Plasma gasification: Clean renewable fuel through vaporization of waste

Plasma gasification technology in the US is developing fast, and could be the perfect way to divert MSW from landfill and produce valuable by-products. Here, we look into the benefits.

by Ed Dodge

Plasma gasification is an emerging technology which can process landfill waste to extract commodity recyclables and convert carbon-based materials into fuels. It can form an integral component in a system to achieve zero-waste and produce renewable fuels, whilst caring for the environment. Plasma arc processing has been used for years to treat hazardous waste, such as incinerator ash and chemical weapons, and convert them into non-hazardous slag.

Utilizing this technology to convert municipal solid waste (MSW) to energy is still young, but it has great potential to operate more efficiently than other pyrolysis and combustion systems due to its high temperature, heat density, and nearly complete conversion of carbon-based materials to syngas, and non-organics to slag.

Syngas is a simple fuel gas comprised of carbon monoxide and hydrogen that can be combusted directly or refined into higher-grade fuels and chemicals. Slag is a glass-like substance which is the cooled remains of the melted waste; it is tightly bound, safe and suitable for use as a construction material.

Plasma torch technology has proven reliable at destroying hazardous waste and can help transform environmental liabilities into renewable energy assets.

Plasma gasification process

Plasma gasification is a multi-stage process which starts with feed inputs – ranging from waste to coal to plant matter, and can include hazardous wastes. The first step is to process the feed stock to make it uniform and dry, and have the valuable recyclables sorted out. The second step is gasification, where extreme heat from the plasma torches is applied inside a sealed, air-controlled reactor. During gasification, carbon-based materials break down into gases and the inorganic materials melt into liquid slag which is poured off and cooled. The heat causes hazards and poisons to be completely destroyed. The third stage is gas clean-up and heat recovery, where the gases are scrubbed of impurities to form clean fuel, and heat exchangers recycle the heat back into the system as steam. The final stage is fuel production – the output can range from electricity to a variety of fuels as well as chemicals, hydrogen and polymers.

Gasification has a long history in industry where it has been used to refine coal and biomass into a variety of liquid fuels, gases and chemicals. Modern clean coal plants are all gasifiers, and so were the earliest 19th century municipal light and power systems.

Plasma gasification refers to the use of plasma torches as the heat source, as opposed to conventional fires and furnaces. Plasma torches have the advantage of being one of the most intense heat sources available while being relatively simple to operate.

Plasma is a superheated column of electrically conductive gas. In nature, plasma is found in lightning and on the surface of the sun. Plasma torches burn at temperatures approaching 5500ºC (10,000˚F) and can reliably destroy any materials found on earth – with the exception of nuclear waste.

Plasma torches are used in foundries to melt and cut metals. When utilized for waste treatment, plasma torches are very efficient at causing organic and carbonaceous materials to vaporize into gas. Non-organic materials are melted and cool into a vitrified glass.

Waste gasification typically operates at temperatures of 1500˚C (2700˚F), and at those temperatures materials are subject to a process called molecular disassociation, meaning their molecular bonds are broken down and in the process all toxins and organic poisons are destroyed. Plasma torches have been used for many years to destroy chemical weapons and toxic wastes, like printed circuit boards (PCBs) and asbestos, but it is only recently that these processes have been optimized for energy capture and fuel production.

America's Westinghouse Corporation began building plasma torches with NASA for the Apollo Space Program in the 1960s to test the heat shields for spacecraft at 5500˚C. In the late 1990s, the first pilot-scale plasma gasification projects were built in Japan to convert MSW, sewage sludge, and auto-shredder residue to energy. The Japanese pilot plants have been successful, and commercial-scale projects are under development now in Canada and other countries, by companies such as Alter NRG, from Alberta, Canada.

Economics

The economics of MSW plasma gasification are favourable, although complex. Waste gasification facilities get paid for their intake of waste, via tipping fees. The system then earns revenues from the sale of power produced. Electricity is the primary product today, but liquid fuels, hydrogen, and synthetic natural gas are all possibilities for the future.

Sorting the MSW to capture commodity recyclables, such as metals and high-value plastics, presents a third revenue stream. Minor revenue streams include the sales of slag and sulphur. Slag has the potential to be used for a number of construction products, such as rock wool, bricks and architectural tiles, and sulphur has some commodity value as fertilizer.

Additional costs are avoided by diverting waste from landfills and minimizing transportation of waste. Government subsidies for renewable energy or carbon credits may be substantial in the future, but are difficult to project.

A base case scenario with a 680 tonne per day (750 US tons) waste gasification plant which would be appropriate for a small city or regional facility, would cost an estimated $150 million (€108 million) to construct. A municipality that funds the entire project through bonds should seek a positive cash flow year-after-year via revenues from tipping fees, recyclables and electricity sales, as well as sales of slag and sulphur. There is considerable range in the values for each of these variables, and any proposed development would require extensive due diligence to determine local prices for each line item. Tipping fees, electricity rates, commodity recyclables, as well as interest rates and taxes, all vary dramatically – creating a model which needs to be thoroughly evaluated for any proposed development.

The economics of waste gasification heavily favour recycling – inorganic materials like metal and glass have no value as fuel and make the gasification process less efficient, even though plasma torches have the ability to melt them. High-value plastics and papers that can be readily separated are far more valuable as recyclables than as fuel. Certain plastics earn €195 per tonne ($300 per US ton) and certain types of paper can earn around €53 per tonne ($75 per US ton). For comparison, a tonne of waste may produce 0.8 MW of electricity, worth around €51 ($70) per MW. It is clear that any of these materials that can be separated and sold, are worth much more as commodities than as fuel.

Wide variety of inputs and outputs

There are additional waste streams available in certain locations which earn higher tipping fees than MSW because they are toxic and yet have excellent fuel value. Refinery wastes from petroleum and chemical plants, medical waste, auto-shredder residue, construction debris, tyres and telegraph poles, are all examples of potential fuels that can earn high tipping fees and provide good heat value. Additionally, there are millions of tonnes of low-grade waste coal that exist in massive piles throughout the Appalachian region of Pennsylvania and West Virginia, US, that can be utilized for gasification.

Multiple outputs can be produced from a single facility. Heat and steam can be sold, and electricity production can be combined with ethanol or hydrogen production to maximize resources. Hydrogen can be readily produced from syngas by separating it from the carbon and oxygen, while synthetic natural gas can be produced by upgrading the methane content of syngas.

Liquid fuels are typically produced from syngas through catalytic conversion processes such as Fischer-Tropsch – which has been widely used since World War II to produce motor fuels from coal. Biotech methods to produce liquid fuels are also being developed to use enzymes or micro-organisms to make the conversion.

Much research and effort is being put into developing more selective catalysts and productive enzymes which will raise system efficiencies to levels needed to be competitive. Currently, ethanol from gasification costs more than $2 a gallon (equivalent of €0.37 per litre), and it is estimated that production needs to cost closer to $1.25 (€0.90) or $1.50 (€1.10). Production of ethanol at demonstration scale has shown that one US ton of MSW can produce around 100 gallons (equivalent of 0.9 tonnes producing 380 litres) of ethanol, give or take 20%. Cost estimation for ethanol production is difficult, but rough calculations indicate that ethanol could potentially be more profitable than electricity.

Environmental Issues

Improved waste management

Gasification is superior to landfilling MSW for a number of reasons. First of all, landfills are toxic to the environment due to the production of toxic liquid leachate and methane gases. The EPA (US Environmental Protection Agency) has a lengthy protocol for airborne and liquid chemicals which must be contained and monitored for every landfill. Landfills must be constructed with extensive liners, drains and monitoring equipment to comply with regulations. Plasma gasification can divert waste from landfills and create beneficial uses for the material, by maximizing recycling and cleanly using the rest for fuel.

Gasification is superior to incineration

Gasification is superior to incineration and offers a dramatic improvement in environmental impact and energy performance. Incinerators are high-temperature burners that use the heat generated from the fire to run a boiler and steam turbine in order to produce electricity. During combustion, complex chemical reactions take place that bind oxygen to molecules and form pollutants, such as nitrous oxides and dioxins. These pollutants pass through the smokestack – unless exhaust scrubbers are put in place to clean the gases.

Gasification by contrast is a low-oxygen process, and fewer oxides are formed. The scrubbers for gasification are placed in line and are critical to the formation of clean gas, regardless of the regulatory environment. For combustion systems, the smokestack scrubbers offer no operational benefit and are put in place primarily to meet legal requirements. Plasma gasification systems employing proper scrubbers have extremely low emissions and no trouble meeting and beating the most stringent emissions targets.

The objective of gasification systems is to produce a clean gas used for downstream processes which requires specific chemistry, free of acids and particulates – so the scrubbing is an integral component to the system engineering, as opposed to a legal requirement that must be met.

Incinerator ash is also highly toxic and is generally disposed of in landfills, while the slag from plasma gasification is safe because it is melted and reforms in a tightly-bound molecular structure.

In fact, one of the main uses for plasma torches in the hazardous waste destruction industry has been to melt toxic incinerator ash into safe slag. The glassy slag is subject to EPA Toxicity Characteristic Leaching Procedure (TCLP) regulations that measure eight harmful elements. Data from existing facilities, even those processing highly hazardous waste, has shown them to be well below regulatory limits.

Electricity production from plasma gasification is superior to that from incinerator combustion. Incinerators typically use the heat from combustion to power a steam turbine to produce power. Gasification systems can use gas turbines that are far more efficient, particularly when configured in integrated gasification combined cycle mode (IGCC). Just as IGCC is the state-of-the-art in producing power from coal, the same is true when using MSW as the fuel source.

Carbon impact

The carbon impact of plasma gasification is significantly lower than other waste treatment methods. It is rated to have a negative carbon impact, especially when compared to allowing methane to form in landfills. Gasification is also an important enabling technology for carbon separation. It is primarily a carbon processing technology; it transforms solid carbon into gas form.

Syngas is comprised of carbon monoxide and hydrogen. The hydrogen readily separates from the carbon monoxide allowing the hydrogen to be used while the carbon is sequestered. The US Department of Energy has identified gasification through its clean coal projects as a critical tool to enable carbon capture

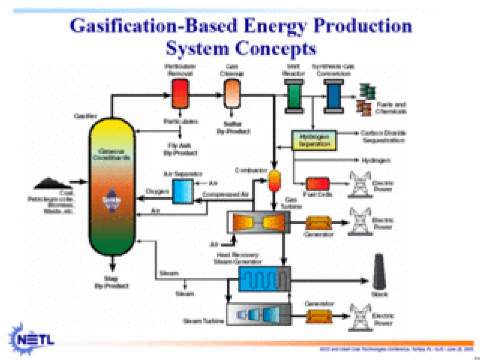
Environmental opposition

Environmentalists have expressed opposition to waste gasification for two main reasons. The first argument is that any waste-to-energy facility will discourage recycling and divert resources from efforts to reduce, reuse and recycle. Economic studies of the waste markets show the opposite to be true; waste-to-energy heavily favours the processing of waste to separate valuable commodities and to maximize its value for fuel.

The second argument made against waste gasification is that has the same emissions as incineration. These arguments are based on gasification systems which do not clean the gases and instead combust dirty syngas. Such systems are essentially two-stage burners and are not recommended for environmental reasons. There are many variations of combustion, pyrolysis and gasification – all used in different combinations. Proper engineering is required to achieve positive environmental performance.

Technology

Plasma gasification of MSW is a fairly new application that combines well-established sub-systems into one new system. The sub-systems are waste processing and sorting, plasma treatment, gas cleaning and energy production. The integration of these systems is rapidly maturing, but has still not been built in large industrial systems. Demonstration and pilot-scale systems are running successfully in Japan and Canada with more starting in the US and Europe.



Gasification-based energy conversion system concepts Source: NETL
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Pre-processing

Waste sorting and processing is a mature industry for recycling. A wide range of drying and separation equipment is commercially available. The goal in treating MSW is to shred it into uniformly small pieces and separate out all the metal, glass and other inorganics that have no value as fuel. Valuable recyclables should be separated for sale. MSW in this form is often called RDF, refuse-derived fuel.

The next step

Following the pre-processing, the wastes are vapourized using the high heat from the plasma torches.

As the materials are vapourized the gasses flow out the top, while the molten slag pours out the bottom of the reactor. Gasification of MSW requires temperatures above 1200˚C (2200˚F) and systems are targeted to operate around 1500˚C (2700˚F). As the hot gases exit the reactor they are cooled through a combination of quenching and heat exchangers. The heat is very valuable and is recycled back into the system to generate steam for other purposes.

There are engineering challenges in using heat exchangers at 1500˚C, as temperatures will strain steel and other materials. The heat exchanging sub-system is one of the areas which would benefit from further development.

Scrubbing

Once the gases are cooled, they pass through a series of gas cleaning operations which are tuned to the downstream requirements as well as environmental regulations. There are many different designs for scrubber systems and it is a mature industry. Scrubbers are routinely used to clean smokestack exhaust in power plants and industry.

Energy production

Electricity is produced using boilers, engines or gas turbines. Gas engines and turbines require very clean gases, but straight combustion to fire a boiler can use less clean gas and has the lowest cost. Steam systems may generate 450–550 kWh per tonne (500–600 kWh per US ton) of MSW. Gas turbines in a combined cycle may generate 900–1200 kWh per tonne (1000–1200 kWh per ton) of MSW. IGCC is considered the state-of-the-art and the most efficient means to generate power from carbon resources. It is the model used for modern clean coal power plants.

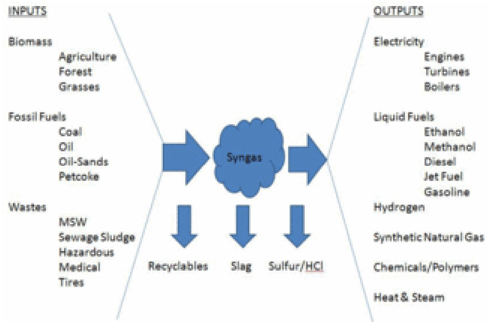
In IGCC the syngas is combusted in a turbine to produce electricity, at the same time the hot turbine exhaust is captured in a heat recovery steam generator (HRSG) to produce electricity via a steam turbine. The combination of a steam turbine with the gas turbine is the combined cycle.

Heat recovery steam generators can also use the captured heat from the gases in addition to the heat from the turbine exhaust. The gases pass out of the reactor at around 1200˚C and the heat can be used to generate significant energy for the facility. In theory, the torches and the facility would consume only 25% of the energy produced, leaving 75% available for sale.

Conclusions

The time is becoming ripe for waste gasification. The world is facing profound problems in the search for new sources of energy, in addition to facing ongoing environmental degradation.

Plasma gasification of waste can be part of the solution to both problems. Using toxic waste materials, as feed stocks for producing renewable fuels, transforms liabilities into assets. As a municipal or publicly funded operation, a waste gasification plant can help balance budgets and provide a hedge against future increases in energy prices. The complexity and expense make plasma gasification a challenge for private investors and for municipalities.



Plasma gasification, inputs and outputs
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Fortunately, the technologies needed to make waste gasification work are coming along fast. The most encouraging aspect of plasma gasification is that the individual sub-systems are all very mature and established. It is simply the integration between them that needs further refinement. All of the waste sorting and preparing equipment is readily available, plasma torches have been used reliably for decades, and gasification and gas cleaning is also well understood.

Energy production from syngas can be done profitably today by producing electricity, and it is hoped that ethanol will soon be economical. Hydrogen and synthetic natural gas are also in the wings, waiting for the right time to emerge. It is entirely possible that a decade from now, society could be producing significant quantities of renewable fuels by using landfill waste, and in doing so, clean up the environment at the same time.

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