The Massachusetts Powerplant Rule (310 CMR 7.29, 2001) focuses on four primary pollutants – SO_2, NOx, Hg and CO_2 (which will transfer to RGGI – Regional Greenhouse Gas Initiative, which is a Federal programme)*

[40] *Air Pollution Control*

Figure 31: Schematic representation of the Power Plant Repowering project model



Source: Juniper interpretation of Alter NRG information

NRG Energy has secured a permit to use various biomass materials, such as; green wood, urban tree trimmings, construction & demolition wood, paper cubes and liquid biodiesel.

Gasification of MSW to Ethanol

Alter NRG's Waltz Mill pilot gasification facility in Madison, Pennsylvania has been chosen by Coskata Inc. as the site at which they will construct the first commercial demonstrator for their much talked about ethanol from cellulose technology. This demonstrator will take syngas from Waltz Mill and convert it into ethanol using their proprietary syngas to ethanol conversion technology.

The facility is planned to deliver 30,000 - 40,000 US gallons per year of ethanol. Alter NRG will use their existing gasification pilot plant to convert various biomass and waste materials into syngas which will be fed to the Coskata bioreactor – that uses a microbial anaerobic fermentation system.

Some naturally occurring bacteria produce ethanol from syngas via the action of their metabolism; including Clostridium Ljungdahlii, Clostridium Autoethanogenum and Clostridium Carboxidivorans. The bacteria operate best in an aqueous environment and in the absence of oxygen (as it is fatal to them), under mild conditions, i.e. ambient temperature and low pressure. Coskata has developed a bioreactor that harnesses the capability of these bacteria to produce ethanol from syngas at an industrial scale. The Coskata concept has three major steps:

1. clean syngas production (outsourced to Alter NRG);
2. syngas fermentation into alcohol; and
3. alcohol refining.

The first step will be carried out by Alter NRG's plasma gasification reactor in which biomass and wastes will be gasified to produce a raw syngas. This syngas will then be cooled and cleaned. Although cooling the syngas facilitates its clean-up, the main reason for doing so is that the bio-reactor needs to operate at a temperature of 37ºC, which is the temperature at which the bacteria thrive. Energy could be recovered from this step.

In the second step, the syngas enters the bioreactor and comes into contact with the bacteria. The bacteria produce ethanol and release it into the water media. This process is said to have several advantages over catalytic processes (such as Alcohols synthesis and Fischer-Tropsch), which include:

- higher specificity, yielding higher amounts of the main product (ethanol) and fewer by-products;
- lower energy requirements;
- milder conditions, with low temperature and pressure;
- generally greater resistance to catalyst poisoning by trace contaminants in the syngas stream, such as H_2S and COS; and
- the fact that the chemical reactions are irreversible which facilitates complete conversion.

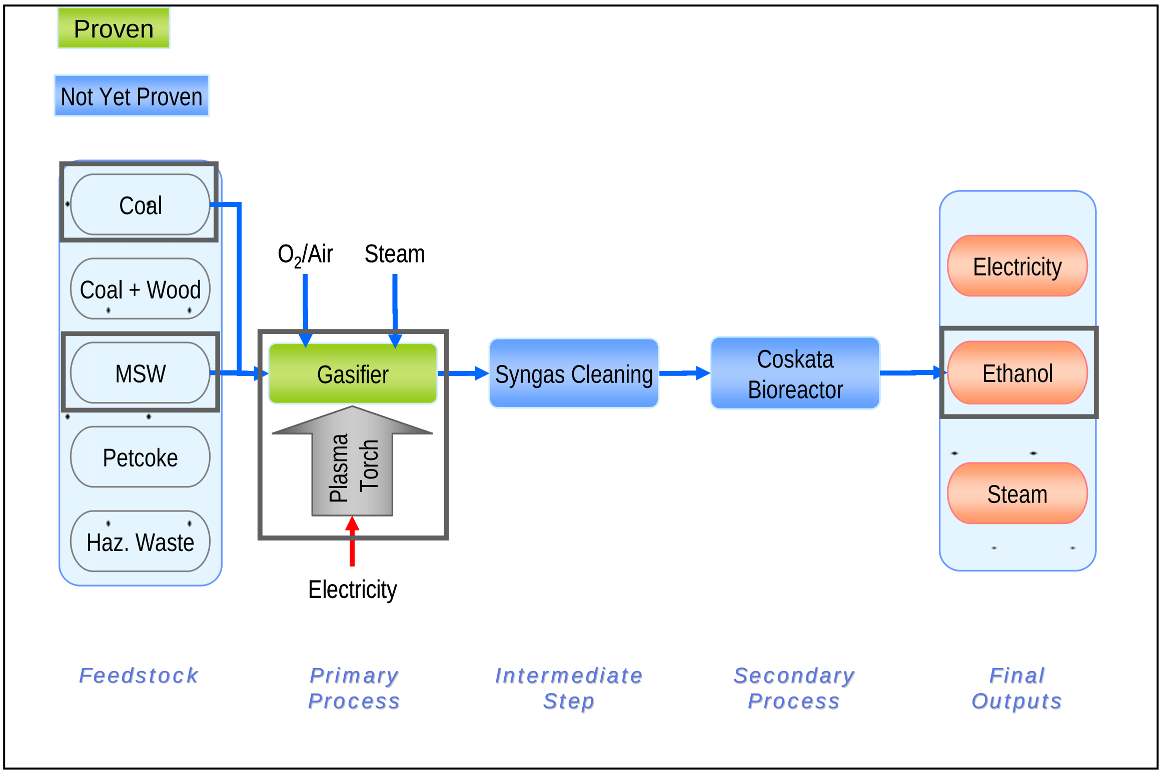
Coskata is not the only company using this pathway to produce ethanol, but the company claims to have developed a unique reactor design that maximises the yield of ethanol. No details of the internal design of the Coskata bioreactor were available for review. From descriptions we have read it would appear that the reactor is a vessel filled with packed thin hollow fibres. The syngas is delivered through the fibres, water, bacteria and nutrients circulate on the outside of the fibres filling the vessel without making direct contact with the syngas. The bacteria grow in biofilms on the outer wall of the fibres and reach the syngas as the latter diffuses outwardly through the membrane-like walls of the fibres. The bacteria release the ethanol in the water media which is subsequently carried away. This design apparently results in higher ethanol yields because:

- syngas is fed to the bacteria in higher concentrations than would be possible by dissolving the syngas in the water media; and
- water circulation can be optimised to keep the concentration of ethanol within the limits at which it is not toxic to the bacteria[41], but without carrying away the syngas or bacteria with it.

The last step of the process is the ethanol refining system. A description of the process suggests that it uses permeation, a process that funnels the water/ethanol mix through microscopic tubes coated with a polymer that attracts water. The water is sucked out and recycled back to the bioreactor, leaving pure ethanol vapour to condense. Although this technology is already known, it has not generally been used to refine ethanol from direct fermentation of grains and sugar sources because residues in suspension can clog the tubes and cause the system to fail.

[41] *A report by Vessia, Ø. (Biofuels from lignocellulosic material – In the Norwegian context 2010 – Technology, Potential and Costs. Norwegian University of Science and Technology, 2005) suggests that concentration of ethanol in the aqueous solution must be kept below 3%.*

Figure 32: Schematic representation of the process configuration for the Alter NRG / Coskata partnership



Source: Juniper interpretation of Alter NRG information

In January 2008, General Motors (GM) and Coskata announced a partnership to produce ethanol at commercial scale from virtually any renewable organic materials. We understand that GM views this as a major strategic alliance. The alliance can also indirectly benefit Alter NRG because the Coskata process requires the organic feed to be converted to syngas and their plasma gasification technology can deliver that objective.

Coskata has stated that it can produce commercial ethanol at $1 per US gallon[42]. Recently, an energy analyst (Robert Rapier) has questioned this number as "... unbelievable!" because he points out that Coskata's economic calculations do not appear to include the capital cost of the plasma gasifier. Coskata has subsequently said in response that the pilot unit does not benefit from economies of scale and their calculations for larger scale plants are much more favourable. Although Juniper has reviewed the economics of producing syngas, we have not had access to proprietary cost data from Coskata and so cannot comment.

Gasification of Petcoke

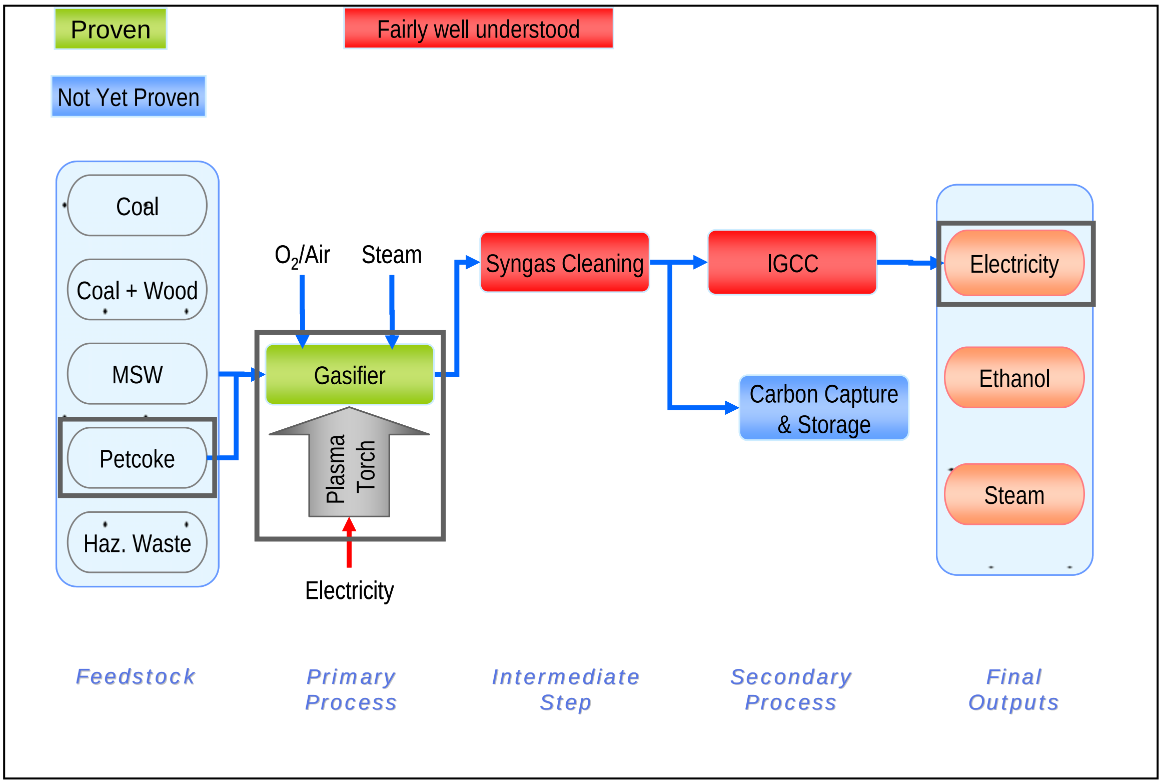
Alter NRG is pursuing a petcoke gasification project in the Alberta oil sands area. The gasification of petcoke (a by-product of crude oil upgrading) can produce a suitable syngas for displacing natural gas in upgrading operations or electrical power.

In January 2008, Alter NRG announced a large project in Bruderheim near Alberta. This will employ an IGCC facility with an expected 120 MW power generation capability. The plasma gasification reactor will process petcoke and oilfield waste to produce syngas which will be cleaned to a quality suitable for use in a gas turbine.

[42] *this relates to operating costs only and does not include capital or financing*

The Bruderheim site, which Alter NRG has confirmed they have now purchased, presents an excellent opportunity for Alter NRG because it has existing infrastructure including rail access, buildings and a connection to the power grid. Alter NRG will be paid a tipping fee (gate fee) for the oilfield waste and the proposed CO_2 capture facility will produce a product which they say can be sold to nearby oilfields for enhanced oil recovery.

Figure 33: Schematic representation of the Petcoke to Power via IGCC configuration



Source: Juniper interpretation of Alter NRG information

We understand that the project, which should be Alter NRG's first operational project in their home market, will be completed in two phases:

1. Natural gas will be used in a gas turbine to produce 120 MW of power. This is a low risk project which will not require excessive engineering and should receive regulatory approvals relatively quickly. This first phase is scheduled for completion in early 2010;

2. Install a plasma gasifier to produce syngas to replace the majority of the natural gas in the same gas turbine and maintain the same power output of 120 MW.

There are already several petcoke IGCC plants (supplied by GE and Shell) operating and the syngas cleaning requirements for utilisation in a gas turbine are reasonably well understood. Therefore, Alter NRG should be able to tap into an existing knowledgebase that could help to mitigate the risks associated with their Bruderheim project.

The company will also explore opportunities to apply its gasification technology in other areas of Alberta where oil and gas related by-products present economic potential.

Coal to Liquids (CTL)

Alter NRG owns 468 million tonnes of coal reserves in Alberta and, with the current interest in transportation fuels; it plans to convert this large asset into high value liquid fuels, such as diesel and naphtha using a gasification process and Fischer-Tropsch catalytic technology supplied by others.

The company has made a strategic decision to develop a Coal-to-Liquids project. They plan to build a plant at Fox Creek to convert this coal asset into synthetic diesel. They have not yet selected the gasification process for this project. Alter NRG has calculated that "*... this quantity of coal could be converted to approximately 50,000 barrels/day of diesel for about 40 years*". The Fox Creek location possesses other advantages, such as close proximity to major light oilfields which could allow CO_2 sequestration. It is also close to existing refinery infrastructure and product end markets.

Alter NRG has informed Juniper that they have initiated a search for strategic partners and have begun the process of gaining regulatory approvals. The first phase of the CTL plant has been projected to commence operation some time in the 2014 – 2016 time window.

Like the petcoke to power via IGCC application, the conversion of coal to syngas, cleaning to the quality required by Fischer-Tropsch catalytic process and the catalytic conversion to synthetic diesel are all fairly well known processes. There is therefore an existing knowledge base but technical risks would need to be identified, acknowledged and managed to ensure a successful implementation of this process concept.

JUNIPER'S OPINION

Alter NRG has publically declared its strategic intent to become "... a meaningful producer of energy and commercial fuels ... by leveraging the WPC plasma gasification technology". They have announced projects where they will use the plasma process to gasify: coal; petcoke; biomass and wastes to produce: power; 'over-the-fence' steam; syngas and ethanol. This is an ambitious objective in the context of the current stage of development of both the overall market for plasma gasification and Alter NRG's relatively limited track record. Nevertheless, Juniper believes that this company is better positioned than many to capitalise on this opportunity for the reasons outlined below.

The company is clearly pursuing a market driven rather than technology driven strategy. In our view they have accurately identified that there is real interest in North America to develop clean coal and waste/biomass to fuels opportunities, led by the current cost of oil and gas and the political fears concerning energy security.

The public announcements made so far by the company relate to projects in different market niches:

- MSW-to-Energy projects. Our analysis indicates that there is a significant appetite around the world for plasma gasification plants to process MSW. In our opinion, many traditional waste management companies have under-exploited this interest, leaving scope for relatively new, more pro-active players. This technology is seen as an advanced, cleaner technology than conventional incineration and the market potential is huge. The St Lucie project was the first plasma gasification project announced, originally by Geoplasma, which would utilise the WPC technology. It would appear that, since their involvement, Alter NRG has re-focused this project on a lower risk implementation. We see this as a positive step, but the project's future remains uncertain and failure or troublesome commissioning could adversely impact on Alter NRG's image in this core market sector.
- Power Plant Repowering. For several years now, Juniper has seen this application as an extremely attractive market opportunity. Recent trends in energy prices and pro-active economic initiatives to lower the greenhouse gas impact of electricity generation have made it more so. Alter NRG's alliance with NRG could deliver an attractive reference project that could be 'cloned' widely. If successful, we would expect this project to attract the attention of utilities worldwide. For this reason, we see this as a major growth opportunity for Alter NRG.
- Petcoke to Power. Large scale gasification of petcoke is a reasonably proven technology and we have been informed that Alter NRG has conducted extensive trials at Waltz Mill with petcoke. The Bruderheim project is a response to the upsurge of activity in the Canadian oil sands, which requires a significant amount of energy to mine and recover the oil tars. The project is planned to convert petcoke and oilfields waste into electrical power and, if successful, would be at a scale to place Alter NRG alongside the other leaders in this market, such as GE and Shell.
- Coal-to-Liquids. The Fox Creek project is a major strategic development for Alter NRG. The company plans to convert its own Alberta coal assets into liquid fuels, such as synthetic diesel, to supply the burgeoning alternative vehicle fuels market in North America. The company has stated[43] that "... their coal assets could produce some 50,000 barrels per day of diesel for 40 years". This contribution to the diversion of vehicle fuels away from crude oil dependence would be of great interest to other countries outside North America.
- Hazardous waste gasification. This market opportunity allows Alter NRG, through WPC, to sell the plasma torch technology and engineering designs for the PGR to third party customers who then take responsibility to design, engineer and construct the balance of plant. Alter NRG therefore benefits from the equipment and licence revenues, which will create welcome cashflow for the business. However, if the third party project implementation and plant operation is sub-standard then the possible poor image that these projects might create in the marketplace could have a negative impact on Alter NRG's reputation and create a negative stigma for the company. This aspect of commercial risk needs careful monitoring and pro-active management.

[43] *Alter NRG Corporate presentation, September 2008, from www.alternrg.ca*

In our opinion, this is an unusually rich portfolio of opportunities, which could result in major growth for Alter NRG. The company also appears to be different from most of their competitors who seem to be focussing only on one opportunity - the MSW market. Alter NRG therefore has a more flexible market strategy and is addressing both the waste management and power generation markets, thus diversifying market risk. However, developing such a broad portfolio could stretch resources, which in turn may increase project risk for individual opportunities.

There is a significant amount of visibility surrounding plasma-based waste processes at the present time with many companies actively promoting technologies for MSW applications. In order to be successful, technologies must be able to demonstrate actual continuous operation, preferably in a commercial environment, which would make them 'bankable' in the eyes of the financial community and their advisors. This requirement is accentuated by recent tightening in financial markets that have led to a greater intolerance of technology risk by sources of project finance.

Alter NRG has a number of competitors with technologies at varying stages of development. The fact that the company has access to a world class pilot facility (see Waltz Mill Pilot Plant, page 8) and two commercial reference plants processing MSW (albeit using other wastes as co-feeds and built and operated by Hitachi Metals rather than themselves) at Utashinai (see page 31) and Mihama-Mikata (see page 36) give Alter NRG a significant commercial advantage. The two Japanese reference plants, although relatively small capacity, have operated for several years.

With respect to the plasma gasification island Juniper considers the Westinghouse core technology to be more proven for MSW applications than directly competitive plasma-based systems. WPC has stated publically that their plasma torches have currently operated for more than 500,000 hours in various industrial applications since 1989.

However, for an overall project to be successful the complete integrated process with the 'balance of plant'; including the syngas cleaning processes and the power island and their integration all need to demonstrated in a fully commercial project. At this time Alter NRG cannot demonstrate their process is fully proven because they have not yet implemented a MSW project.

A critical success factor required to fulfil this potential is the selection and partnership with one or more EPC contractors. As we have discussed (see Project Delivery, page 48) Alter NRG intends to supply the gasification island only, which it sees as the core technology. We understand that for each project the proposed strategy would require a partnership with an EPC contractor to: procure the balance of plant (via third party suppliers); undertake the required detailed engineering of ancillary systems and integration of the process elements; project manage the complete project; and commission the process up to handover to the client. As yet, Alter NRG has not worked in this mode with any EPC contractor and, in our opinion; there are contingent risks (both commercial and technical) associated with this business model. We understand that Alter NRG is prepared to take an equity stake in the SPV[44] created for such projects and this will provide comfort to the major shareholder in the SPV that the company is prepared to stand behind the technology. In our experience; however, EPC contractors are reticent to take an equity position in a project and it is unlikely that any EPC contractor would demonstrate such commitment. The issue of the overall process guarantee is also a critical factor and a strategy for delivering this to a project must be developed to satisfy: the client, their advisors, the banks providing project finance and their advisors.

Alter NRG has a number of commercial advantages over its competitors. It now owns the WPC technology and its extensive patent portfolio, and has retained the key personnel from WPC, with their combined technical experience, to become a world leader in the design and supply of plasma-based systems. The Waltz Mill pilot

[44] *Special Purpose Vehicle – a company created specifically for large waste projects*

facility is a major advantage as it provides the opportunity to run in-house test programmes and the ability to test actual waste streams for potential clients. We understand that Alter NRG has an agreement with Hitachi Metals which gives them full access to the two commercial plants in Japan. It is critical to Alter NRG's sales and marketing activities that the Japanese plants remain available for client visits. Consequently, it is essential that the company maintains its good relationship with Hitachi Metals. Alter NRG's main competitors do not have an operating reference plant or, in many cases, a credible pilot plant to assist with marketing their processes.

Notwithstanding these advantages, Alter NRG faces a number of technical challenges to implement the current projects it is developing.

They have no experience with the handling and pre-treatment of MSW. We see this as a significant issue for them and their US partners (who have a similar lack of experience). Juniper has reviewed such front-end processes ahead of gasification plant, in a due diligence context, and we have found that many companies considered such processes to be simple and they spent little time on the specification and design of these process elements. In a number of cases this proved to be a mistake and significant technical and operational problems were encountered that involved major injections of additional capital expenditure to rectify design errors and operational issues. Other plasma gasification developers have a similar lack of expertise and experience in this area.

The Japanese plants built by Hitachi Metals are small in relation to most of the other commercial non-plasma gasification plants. There will be a technical risk associated with the scale-up of the gasification reactor (PGR), which is a seven times increase in scale. In chemical engineering terms, this is a fairly large step change in scale but Alter NRG has tried to mitigate the risk by undertaking an extensive CFD modelling study combined with testing at the Waltz Mill pilot plant.

Feed composition and variability is an area of concern. The differences in performance between the Utashinai and Mihama-Mikata plants have been significant. With MSW only, except for a small co-feed of dried sewage sludge the performance of Mihama-Mikata has been good, whereas significant technical challenges have been faced at Utashinai. Hitachi Metals blame these operational problems on the 50:50 co-feed of MSW and ASR with the blame being attributed to the ASR. Whilst most of the challenges can be attributed to equipment downstream of the gasifier, Alter NRG believes that the reactor redesign should alleviate the difficulties experienced by Hitachi Metals.

Similar issues could be faced at the plants in India, since Alter NRG has no direct involvement in assessing feed suitability. Poor performance at these plants, which are the first built since Alter NRG acquired Westinghouse, could have an adverse impact on the credibility of the technology in the marketplace.

Alter NRG has stated their intention to process MSW with a 5% by weight co-feed of shredded scrap automotive tyres. The reasons given for the addition of scrap tyres is the increase in energy content (CV) of the feed to the gasifier and the tipping fee (gate fee) received for scrap tyres is generally much higher than MSW. However, these benefits must be balanced against the downside of the additional technical challenges in the gasification and syngas cleaning sections of the process, which we have identified in this report.

Use of met coke within the reactor bed plays an important and understandable role in the operation of the gasification and melting processes but it also, unfortunately lowers the 'carbon credentials' of the technology and impacts on operating cost.

The need to co-fire natural gas with syngas in the gas turbine is a commercial weakness of the proposed IGCC design. It too will increase the carbon footprint and potentially adversely affect the image of the technology with both industrial customers and political decision makers, particularly in the MSW sector. By exposing a project to volatile fuel costs, the risk profile is also increased relative to projects that are banked on long-term 'put-or-pay' tipping fees. The non-MSW projects planned for Bruderheim and Fox Creek would probably produce enough syngas for the gas turbine because the petcoke and coal to be processed by each respective plant have much greater energy content that MSW. This challenge seems therefore to relate only to the MSW WTE opportunities.

The Somerset repowering project will utilise a co-feed of coal and wood chips, with the wood (a renewable biomass fuel) displacing coal as the energy input to the boiler. For both of these types of project, we understand, Alter NRG has carried out CFD modelling to determine the flow characteristics of these co-feeds and pilot scale testing is underway to verify and validate the results of the CFD work. Nevertheless, satisfactory performance at the first commercial implementation is vital to capitalising on this attractive market opportunity.

Although syngas cleaning to gas turbine quality is well proven for coal and refinery gasification applications there are fewer MSW gasification plants that clean syngas for high efficiency power conversion. The ultimate goal of the company is to use IGCC, which involves, in our opinion, a significant level of technology risk relating to the complexity of the syngas cleaning parts of the process and the methods employed to protect the gas turbine.

Alter NRG has recruited several members of staff with significant experience and track records in the gasification space. Juniper was impressed with the technical and commercial capabilities of the engineering team put together by the company, including those retained from WPC. Nevertheless, this is a new, small team relative to the number of initiatives being pursued.

We are satisfied that this team has an appropriate level of knowledge to design the syngas cleaning/upgrading part of their core deign. In our discussions with the company they clearly understand the key parameters associated with this design. But one needs to bear in mind that the DBM, when implemented, would be one of the most complex and challenging waste processing configurations operating anywhere in the world and this company has much less experience and track record than other more qualified companies that have baulked at this challenge. In this context we welcome Alter NRG's pragmatic decision to focus on less challenging configurations for their early waste processing projects.

Producing a partially cleaned syngas for direct combustion in a coal-fired utility boiler and concentrating corporate effort and resources on the Bruderheim IGCC project would seem to be the least risky development strategy. This would allow the scaled-up plasma gasification reactor to be proven in these applications, particularly as syngas cleaning processes for gas turbine use from petcoke processing has been reasonably well proven in several plants.

Having reviewed the Alter NRG cost model under confidentiality, Juniper considers that it is robust and incorporates realistic assumptions. However, many of the core assumptions remain to be validated at an operational reference plant. The model relates to the IGCC variant and North American market so it should not be compared directly with other geographies. Juniper has not found a flaw or 'stopper' and therefore if Alter NRG can demonstrate the technology and prove it works on a commercial basis then the market opportunities are potentially large.

The main reason why the economics of Alter NRG's core configuration (MSW + 5% tyres to IGCC) are favourable is the increased energy efficiency of the IGCC, resulting in greater 'back-end' revenues, and the use of a higher CV input (including the co-firing of natural gas and tyres). Without these co-feeds, the economic advantages of the plasma reactor are not so self-evident, since there is the additional complexity (and cost) associated with the design.

It is important that Alter NRG achieves the goal of implementing a project in one of their target markets quickly and, to that end; they should focus on the one specific project that would ensure a facility is operational as soon as possible.

The **Alter NRG/Westinghouse plasma assisted gasification technology is more proven than most** direct competitors and offers an alternative to more conventional gasification or incineration processes that will be attractive for many stakeholders in the waste management and biofuels markets.

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