

PLASMA WASTE GASIFICATION: DECENTRALIZED APPROACH TO PRODUCTION OF ENERGY FROM WASTE

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SUMMARY: The Plasma Resource Recovery System (PRRS) uses a two stage gasification process to convert waste into electrical energy, metal, and vitreous slag. In the PRRS system, unsorted waste is fed into a graphite arc plasma furnace where gasification of the organic fraction of the waste produces a synthesis gas. In this first stage, the inorganic portion melts in the plasma furnace and is tapped separately to form metal ingots and vitrified slag which could have applications in the construction industry. The produced synthesis gas from the first stage is then polished in a patented second stage plasma gasification reactor, followed by quenching with fresh water and cleaning in multiple stages to remove particulates, heavy metals and acid gases such as HCl and H₂S. The produced clean synthesis gas is fed into an internal combustion engine to produce electricity and thermal energy. PyroGenesis Canada Inc. (PCI) has been developing the PRRS system over the past 7 years and operates a two metric tonnes per day prototype facility in Montreal, Quebec, Canada. A transportable 10.5 metric tonnes per day PRRS has recently been installed and commissioned at the US Air Force Special Operations Command (AFSOC) military base in Hurlburt Field, Florida, USA. The patented PRRS (Plasma Resource Recovery) process will allow gasification of all waste produced by the base (municipal solid waste, biomedical waste, and hazardous waste). The installed PRRS produces electrical energy which is returned to the grid, along with reusable products such as vitrified rock and metal. The 10.5 ton per day transportable PRRS project received financial support from the US Department of Defence, the Government of Canada, the Government of Quebec, and Gulf Power. The advantages of plasma technology are fully realized with this transportable system as the extreme temperatures allow for the design of compact systems which have maximum flexibility in the types of waste that can be treated without the need for pre-sorting. The benefits of this technology make it an ideal solution for the treatment of waste in isolated/island communities, hospitals and military bases. Air emissions from the PRRS system meet the most stringent standards in application today. Preliminary results indicate that 850 Sm³/h (500 scfm) of Syngas can be produced for a feed rate of 10.5 metric tonnes per day (TPD) of MSW. Results also indicate that typical syngas composition of 15% H₂, 14% CO, 11% CO₂ can be produced, with virtually no residual oxygen. It is expected that this gas composition can be further improved by fine tuning of the process to increase the CO/CO₂ ratio. This paper presents a history and an update of the status of the US AFSOC project, including the permitting process for this novel technology, design and construction of the system, preparation of the site, installation, and road to implementation, as well as preliminary results from the first month of operation.

1. INTRODUCTION

Increasing population, consumerism and industrial development have led to an increase in the quantities of hazardous and municipal solid waste (MSW) generated worldwide. This situation coupled with the ever increasing demand for energy, has given a huge momentum to energy recovery from MSW. Use of plasma for the treatment of waste has been studied extensively for many years because of the ability of plasma to vaporize a wide variety of compounds and break chemical bonds (Heberlein and Murphy, 2008; Zhukov and Zasytkin, 2007; Heberlein, 1992). Due to the advantages of the thermal plasma technology, such as high energy densities, high temperatures, and high heat transfer rates, it has become a viable option for waste treatment. Over the past decade, many commercial systems using thermal plasma technology have been successfully commissioned and are being operated (Gomez & al., 2009). PyroGenesis Canada Inc., (PCI) has developed and patented a two-stage plasma gasification and vitrification system, the Plasma Resource Recovery System (PRRS), to treat and recover energy from unsorted MSW, Hazardous Waste and Biomedical Waste (Carabin & al., 20004). PRRS uses plasma arc technology to vitrify the inorganic portion of the waste and two stage plasma gasification technologies to convert the organic portion of the waste to synthesis gas (syngas). The produced syngas, after a series of gas cleaning steps, is fed to an internal combustion engine to produce electricity. This paper gives a description of the 10.5 tonnes per day (TPD) PRRS system built recently by PCI.

2. PRRS PROCESS DESCRIPTION

PCI's two-stage gasification and vitrification process (Figure 1) uses thermal plasma technology to convert the organic fraction of waste into a clean fuel and the inorganic fraction into a stable and inert slag. The clean gaseous fuel (or synthesis gas) is used for the production of electricity and the inert slag (glass) can be used for construction applications or converted into other added value products.

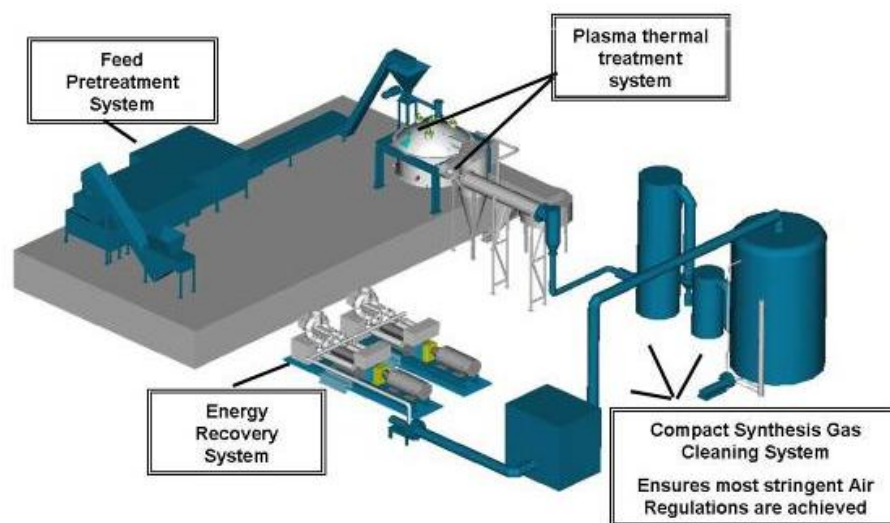


Figure 1. PRRS process overview

This process consists of four main sub-systems:

- Waste preparation and feeding system
- Plasma thermal treatment system
- Synthesis gas cleaning system
- Energy Recovery system

Unsorted MSW is first fed to a shredder, where it is then fed continuously to the primary gasification reactor through an airlock. Special waste that cannot be shredded, such as medical waste, is fed directly to the furnace without shredding through a special box feeder. The box feeder has been designed to accommodate boxes of maximum size of 60 cm x 60 cm x 30 cm. Figure 2 shows a schematic representation of the primary gasification reactor. In the patented primary gasification plasma reactor, that has a design similar to a DC electric arc reactor, the organic fraction of the waste is converted into a useable fuel. The inorganic portion of the waste (metals, glass, ash, etc.) melts in the plasma reactor and is recovered periodically as a molten metal phase and a molten inert slag (glass) phase. Plasma arcs are generated in the reactor using graphite electrodes. The temperature of the molten pool in the reactor is maintained above 1 550°C.

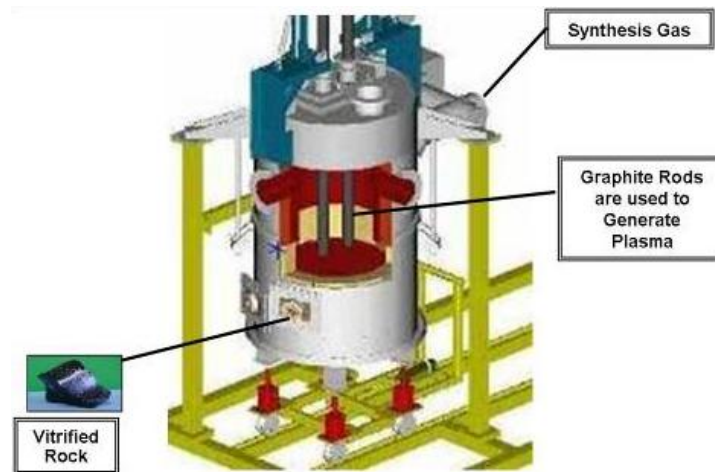


Figure 2. Schematic of the Primary Gasification Reactor

Gasification is a complex process where several concurrent exothermic and endothermic reactions occur at the same time. However, the process can be simplified by looking at waste as a source of carbon. From that point of view, the main chemical reactions involved in the gasification are listed below:

Table 1 – Main Gasification Reactions

Type	Reaction	Thermicity
Combustion reaction	$C + O_2 \rightarrow CO_2$	Exothermic
Water gas reaction	$C + H_2O \rightarrow CO + H_2$	Endothermic
Boudouard reaction	$C + CO_2 \rightarrow 2 CO$	Endothermic
Water gas shift reaction	$CO + H_2O \rightarrow CO_2 + H_2$	Exothermic

In order to predict the composition of syngas, due to the complexity and number of reactions involved in the process, the use of simple stoichiometric model is difficult. Therefore, a Gibbs' free energy minimization thermodynamic model has been used. The simulation process involves

an iterative solution whereby the composition is a function of the oxygen (air) stoichiometric ratio, water content of the waste, temperature and plasma energy addition.

The molten metal is recovered periodically and cooled as ingots for recycling. The molten slag is also removed periodically and either granulated, when collected in water, or cast into moulds, depending on the required end use of the vitrified slag. This slag, shown in Figure 3 is a highly stable material which can be used for construction or other commercial uses. In a previous study (Carabin & al. 2004, Carabin and Gagnon, 2006), the leaching rate of elements from the slag has been shown to be several orders of magnitude below the US EPA regulations (Carabin & al, 2000).



Figure 3. Vitrified Slag

The gasified organic portion of the waste exits the primary gasification plasma reactor as a dirty synthesis gas, composed primarily of CO and H₂, but also containing a certain amount of carbon soot, acid gases, moisture, partially decomposed hydrocarbons, particulate matter and trace metals. The dirty synthesis gas is then fed through a patented secondary gasifier, fired by a plasma torch, where a more than 5 000°C plasma plume breaks apart any complex hydrocarbons using a combination of heat and chemical energy. This polishing step ensures that all complex organic molecules such as tars are converted into CO and H₂.

The synthesis gas exiting the secondary gasifier is immediately quenched with water from 1 100°C to less than 100°C, in less than half a second. This quenching process maintains the high temperature thermodynamic equilibrium of the hot syngas, and avoids the reformation of dioxins, furans or other complex organic molecules.

The synthesis gas is then cleaned in multiple stages, to make it a suitable fuel for use in an internal combustion engine. The synthesis gas cleaning system allows for the removal of contaminants such as any acidic HCl, dust particles, sulphur and volatile heavy metals.

The whole PRRS is kept under negative pressure using an induced draft (ID) fan.

3. HISTORY AND STATUS OF THE PROJECT

Over the past seven years PCI has developed a two stage plasma vitrification and gasification technology to treat MSW and recovery energy. PCI has a 0.5 to 2 TPD prototype PRRS at its Montreal facility and has operated this unit for the past seven years.

During the summer of 2010, PCI completed the installation of a scaled up PRRS for the US Air Force Special Operations Command (AFSOC) military base in Hurlburt Field, Florida, USA (Figure 4). The scaled up PRRS is a 10.5 TPD nominal, transportable (i.e., skid mounted on standard ISO containers) system, for gasification of all waste produced on the base (municipal solid waste, biomedical waste, and hazardous waste). The installed PRRS produces electrical energy, as well as reusable products (vitrified rock and metals).



Figure 4. 10.5 TPD PRR system – Thermal Section

4. PERMITTING PROCESS

As the PRRS is considered a waste treatment facility, PCI had to apply and obtain three different permits from the Florida Department of Environmental Protection (FDEP), the environmental authority regulating the state, prior to construction of the system. Three different permit applications, namely solid waste handling permit, air emission permit and waste water effluent permit applications were prepared in detail and were submitted to FDEP. The entire permitting process was led by PCI and took 10 months to complete.

5. DESIGN AND CONSTRUCTION OF THE PRRS SYSTEM

For the 10.5 TPD PRRS system, a complete computer process simulation model with as many as 100 process streams was developed. An average MSW composition, as provided by the client and detailed using references from literature (Tillman, 1991; Niessen, 2002) was used as input information to the model. A complete process flow diagram (PFD) establishing the design basis for the mass and energy balance was developed. All the process utility requirements such as compressed air, compressed nitrogen, cooling water and fresh water required for the production plant were calculated using this model. After establishing a detailed PFD, piping and instrumentation diagram (P&ID) were prepared. Detailed engineering was carried out to

establish fabrication drawings of the gasification chambers and inter connecting pipes. For gas cleaning applications, proven commercially available technologies were researched and identified. The identified gas cleaning process were ordered and integrated to the PRR system by PCI.

The entire “turn key” project took 26 months to complete. The scope of the project included the building of a facility on a green-field site, all of the necessary environmental and construction permits, a fully operational plasma system with all of the required operation and maintenance manuals. As this is a military project, PCI was required to provide monthly reports on the progress of the various tasks. The entire engineering design phase lasted ~8 months , and was followed by procurement, fabrication and construction which took approximately 13 months to complete. At this point in time PCI began installing and commissioning the various PRRS subsystems. The system produced electricity from waste for the first time 26 months from the start of the project. PCI estimates that future units will take much less time to deliver.

6. INSTALLATION AND IMPLEMENTATION

Installation of the different sub units of the PRRS system and their interconnection was carried out by PCI. As the PRRS was designed as a transportable unit all the equipments were skid mounted on standard ISO containers. Most of the skids were shipped to the AFSOC site prewired and were installed. Figure 5 shows system during the installation and commissioning phase of the project.



Figure 5 Installation pictures of the 10.5 TPD PRR system

7. RESULTS AND CONCLUSIONS

The plant was commissioned and started operating during August of 2010. To date the plant has been running for over 30 days and has started processing the waste and producing electricity. All systems such as the waste preparation and feeding system, thermal processing system, syngas cleaning system and the energy recovery system are operating as expected. During the first month of operation, the PRRS was run at a feed rate of up to 320 kg/hr as compared to the

nominal waste processing rate of 437.5 kg/hr (10.5 TPD). **Error! Reference source not found.** compares the measured composition of the syngas produced from the PRRS system versus the theoretical prediction from the computer simulation model. As can be seen from **Error! Reference source not found.**, the actual hydrogen and carbon monoxide content are lower than the theoretically predicted values. This could be explained by the presence of an excessive amount of air in actual operation compared to the model.

Table 2 - Syngas Composition Theoretical Vs. Measured

Component	Theoretical Prediction from Computer Simulations	Measured
CO (dry vol%)	22	14
CO ₂ (dry vol%)	7	11
H ₂ (dry vol%)	19	15
N ₂ (bal, (dry vol%))	52	60

The system is producing clean steady flow of syngas with stable composition (Figure 6). An internal combustion engine is running on this syngas and producing electricity. To date the engine performance has been satisfactory. It is expected that this gas composition can be further improved by fine tuning of the process to increase the CO/CO₂ ratio and hydrogen content.

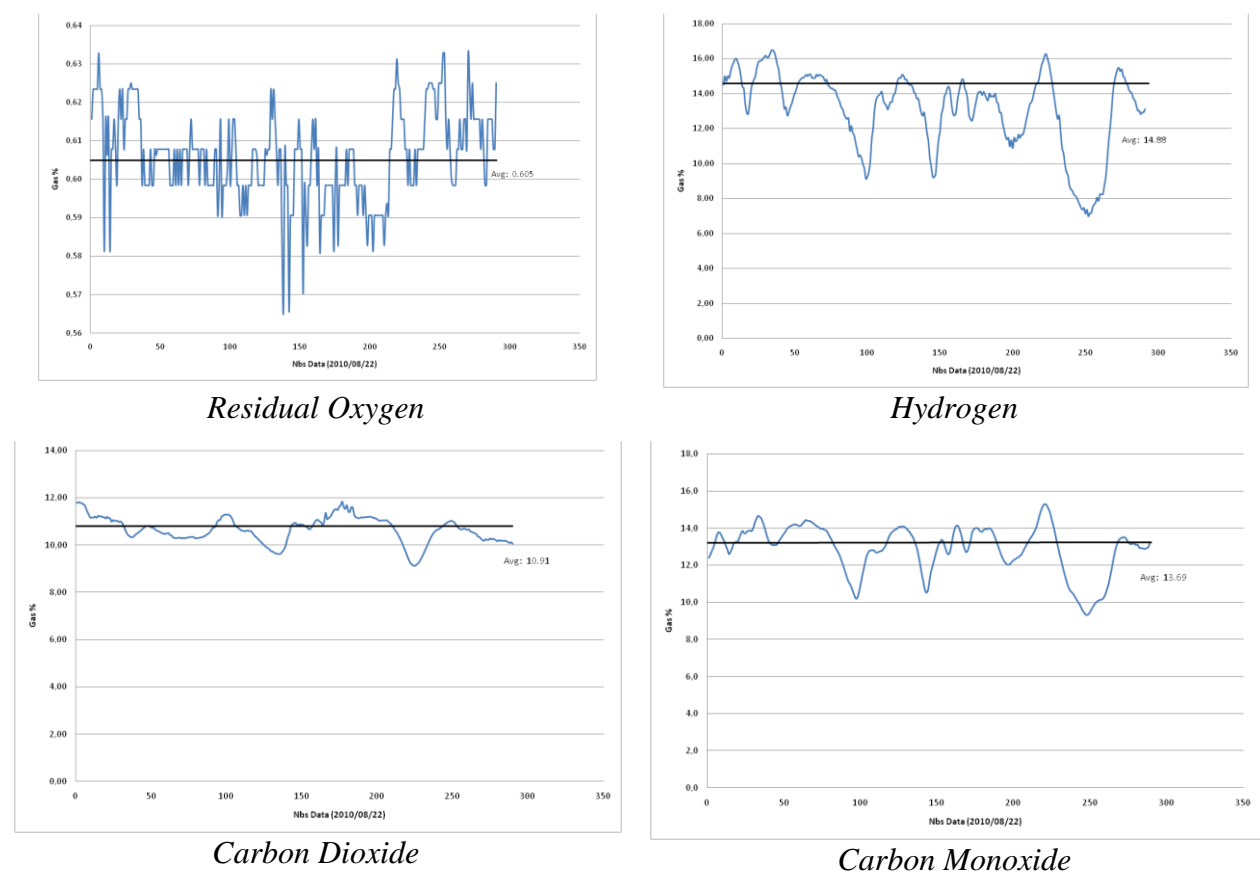


Figure 6. Syngas Composition Trend

8. REFERENCES

- Carabin P., Alexakis T., LeRoy, R., Drouet, M.G. & Tsantrizos, P.G. (2000) Vitrification and gasification of pulp and paper hog fuel boiler ash. *Proceedings of the 19th International Conference on Incineration and Thermal Treatment Technologies, Portland, OR, USA.*
- Carabin P., Palumbo, E. & Alexakis T. (2004) Two-stage plasma gasification of waste. *Proceedings of the 23rd International Conference on Incineration and Thermal Treatment Technologies, Phoenix, Arizona, USA.*
- Carabin P. and Gagnon, J.R. (2007) Plasma gasification and vitrification of ash – conversion of ash into glass-like products and syngas. *Proceedings - World of Coal Ash 2007 Conference, Covington, KY, USA.*
- Gomez E., Rania D. A., Cheeseman C.R., Deegan D., Wisec M. & Boccaccini, A.R. (2009); Thermal plasma technology for the treatment of wastes: a critical review. *Journal of Hazardous Materials*, 161, 614–626.
- Heberlein, J. (1992) Generation of thermal and pseudo-thermal plasmas, *J. Pure Appl. Chem.*, 64, 629.
- Heberlein J. and Murphy B.A. (2008) Thermal plasma waste treatment. *J. Phys. D: Appl. Phys.*, 41, 1-20
- Niessen W.R (2002) *Combustion and Incineration Processes*, Marcel Dekker Inc, New York.
- Tillman D.A (1991) *The Combustion of Solid Fuels and Wastes*, Academic Press Inc., Toronto.
- Zhukov M.F., and Zasytkin I.M. (2007) *Thermal Plasma Torches-Design, Characteristics, Applications*. Cambridge International Science Publishing, Cambridge.