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Plasma Arc The Leading Light?

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Various thermal processes are now available for managing solid waste but which one comes out top when it comes to both environmental and economic grounds? Dr Gary Young discusses a comparative study of the five forms of thermal pyrolysis/gasification technology - including plasma arc.

Pyrolysis/gasification technology is emerging as one of the most attractive and economically viable ways to manage and treat waste. This includes municipal solid waste (MSW), solid wastes (SW) and/or semi-solid waste (SSW). With these five thermal processes and syngas options for managing waste solids, what thermal process should be considered for converting waste solids to syngas energy? To answer this question, the thermal efficiency and economics of the five technologies were determined and compared.

The typical choice of thermal process technologies is pyrolysis, pyrolysis/gasification, conventional gasification and plasma arc gasification. Mass burn (incineration) is another alternative thermal process technology.

A key product from these thermal gasification technologies is the conversion of solid waste into syngas, which is predominantly carbon monoxide (CO) and hydrogen (H_2). This syngas can be converted to energy (steam and/or electricity), other gases, fuels and/or chemicals.

The five competing technologies have differing features and applications:

Pyrolysis: the thermal decomposition of carbon-based materials in an oxygen deficient atmosphere using heat to produce a synthetic gas (syngas). No air or oxygen is present and no direct burning takes place. The process is endothermic.

Pyrolysis/gasification: a variation of the pyrolysis process in which a close-coupled reactor is added to further gasify any carbon char or pyrolysis liquids from the initial pyrolysis step using air, oxygen and/or steam for the gasification reactions.

Conventional gasification: a thermal process that converts carbonaceous materials, such as solid wastes, into a syngas using a limited quantity of air or oxygen. Conventional gasification conditions are sometimes stated as 790°C - 1650°C (1450°F - 3000°F).

Plasma arc gasification: a high-temperature pyrolysis process whereby the organics of waste solids (carbon-based materials) are converted to a synthesis gas while inorganic materials and minerals produce a rock-like glassy by-product, called vitrified slag. The synthesis gas (syngas) is created in an oxygen-deficient atmosphere and is predominantly carbon monoxide (CO) and hydrogen (H2). The high temperature of this process is created by an electric arc in a torch whereby a gas is converted into plasma. The process containing a reactor with a plasma torch processing organics of waste solids (carbon-based materials) is called plasma arc gasification. The reactor for such a process typically operates at 4000°C - 7000°C (7200°F - 12,600°F).

Finally, mass burn (incineration) can be defined as a combustion process which uses an excess of oxygen and/or air to burn the solid wastes. The mass burn process operates with an excess of oxygen present and is therefore a combustion process. Mass burn is not a pyrolysis process.

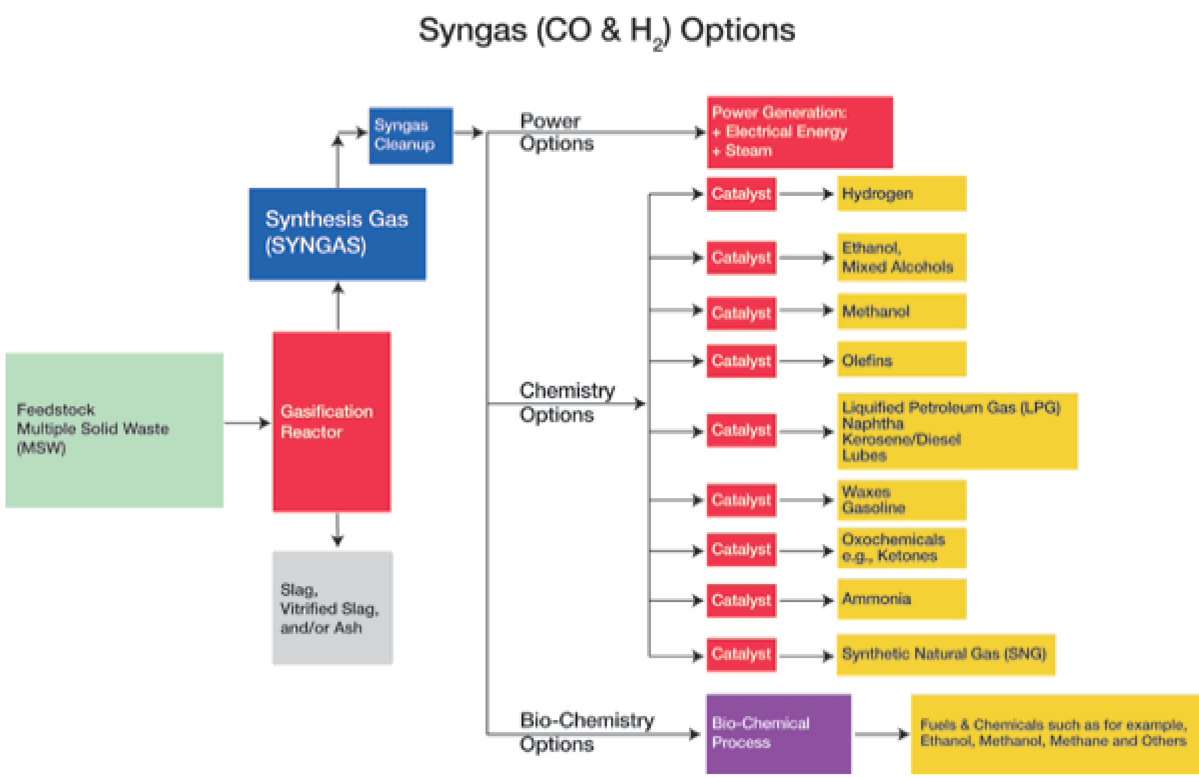

Figure 1. Converting MSW, solid waste or semi-solid waste into energy, gases, fuels and Chemicals

The management of MSW, solid waste or semi-solid waste by gasification to syngas can be accomplished in various ways. Figure 1 shows a typical configuration for gasifying MSW or other solid or semi-solid waste into syngas. The syngas can be converted to energy via several methods:

- A power option to produce steam and/or electricity
- A chemistry option using catalysts such as Fisher-Tropsch catalysts to produce a wide variety of gases or chemicals such as hydrogen, ethanol, methanol, mixed alcohols, olefins, liquid petroleum gas, kerosene, waxes, ammonia and synthetic natural gas

- The bio-chemistry approach using specific microbes for the conversion of the syngas into natural gas or fuels such as ethanol, methanol and methane.

With these five thermal processes and syngas options for managing waste solids, what thermal process should be considered for converting waste solids to syngas energy? To answer this question, the thermal efficiency and economics of the five technologies were determined and compared.

For the comparison, a 454 tonne/day (500 ton/day) MSW facility using each of the five thermal processes was considered with power option to produce electricity from the syngas. The five thermal processes included: plasma arc gasification, conventional gasification, pyrolysis gasification, pyrolysis, and mass burn (incineration).

Performance/thermal efficiency of technologies:

For the Thermal Process Technologies discussed, the typical range of process operation is presented in Table 1.

Type of Thermal Process Technology	Net Energy Production to Grid
Mass Burn (Incineration)	493 kWh/tonne MSW (544 kWh/ton MSW)
Pyrolysis	518 kWh/tonne MSW (571 kWh/ton MSW)
Pyrolysis/Gasification	621 kWh/tonne MSW (685 kWh/ton MSW)
Conventional Gasification	621 kWh/tonne MSW (685 kWh/ton MSW)
Plasma Arc Gasification	740 kWh/tonne MSW (816 kWh/ton MSW)
Note: Except for plasma arc gasification, these processes present environmental issues in the disposing of ash and slag.	

Table 1. Thermal Process Technology(s)

Computations on each thermal process technology were done to determine the net energy production of electricity to the grid per ton of municipal solid waste (MSW) processed as shown in Table 2.

Type of Thermal Process Technology	Net Energy Production to Grid
Mass Burn (Incineration)	493 kWh/tonne MSW (544 kWh/ton MSW)
Pyrolysis	518 kWh/tonne MSW (571 kWh/ton MSW)
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Table 2. Thermal Process Technology and Net Energy to Grid

Economic parameters for the five thermal technologies were determined such as capital investment, operation and maintenance, by-product production and sales, and residue produced and costs. Using the parameters of capital investment, plant capacity, energy production, operation and maintenance costs, tipping fee, green tags, energy sales, and by-product residues - an economic analysis was performed to determine the net revenue (before taxes) of each thermal process as shown in Figure 2.

From reviewing the Net Energy Production to Grid of the various types of thermal process technologies in Table 2, plasma arc gasification produces about 740 kWh/tonne (816 kWh/ton) of MSW compared to only about 621 kWh/tonne (685 kWh/ton) of MSW for a conventional gasification technology. Plasma arc gasification can therefore be considered the most efficient thermal gasification process.

Figure 2 suggests plasma arc gasification is the most attractive process for handling solid wastes such as MSW, both in terms of thermal efficiency and economics, although conventional gasification and plasma arc gasification yielded similar results.

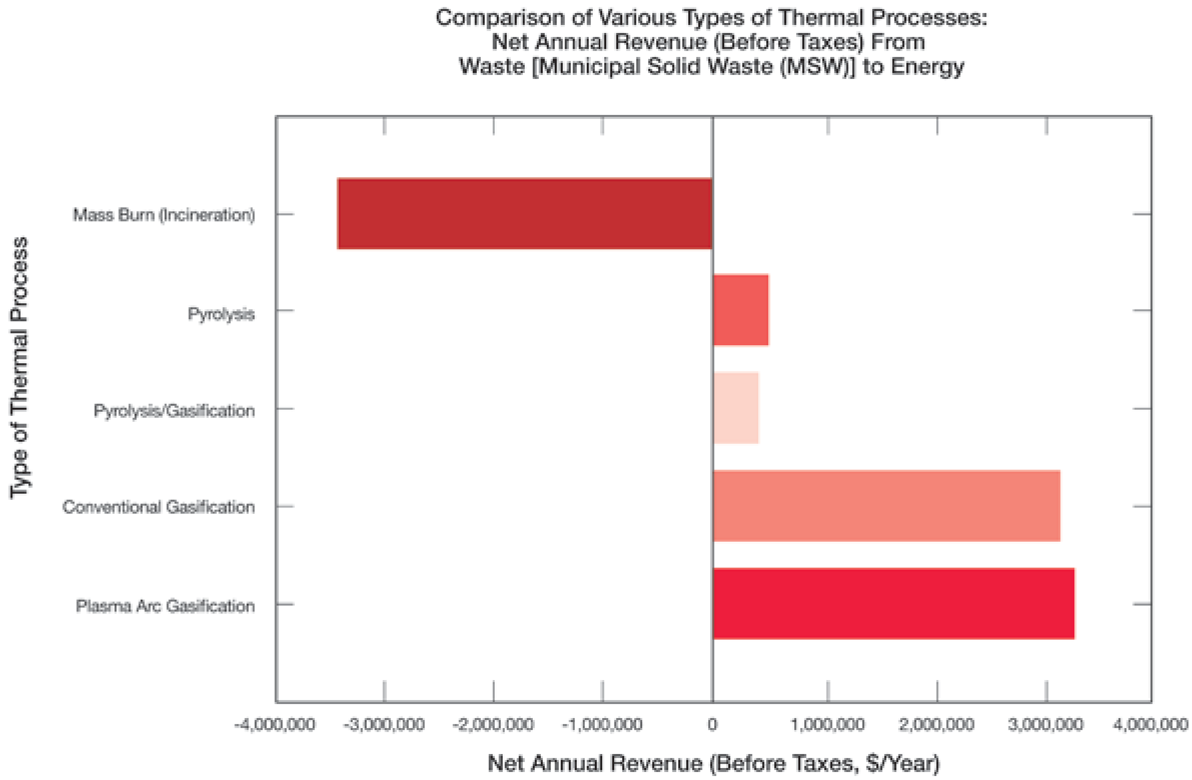

Figure 2. Comparison of Various Types of Thermal Processes

Plasma Arc Gasification also combined these attributes:

- Thermal efficiency
- Process variety of different solid wastes
- Minimal pretreatment/presorting of solid wastes
- Production of syngas for conversion into energy sources such as steam, electricity and/or liquid fuels
- Environmental appeal as the solid by-product, vitrified slag, can be used as a construction material
- Environmental appeal from the use of syngas to produce various energy products, while any discharged gaseous effluents can be treated by currently acceptable environmental processes
- Minimised if not eliminated need for landfill
- Ability to process and eliminate wastes from existing landfills.

Next, the plasma arc gasification process was studied regarding economy of scale to determine what capacity of facility is commercially feasible. For economy of scale analysis, MSW was gasified to syngas and vitrified slag. The syngas was used to generate electricity and the slag used as a road material. The basic plasma arc gasification process being evaluated is represented in Figure 3. Pre-processing is considered minimal for a well-designed plasma arc gasification facility.

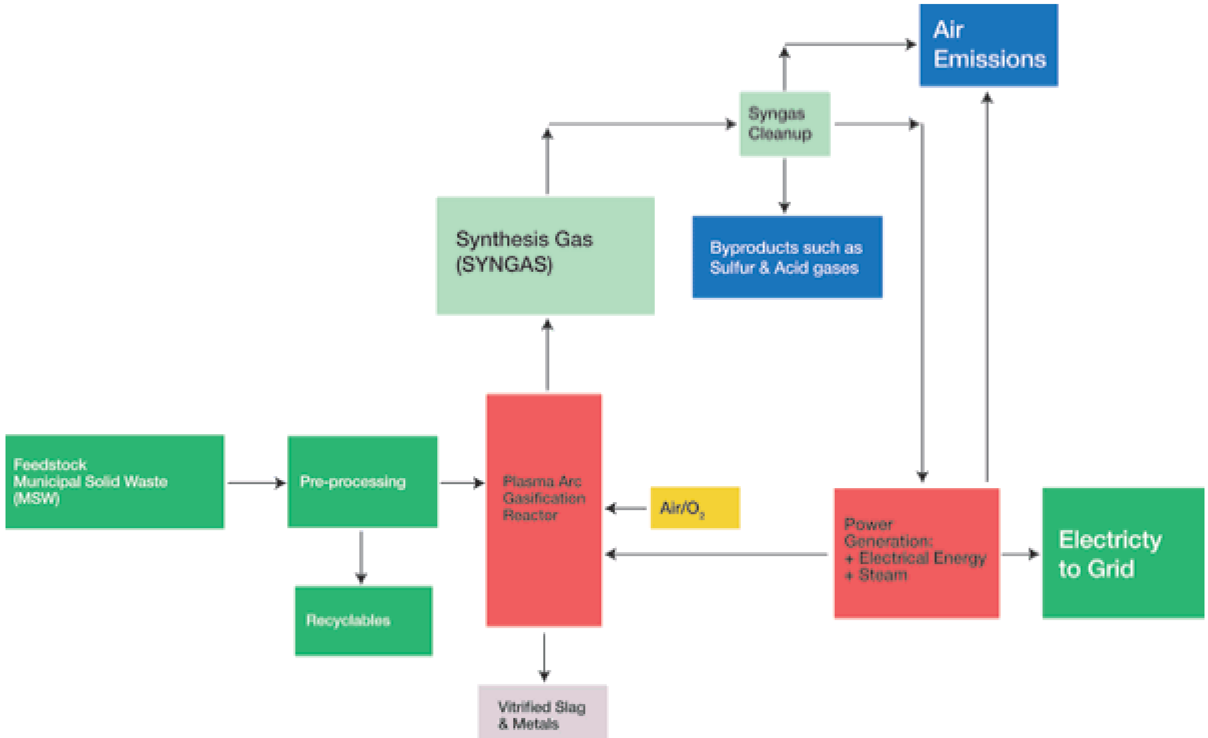

Figure 3: Process schematic for producing electricity from MSW using plasma arc gasification

Several economic analyses for the various plant capacities (MSW tons/day) and various revenues (net annual revenue) at various selling prices of electricity (cents/kWh) were collected to analyse economy of scale.

The analyses suggest that a plasma arc gasification facility is near break-even at a capacity of about 180–270 tonnes waste/day (200–300 tons waste/day). The net annual revenue before taxes and the influence of plant capacity as mentioned is known as economy of scale.

With a feed rate of about 656 tonnes/day of waste (724 tons/day), the plasma arc gasification facility generates about $10 million annually in terms of net annual revenue before taxes (total annual revenues minus total annual expenditures), if electricity is sold at 4.50¢/kWh.

At a selling price to the grid of 5.50¢/kWh, net annual revenue before taxes is about $13 million per year. Electricity sold at 6.50 ¢/kWh generates net annual revenue before taxes of about $16 million per year. Capital investment would be about $130 million.

At a feed rate of 454 tonnes/day of waste (500 tons/day), net annual revenue before taxes is about $5 million/year at 4.5 ¢/kWh, $7 million/year at 5.5 ¢/kWh, and $9 million/year at 6.5 ¢/kWh. Capital investment would be about $102 million.

A plasma arc gasification facility at a capacity of 907 tonnes/day of waste (1000 tons/day) generates a net annual revenue before taxes of between $15 million and $23 million per year, depending upon the selling price of electricity. Capital cost is about $154 million.

Thus, the logical approach is a co-operative effort between one or more governmental bodies and industrial entities, so that the economy of scale is fully realised.

As a final note, the net energy production from a plasma arc gasification facility power plant is estimated at about 21 MW, 30 MW and 43 MW for a capacity of 454 tonnes/day (500 tons/day), 636 tonnes/day (700 tons/day) and 907 tonnes/day (1000 tons/day) of waste, respectively. A review of both the net energy production to grid and economy of scale for the five types of thermal process technologies shows that plasma arc gasification produces about 740 kWh/tonne (816 kWh/ton) of MSW compared with only about 621 kWh/tonne (685 kWh/ton) with conventional gasification technology. Plasma arc gasification can therefore be considered the most efficient thermal gasification process, although Figure 2 shows that conventional gasification is a likely competitor.

Plasma arc gasification technology - examples

Plasma is called the fourth state of matter, as it is distinctly different from solid, liquid and gaseous states.

Plasma can create an ionized gas by electrical forces whereby the temperatures can reach between 2000°C to 5000°C (3632°F to 9032°F).

Plasmas are hot ionized gases created by an electrical discharge. The gas is typically air, oxygen, nitrogen, hydrogen, argon or a combination of these gases.

Plasma torches exist in two types. Transferred torches create an electric arc between the tip of the torch and metal or slag at the bottom of the reactor or the conductive lining of the reactor wall of the plasma arc gasifier. In non-transferred torches, the arc is located inside the torch itself, where the plasma gas is created by passing gas through the torch.

Heated by the arc, it then exits the tip of the torch and is injected into the reactor. Both designs can offer advantages. The Westinghouse Plasma Corporation (WPC) Plasma Gasification Vitrification Reactor (PGVR) is a moving-bed gasifier that employs WPC’s industrial plasma torch technology. The feedstock enters the gasifier where it comes into contact with hot plasma gas.

The amount of air or oxygen used in the torch is controlled to promote the endothermic gasification reactions of the organic material.

Inorganic constituents are converted to a molten slag that cools into a glassy non-hazardous slag. The hot plasma gas flows into the gasifier/reactor to gasify municipal solid waste (MSW) and melt the inorganic materials.

Alter Nrg Corporation uses technology developed by its subsidiary WPC to convert feedstocks such as coal, petroleum coke, municipal solid waste (MSW), industrial waste, bio-mass or bio-solids into commercial syngas.

The plasma arc gasification gasifier is operated with an injection of a carbonaceous material like coal or coke into the plasma arc gasification reactor. This material reacts quickly with the oxygen to produce heat for the pyrolysis reactions in an oxygen-starved environment.

Steam is added to the reactor to promote syngas reactions. The combustion reactions (exothermic reactions) supply heat with additional heat from the plasma arc torches for the pyrolysis reactions (endothermic reactions) yielding a temperature typically between 4000°C –7000°C (7200°F - 12,600°F).

The bottoms from the reactor results in a vitrified slag since operating conditions are very high. The inorganic and mineral elements present in the MSW produce a rock like by-product – a vitrified slag typically of metals and silica glass.

This vitrified slag is basically non-leaching and exceeds EPA standards. Metals can be recovered from the slag and the slag can be used to produce a wide variety of by-products such as rock wool, floor tiles, roof tiles, insulation and landscaping blocks. Vitrified slag's environmental acceptability as a recyclable by-product is a positive attributes of the plasma arc gasification process for the management of MSW.

Another positive attribute for the plasma arc gasification process is that plasma arc gasification reactor design has improved and lessened the need for pre-treatment/pre-processing.

Conclusions

Plasma Arc Gasification is an economically viable technology for managing municipal solid waste. This technology can be used for managing solid wastes: residential waste (RW), commercial waste (CW) and industrial waste (IW) as well as municipal solid waste (MSW), which can be a mixture of these wastes.

In addition, plasma arc gasification technology can minimise if not eliminate the need for landfills and also eliminate existing old landfills. Old wastes in existing landfills can be mined/removed and used as supplemental feed to a plasma arc gasification facility.

Dr Gary C. Young is an expert in industrial processes and the author of the recently published book 'Municipal Solid Waste To Energy Conversion Processes; Economic, Technical and Renewable Comparisons'
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