Plasma-Gasification of Waste

Clean Production of Renewable Fuels through the Vaporization of Garbage

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Executive Summary – Plasma Gasification of Waste

Plasma gasification is an emerging technology that enables the safe vaporization of common and hazardous wastes to produce clean renewable fuels. The developed world is presently facing major environmental problems with garbage as landfills fill up, forcing governments to transport their garbage farther away at greater expense and environmental impact. Society is additionally plagued with growing demand for energy, and traditional oil supplies cannot keep up with the demand.

Plasma gasification works by treating garbage and any carbon-based materials, such as plant matter or fossil fuels, with high heat from plasma torches in a controlled-air environment. Rather than burn, the materials vaporize into their basic molecular elements as gasses. The gasses are cooled and cleaned and can then be converted into electricity, or a variety of valuable fuels such as ethanol, hydrogen or natural gas. The inorganic materials are melted by the plasma torches and pour out. The molten materials then cool and harden into a vitrified glass called slag. The high heat from the gasses is recycled back into the system as steam.

The economics of plasma gasification is very favorable because there are multiple revenue streams. Revenue is earned from tipping fees for taking waste, separation and sale of commodities and recyclables, and the sale of energy. The system makes money on the inputs and the outputs. Commercial-scale facilities are very capital-intensive and the overall systems' integration is still maturing, so there is risk. While all of the individual components in the system are well established, and successful pilots are in operation in Japan and Canada, no single company is able to offer a complete turnkey facility today. Extensive planning needs to be done for any proposed facility.

The environmental impact of plasma gasification is superior to other forms of waste management. Landfills are toxic stews that produce methane and leachate and represent operational and financial burdens. Incinerators produce dioxins and other harmful pollutants and have long been opposed in the United States for their environmental impact. Gasification is distinct from incineration because the system is sealed and the gasses are all cleaned before being used for fuel. The extreme heat from plasma torches safely destroys all hazards, and regulated pollutants are very low in the output fuels. Gasification is a primary technology to enable carbon sequestration, because the carbon can be separated from the gasses and captured.

Plasma gasification offers society the ability to address environmental and energy problems in a single solution. Utilizing waste for a renewable fuel enhances recycling, cleans the environment, and profitably produces valuable renewable energy.

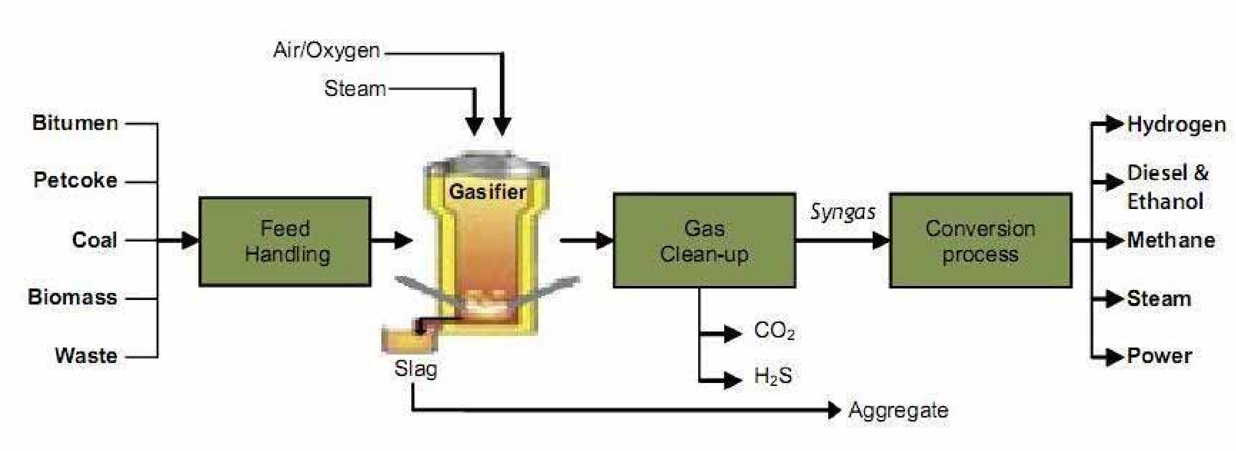
1. Waste Disposal and Green Fuel Production

Waste gasification is an emerging industry that promises to process all manner of wastes into valuable fuels and recyclable commodities. The U.S. along with most of the world has major systemic problems in properly disposing of wastes. In 2006 the U.S. produced more than 250,000,000 tons of municipal solid waste (MSW), or about 4.4 pounds of waste per person per day. Approximately 60 percent of this waste went into landfills. This amounted to more than 140 million tons of waste landfilled during the year[1]. New York City exports at least 4 million tons of residential municipal solid waste a year, at a cost of more than $100 per ton, and transports it hundreds of miles to other regions, creating more pollution for every mile traveled. Material disposed of in landfills is not being utilized for further purposes. Instead, garbage decomposes, forming toxic hazards. Landfills emit methane and are one of the leading manmade contributions to global warming.

Humanity is learning that mineral resources are not unlimited. Global oil production is unable to match rising demand for energy, and that is in turn leading to higher prices for gasoline and other fuels. Emerging technologies such as plasma gasification can process landfill waste to extract commodity recyclables and convert carbon-based materials into valuable fuels. Waste gasification can form an integral component in a system to achieve zero-waste and produce renewable fuels while cleaning the environment.

Plasma Gasification Process

Plasma gasification is a multi-stage process that starts with a variety of inputs ranging from garbage to

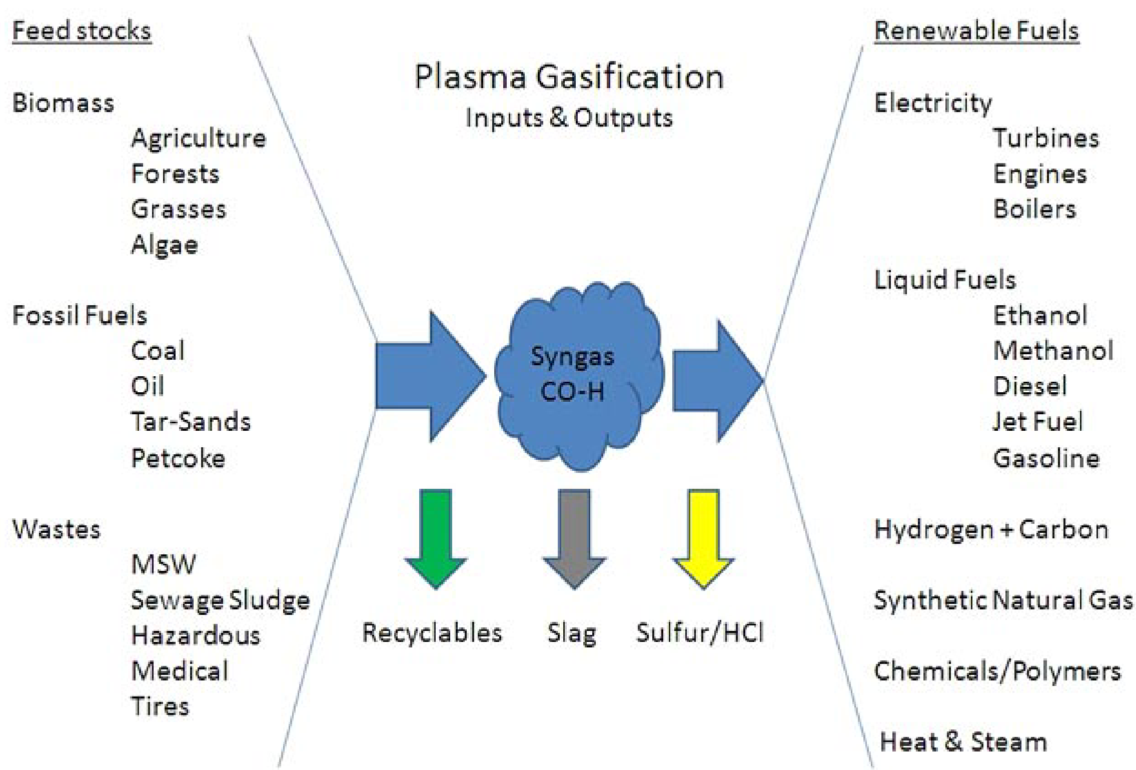


[1] US EPA, United States Environmental Protection Agency, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006*, EPA-530-F-07-030 Nov. 2007.

coal to plant matter, but can include any hazardous waste or carbon-based material. The first step is to process the feed stock to make it more uniform and dry for gasification; in the case of MSW, it will be shredded and 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 gasses. The extreme heat from the torches causes all the inorganic materials to melt and form slag. The extreme heat also causes all the hazards and poisons to be completely destroyed. The technology has its roots in hazardous-waste destruction. The third stage is the gas cleanup and heat recovery. The gasses are scrubbed of all impurities, forming a very clean fuel gas. Heat exchangers are used to recycle the heat back into the system in the form of steam and electricity. The final stage is fuel production which can range from electricity to liquid fuels like ethanol, hydrogen, natural gas, or chemicals and polymers.

What is Gasification?

Gasification is an old industrial process that uses heat in an oxygen-starved and pressurized environment to break down carbon-based materials into fuel gasses. There is a huge variety of



gasification equipment and techniques that are tailored to deal with a wide variety of raw materials. Any material made from carbon is suitable for gasification, and the most common materials used are coal and biomass, such as wood or agricultural wastes. Coal gasification is a major industry with a long history in use to produce fuels ranging from old-fashioned "town-gas" to ultra-clean diesel and chemicals. Modern clean-coal plants all use gasification systems. Many pathways for producing cellulosic ethanol utilize biomass gasification to break down wood waste and other non-food crops to make a gas that can be processed into ethanol. Gasification is more environmentally sound and more fuel-efficient than typical combustion systems, and is being heavily promoted by the energy industry as an environmentally sound means to utilize coal and other unconventional hydrocarbons such as tar sands. As a means to treat garbage, gasification is far superior to incineration, both environmentally and in net energy production.

Gasification is closely related to combustion and pyrolysis, but there are important distinctions. Gasification is like starved-air burning because oxygen is strictly controlled and limited so that as heat is applied the feedstock is not allowed to actually burn. Instead of combusting, the raw materials break down and go through the process of pyrolysis that produces char and tar. At its simplest form, pyrolysis is commonly used to produce charcoal from wood. As the process continues and the heat is taken higher, the char and tar completely break down into gasses. Depending on the process used and the precise chemistry, the resulting gas may come in a few different forms: synthesis gas, producer gas, town gas, wood gas or others.

Synthesis gas, also known as syngas, will be the focus of this report. Syngas is a simple blend of CO-H, carbon monoxide and hydrogen. This gas burns very cleanly with properties very similar to natural gas, although with less heating value. Syngas can be burned to produce heat and steam, or electricity through the use of boilers, engines, and turbines. Alternatively, syngas can be processed using catalysts and refined into a variety of liquid fuels. Fischer-Tropsch synthesis was invented in the 1920's and has been used heavily since WWII to produce gasoline and diesel from coal. Traditionally, coal-to-liquids has been much more expensive than petroleum, but the recent rise in oil prices has made many unconventional energy technologies cost-competitive and new catalysts are being developed to economically produce ethanol. Syngas can also be used to produce hydrogen and is considered a primary pathway to a possible hydrogen economy by the U.S. Dept. of Energy. Syngas can be upgraded into synthetic natural gas or used to make many different industrial chemicals.

What is Plasma?

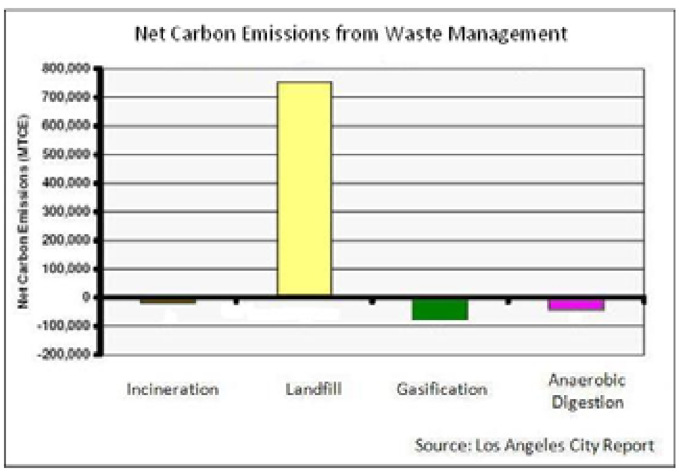
Plasma gasification refers to a range of techniques that utilize plasma torches or plasma arcs to generate extreme temperatures that are particularly effective for highly efficient gasification. Plasma is a superheated column of electrically conductive gas. In nature, plasma is found in lightning and on the surface of the sun. Plasma torches burn at temperatures approaching 10,000˚F and can reliably destroy any materials found here on earth with the exception of nuclear waste, since radioactive isotopes are not broken down by heat. Plasma torches are typically used in foundries to melt and cut metals, and similar electric-powered furnaces melt metals by the ton. 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 and at those temperatures materials are subject to a process called molecular disassociation, which means that 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 PCBs and asbestos, but it is only recently that these processes have been optimized for energy capture and fuel production.

Due to the high operating temperatures, plasma is very effective at vaporizing very difficult waste materials. Plasma gasification is also more robust than other gasification systems which are closely engineered to match the feed stocks being used. Many forms of gasifiers are used for coal and biomass, but plasma systems are unique in their ability to mix and match feed stocks, and even vaporize raw municipal waste, which may include metals, glass and electronics. Tires, medical waste, petroleum refinery wastes, low grade coal, railroad ties and phone poles are all examples of materials that are currently considered toxic and difficult to dispose of and yet are ideal fuels for plasma gasification and can be used to produce clean energy.

All of the non-organic materials contained in the feed stock are melted and pour out of the bottom of the gasifier. This material is called slag, and cools into vitrified glass similar in appearance to obsidian. Slag is very stable and safe, due to its tightly bound molecular formations. It has been subject to many tests and easily passes EPA standards for leachability. Slag may be used as an aggregate in asphalt or concrete and may be subject to various value-added processes to separate metals and form bricks, tiles, or rock wool.

Waste Gasification Cleans Up the Environment

Waste gasification is good for the environment because it gives value to garbage and keeps it out of the landfills. Landfills produce significant amounts of methane, which is considered to be a potent greenhouse gas. Landfills produce toxic liquid leachate that must be collected to prevent contamination of groundwater and aquifers.



Gasification is not incineration and is a distinctly superior environmental solution compared to burning. The overall emissions of primary pollutants are very low from gasification. Gasification also does the best job of reducing overall greenhouse gas emissions, compared to other forms of waste management.

	Gasification	Incineration
Carbon Footprint	• -78,000 MTCE per 1MM tons of MSW • Sequestering possible	• -18,000 MTCE per 1MM tons of MSW • No sequesteration
Air Emissions	• Minimal dioxins (.002 ng/m3) & furans • Pre-combustion cleanup of syngas • Similar to IGCC - SOx (1.2 ppmv) , NOx (31 ppmv)	• Bad history of dioxin (.42 ng/m3) emissions • Post-combustion cleanup (scrubbing, filters, EP) • High SOx (9.3 ppmv), NOx (120 ppmv) , particulates
Ground Emissions	• Slag – safe and non-leachable • 250:1 volume reduction	• ~250 TPD ash per 1,000 TPD MSW, 4:1 reduction • Ash is toxic, leachable and most often landfilled • Concentrates of heavy metals, dioxins, chlorides
Useful Products	• Net electricity ~ 900 kWh/ton • Ethanol ~100 gallons/ton (in development) • Vitreous slag – useful for construction • Recovered metals, sulfur	• Net electricity ~ 550 kWh/ton • Recycled metals
Temperature	• Plasma at 1500˚C • Sealed system – low oxygen • Molecular dissasociation	• Fire at 850˚C • Open air - excess oxygen

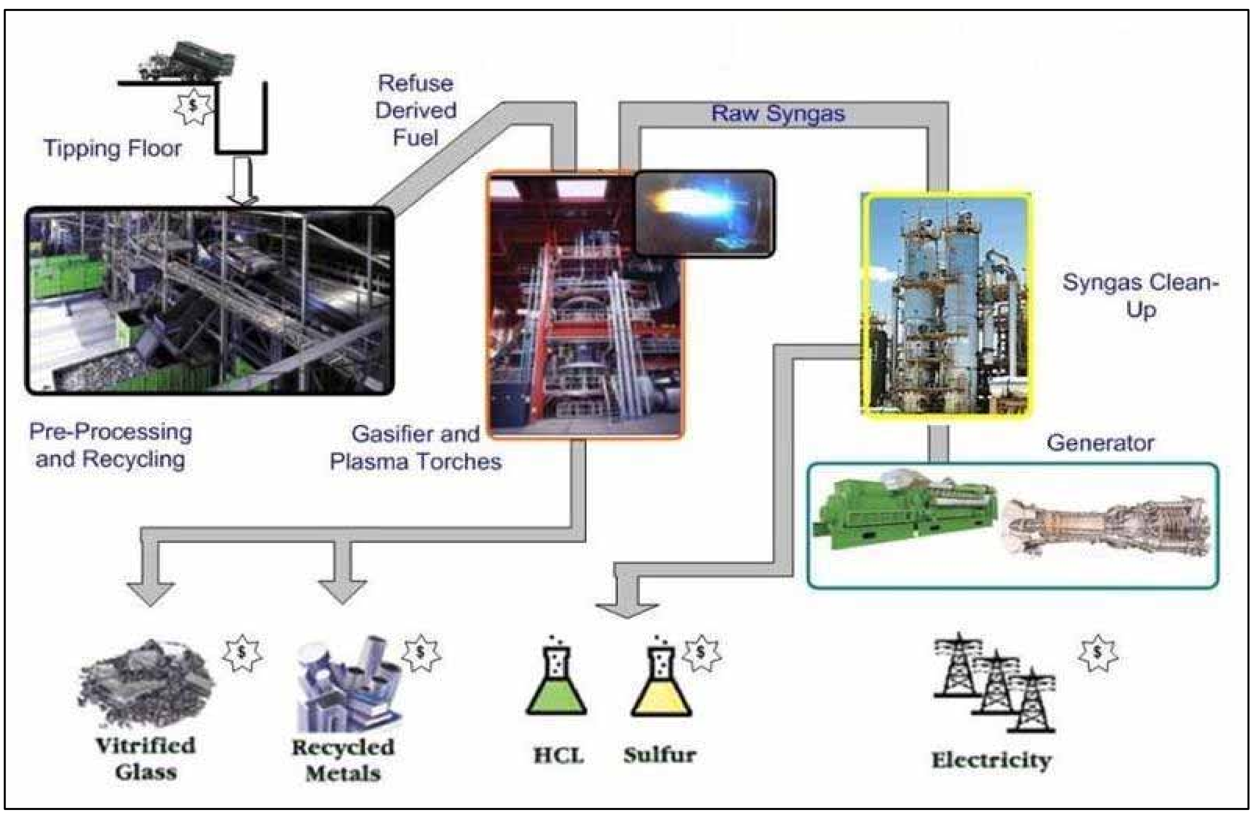
Waste Gasification Pays for Itself

Municipalities can count on waste gasification to pay for itself. Many revenue streams emerge from the collection of waste, recycling of commodities, and fuel production. For municipalities, waste gasification can be utilized to transform waste disposal liabilities into valuable commodities that have value for the public. In addition, many liabilities can be avoided when garbage is diverted from landfills. Municipalities must pay to maintain their landfills forever and are subject to regulations from the EPA concerning air and water emissions. By avoiding landfills, the municipality can save money.

Waste gasification encourages robust recycling because commodity recyclables are far more valuable when sold than when used for fuel, and their removal improves the gasification operation and the quality of the output gas. Municipal solid waste (MSW) is charged a tipping fee at disposal that ranges from $30 a ton up to over $100 a ton for places like New York City where disposal is difficult. The output fuels earn revenues. The operator gets paid to take the waste and then gets paid again as the waste is processed and its value captured. Many products can be delivered from gasification. Liquid fuels, hydrogen and synthetic natural gas are all valuable products, but work is still being done to make their production from garbage profitable. The most immediate fuel product that can be delivered is electricity.

2. Economics

The economics of a municipal waste plasma gasification facility is very favorable, although complex. There are multiple revenue streams to take advantage of. Waste gasification systems earn payments from tipping fees for taking waste. The system earns revenues from the sale of power on the output. Electricity is the primary product in 2008, but liquid fuels, hydrogen, and synthetic natural gas are all possibilities that may earn greater revenues. Sorting the MSW to capture commodity recyclables such as metals and high-value plastics also presents a significant revenue stream. Minor revenue streams include the sales of slag and sulfur. Slag has the potential to be used for a number of products such as rock wool, bricks and architectural tiles. Sulfur revenues are expected to be quite small especially if gasification systems become more common and the market has a glut of sulfur. Additionally, a municipality should consider costs that are avoided by diverting waste from landfills and minimizing transportation of waste. Government subsidies for renewable energy or carbon credits may also be substantial in the future, but as of 2008 are difficult to quantify and would vary by government.



Multiple Revenue Streams

Using a base case scenario of a 750-ton-per-day waste gasification plant, which would be appropriate for a small city or regional facility, the estimated capital cost to construct would be approximately $150 million. Assuming a municipality that funds the entire project through 20-year bonds at 7% interest and pays no taxes, it can expect to receive a positive cash flow year over year by earning revenues from tipping fees, recyclables, and electricity sales. Additional revenues are available from sales of slag and sulfur, but these are minor. There is considerable range in the values for each of these variables, and any proposed development will require extensive due diligence to determine local prices for each line item. For example, the model at left uses tipping fees of $35 a ton which is a conservative value; large urban areas where waste must be trucked a long distance for disposal may have tipping fees over $100 a ton. Electricity prices range from $70 - $110/MWh, and $70 is used in this model. The value of recycled materials also has a large range. Certain plastics and metals can demand $200-$300 a ton, but these prices change from day to day and from state to state. Difficult and hazardous wastes carry higher tipping fees, medical waste and chemicals can earn $200-$1000 a ton but require additional permitting and waste-handling equipment.

Annual Economics	
Revenue	
Electricity Production	$13,230,000
Tipping Fees	$9,187,500
Recycling Sales	$8,568,375
Slag Sales	$315,000
Sulfur/HCl Sales	$1,750
Total	**$31,302,625**
Expenses	
Operating Expenses	($9,828,330)
Debt Payment	($14,407,225)
Taxes	$0
Total	**($24,235,555)**
Annual Cash Flow	**$7,067,070**

The economics of waste gasification heavily favor recycling because inorganic materials like metal and glass have no value as fuel and make the gasification process less efficient by consuming more electricity. Plasma gasification has the capacity to treat unprocessed MSW, but the efficiencies and economics are improved through preprocessing. High-value plastics and papers that can be readily separated are far more valuable as recyclables than as fuel, with certain plastics earning $300 a ton. Paper represents approximately 22% of MSW and certain types can earn around $75 a ton. For comparison, a ton of waste will produce .9MW of electricity worth around $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.

Revenue Calculations					
	Tons Per Day	Per Year (350 days)	Fee Per Ton	Daily Revenue	Annual Revenue
MSW Total Input (tons):	**750**	262,500			
Tipping Fee per ton:			**$35**	$26,250	**$9,187,500**
Recycling from MSW (tons):	**150**	52,500			
Recycling Earnings per ton: (see chart)					**$8,568,375**
MSW Input to Gasifier (tons):	**600**				
IGCC Electricity Production					
Gross Electricity Production = 1.2MWh per ton	720				
Internal Use = .3MWh per ton	180				
Net Electricity for Sale = .9MWh per ton	**540**	189,000			
Electricity Price per MWh:			**$70**	$37,800	**$13,230,000**
Slag					
production = 10% of gasified (tons)	60	21,000			
sales = $15 per ton			**$15**	$900	**$315,000**
Sulfur/HCl					
production (tons)	0.2	70			
sales = $25 per ton			**$25**	$5	**$1,750**
TOTAL					**$31,302,625**
Ethanol Production - (Alternative to Electricity)					
100 gallons per ton	60,000	21,000,000			
$1.25 per gallon			$1.25	$75,000	**$26,250,000**
TOTAL (Alternative)					**$44,322,625**

Recycling efforts have been limited in the past by the difficulty in sorting and the inability to sell materials that are mixed and contaminated. Garbage has paper mixed with low-grade film plastics, food and containers. Many papers are laminated or waxed, particularly paper products used for food. None of these contaminated materials can be recycled. Plasma gasification offers the next step in processing by safely refining the fuel value out of mixed and contaminated waste.

Recycling Revenues					
Material	**Value $/ton**	**Tons per 750**		**Daily Rev**	**Annual Rev**
Glass	$5	2%	15	$75	
Metal	$220	6%	45	$9,900	
Paper	$75	8%	60	$4,500	
Plastic	$300	4%	30	$9,000	
Total			**150**	**$23,475**	**$8,568,375**
source: scrapindex.com					
Commodity prices vary by type, region, day					

When designing the processing system used to separate the recyclables out from the mixed waste, a balance needs to be found that allows for the proper amount of separation. The equipment used to separate involves elaborate mechanical operations to shred, shake, and sort, using sensors, magnets, reverse-eddy magnets, cyclone sorters and other sophisticated machines. These machines can be expensive and require extensive maintenance to ensure proper operation. An operator does not want to over-invest in sorting equipment that may be a maintenance burden or not cost-effective. For example, tires have excellent fuel value because of the heavy rubber, but they are also embedded with steel threads. Equipment exists that can shred tires to any size from 2" chunks to fine powder. The more the tires are processed, the more steel can be removed, but that comes at a higher cost. There are potential markets for tire crumb with all steel removed, such as soft ground covering for school playgrounds. The question is whether that level of processing is cost-effective compared to simple chunking that leaves the steel embedded in the rubber but is still acceptable for use as fuel in a plasma gasification plant. An operator will have to weigh these options to determine what level of waste processing makes the most sense for their facility.

Unconventional Fuels

Additional waste streams not included in this model may available in certain locations and earn higher tipping fees than MSW. Refinery wastes such as petcoke from petroleum and chemical plants are toxic and costly to dispose of but represent excellent fuel for plasma gasification. Auto shredder residue, all the plastics and fluff from automobile destruction after the metal has been removed, has been utilized successfully in Japan for gasification. Construction debris can make an excellent fuel. Millions of tons of low-grade waste coal exist in massive piles throughout Appalachian coal regions because it is not suitable for burning, but it is fine for gasification. Plasma gasification opens up the possibility of using a very wide variety of unconventional fuel sources in a single facility.

Availability and Heating Value of Select Opportunity Fuels

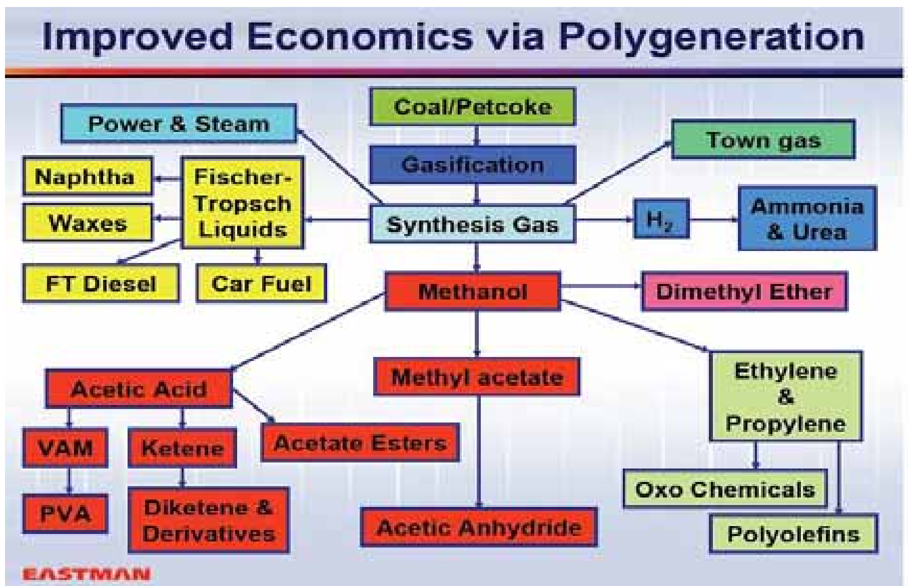
Fuel	Quantity Available	Heating Value
Other Fuels		
Petcoke	29 million tons/yr produced by U.S. refineries [1]	12,600 – 14,500 Btu/lb [5]
Tires	290 million scrap tires generated annually. 46% currently used as fuel. [3]	ca. 15,500 Btu/lb [4]
MSW	190 million tons/yr combustible MSW generated [2]	5,500 – 7,200 Btu/lb[6]

[1] Energy Publishing, LLC Domestic & International Petcoke Report May 2005
[2] Based on US EPA MSW Generation Data for 2003 and 80% Combustible Material
[3] US EPA, 2003 Data
[4] Proprietary Report. $2005 dollars
[5] Firing Refinery By-Products in CFB Steam Generators. Foster-Wheeler
[6] State of Connecticut Office of Policy and Management Energy Data. May 9, 2006

A single plasma gasification plant can utilize mixed feed stocks and ideally would blend the feeds to achieve a recipe that meets both waste disposal needs and gasification performance requirements. MSW can be mixed with pet coke or coal to raise the heat value, or may be mixed with sewage sludge to assist in disposal. Dedicated streams of yard waste and organics may have value as compost, and a judgment must be made by the operator concerning local needs and considerations. Different feed resources have different economic and fuel values that must be balanced by the operator.

Wide Variety of Products

Multiple outputs can be produced from a single facility. Heat and steam are abundant in gasification facilities, where they may be converted into power to use internally while excess may provide heat to neighboring facilities. Electricity production can be combined with ethanol or hydrogen production to maximize resource and financial benefits. Eastman Kodak has operated a coal-to-chemicals gasification plant since the early 1980's that produces methanol and a wide variety of chemicals.



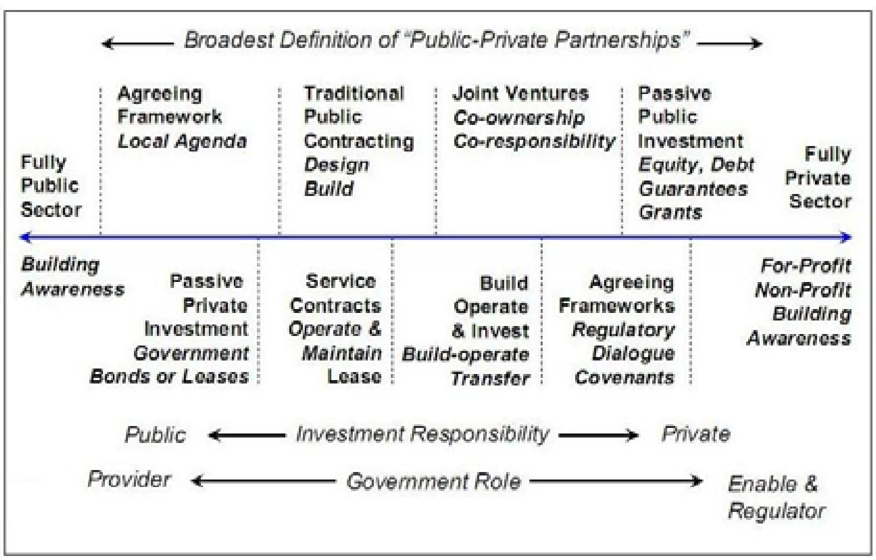
Liquid fuels are produced by two primary pathways. The conventional means is to use catalysts to refine the gasses into various fuels. There is a long and well established history of using Fischer-Tropsch catalysts to produce low-sulfur diesel and gasoline from coal. Methanol production is traditionally done in industry using catalytic conversion of syngas. Efforts today are focused on developing more selective catalysts that will produce ethanol at desired concentrations from syngas. Presently ethanol from gasification costs more than $2 a gallon and it is estimated that production needs to cost closer to $1.25 or $1.50 to be competitive. But with rising petroleum prices, these market dynamics continue to change. Production of ethanol at demonstration scale has shown that 1 ton of MSW can produce around 100 gallons of ethanol, give or take 20%. Cost estimation for ethanol production is very difficult because the technology has not matured. Rough calculations indicate that production of ethanol can be significantly more profitable than production of electricity.

There is a second emerging pathway to producing liquid fuels, and that is using enzymes or micro-organisms to refine syngas. Significant challenges remain to utilizing these biotech methods for liquid-fuels production, but a lot of effort and investment is going into the industry now. Companies such as Bioengineering Resources and Coskata are actively working on these pathways, which are considered among the promising routes to eventual large-scale production of cellulosic ethanol.

Hydrogen can be readily produced from syngas and the Dept. of Energy considers gasification to be a primary means of large-scale hydrogen production.[2] Presently the demand for hydrogen is insufficient to justify large-scale investment in hydrogen production, although much of the existing hydrogen used in industry does come from gasification plants. Improvements in fuel cells may eventually spur the demand for hydrogen among the public. Synthetic natural gas can be produced via gasification by upgrading the methane content. Great Point Energy is investing heavily in proprietary gasification techniques utilizing catalysts to produce natural gas from coal. In theory, similar techniques could be applied to MSW, but that would be years away from production.

Facility Development

One of the first steps in developing a plasma gasification facility is to identify a site and contract long-term fuel supply and power purchase agreements. In order to finance a 20-year bond to cover the capital costs, 20-year feed stock and power purchase agreements are required. Municipalities are at a potential advantage, because they may already own the landfills and be responsible for the waste stream inside their borders, so it may be relatively easy to contract the feed stock agreements. If the municipality can also be the primary consumer of the power produced by fueling their own buses and service vehicles or buildings, then it can use the facility as a hedge against rising fuel costs.



[2] http://www.hydrogen.energy.gov/production.html

Public-Private-Partnerships
Only O & M by private sector
Turnkey by private sector to public entity
Lease – purchase
Lease – develop – operate
Build – transfer – operate
Build – own – operate – transfer
Build – own - operate

Partners in the form of equipment vendors, engineers and financiers also need to be identified. There is no single company that can provide a turnkey plasma gasification facility at this time. All of the subsystems are products of different vendors. Alter NRG, which owns the Westinghouse Plasma technology, offers gasification reactors and complete engineering services, while other major technology firms like GE offer electrical production and a large suite of services. Many vendors offer to take an equity position in the facility, and public-private partnerships can be formed that reduce the risk for the municipality and the vendors. Plasma gasification systems require years of development in the engineering and architecture, as well the siting and permitting, before ground is broken. So all the partners involved have to be able to work on long time frames and finance years of investment before any revenues are generated. Many companies are entering the waste-to-energy business and offering a wide variety of technologies including pyrolysis, various forms of gasification, and variations on plasma gasification. The claims of any firm must be evaluated closely because very few have actual production experience.

Abbreviated List of Typically Required Regulatory Approvals

Approval	Agency	Activity
Permit to Construct Air Contaminant Sources	EPA	Construction of air contaminant sources or indirect sources (flares, turbines, material handling systems, control equipment)
Certificate to Operate for Sources of Air Contamination	EPA	Operation of air contaminant sources or indirect sources
Wastewater Treatment Plant Construction Permit	EPA	Any discharge of sewage, industrial wastes, storm water, or other wastes to surface water or groundwater
Water Supply Permit	EPA	Construction of wastewater treatment facility, including: cooling towers, coal pile runoff ponds, sewage treatment facilities
Solid Waste Construction Permit	EPA	Water supply and water allocation
Solid Waste Operating Permit	EPA	Construction of solid waste management facility, including storage, transfer, processing, recovering, reclaiming, and disposal
Corps of Engineers (COE) Permit	COE	Any activity in or affecting navigable water of the states including any marshes, estuaries, and wetlands adjacent to navigable water (intake/discharge structures, pipelines, transmission lines)
401 Certification	EPA	Required for any federal permit indicating that approval will not cause a violation of state water quality standards
Construction in Flood Hazard Area Permit	EPA/Local	Construction within 100-year floodplain
State Environmental Quality Review	EPA	Reviw of environmental impacts associated with the Project (threatened, endangered, or protected species; historic buildings, natural resources)
Building Permit, Zoning Approval	EPA	Permit required for occupancy of a structure including: ellectrical, plumbing, HVAC, fire protection, life safety, also for boilers, pressure vessels, eleveators, land use, zoning

US Dept of Energy, NETL - National Energy Technology Laboratory, April 2007

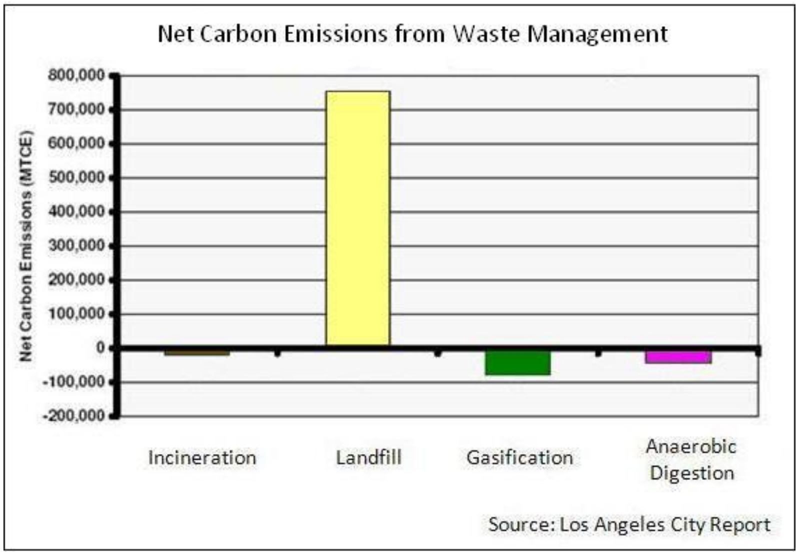
Significant government subsidies and tax credits may come available in form of renewable energy credits or also carbon reduction credits. These policies are still emerging, but there is significant political will to provide subsidies for renewable energy. Economic models in this report do not include any of these potential financial incentives. A facility should be able to pay for itself without requiring these credits. Yet these credits may prove to be very significant and offer substantial financial improvements to the bottom line.

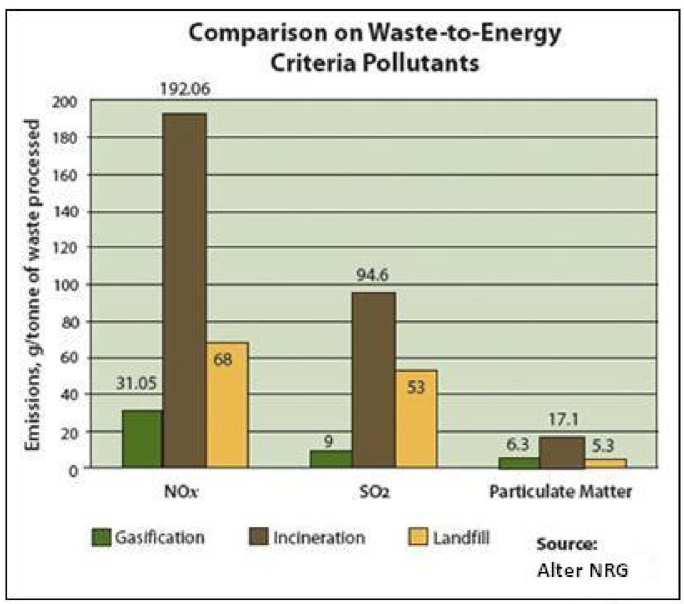
Early commercial developments need to incorporate appropriate risk-mitigation strategies. The most effective risk-mitigation measure for a municipal utility is to contract for power from a project without taking on the risk of ownership, until the project has demonstrated its reliability. The economics of MSW gasification are highly dependent on the costs for alternative power and the cost of disposing of MSW in landfills. Recent studies indicate that these costs may now be reaching levels at which plasma gasification becomes economically viable. Definitive conclusions about economics require specification of an actual project, including the site and arrangements for the MSW. Another significant concern is that regulations and legislation are lagging behind the development of the technologies. Detailed reports have been produced for the city and county of Los Angeles, CA, the city of Alameda, CA, and Halton, Ontario, that review various technologies for MSW processing and review the legal, institutional factors that play into decision-making. It is a significant commitment for a municipality or state to invest hundreds of millions of dollars and center their waste-management practices around a new and not well known technology. Visionaries claim great benefits, and on paper plasma gasification appears to be a remarkable solution, yet the systems are very complex and to date have not been built at large commercial scales. Decision-makers would be prudent to do a very thorough investigation of their specific situation, detailing the economics and engineering in great detail.

3. Environment

Improved Waste Management

Gasification is superior to burning or landfilling of MSW for a number of reasons. First of all, landfills are in themselves toxic to the environment. Decomposition and chemical reactions among the waste produces liquids that leach out and may contaminate ground water. Decomposition of organic matter produces methane, which is a potent greenhouse gas. Other chemicals may be produced that toxify the air around a landfill and may be harmful to neighbors. The EPA has a lengthy protocol of airborne and liquid chemicals that must be contained and monitored into eternity for every landfill. Modern landfills must be constructed with liners and leachate drains. These facilities are becoming increasingly expensive as more environmental regulations come into existence. When landfills are closed, they must be capped and monitored indefinitely. Despite expensive management strategies, the only good solution for landfills is to avoid them. Plasma gasification is an ideal treatment strategy to divert waste from landfills and create beneficial uses for the material by maximizing recycling of valuables and cleanly use the rest for its fuel value. The carbon impact of plasma gasification is significantly lower than other waste treatment methods and is rated to have a negative carbon impact compared to allowing methane to form in landfills.





Sewage sludge is also a very important waste product from a municipal perspective. Conventional waste water treatment facilities produce a thick sludge on a daily basis after all the clean water has been filtered out. To date there have not been many good options for how to treat sewage sludge. Sludge is typically dumped on farm fields despite the presence of metals, pathogens and organic pollutants. Nationally, over 60% of the 6.2 million dry metric tons of sludge produced annually are applied to land.[3] The exact nature of the contaminants contained in sludge varies widely between treatment facilities, depending on the processes used and the nature of the effluent that is being worked with. The practical reality is that many types of harmful contaminants are often contained in sludge and are difficult and cost-prohibitive to remove, so they remain in the sludge when it gets deposited on fields. Municipalities need better solutions for treatment of harmful biosolids. Gasification can be a practical solution.

Gasification is superior to incineration, and offers dramatic improvement in both its environmental impact as well as its energy performance. Incineration has long had problems with the formation of dioxins and other critical pollutants. Incinerators are high-temperature burners that use the heat generated from the fire to run a boiler and steam turbine to produce electricity, very similar to conventional coal-fired power plants. During combustion, complex chemical reactions take place that bind oxygen to various molecules and form pollutants such as sulfur oxides, nitrogen oxides and dioxins. These pollutants pass through the smokestack unless exhaust scrubbers are put in place to clean the gasses. 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. Scrubbers in a gasification system are integral to the operation of the system regardless of the regulatory environment. For combustion systems, the

COMPARISON OF POLLUTION PERFORMANCE

	MSW IGCC MODELED	MSW COMBUSTION PERMIT LIMITS
Carbon Monoxide (CO)	39	150 ppm
Sulfur Oxides (SOx)	15	30 ppm or 80% sulfur removal, whichever is less stringent
Nitrogen oxides (NOx)	Not provided - Likely to be much lower than limit	180 ppm – 1st year 150 ppm after 1st year
Particulate Matter	8.2	24 mg/Nm^3 (dry) and < 10% opacity (6-minute average)
Dioxin and Furan	0.01	30 ng/Nm3 (dry)
Hydrogen Chloride (HCl)	< 1	25 ppm or 95% reduction, whichever is less stringent
Mercury (Hg)	0.0006	0.08 mg/Nm^3 (dry) or 85% reduction by weight, whichever is less stringent
Lead (Pb)	0.008	0.2 mg/Nm^3 (dry)
Cadmium (Cd)	0.004	0.02 mg/Nm^3 (dry)

Source: NETL, National Energy Technology Laboratory, US Department of Energy MAJOR ENVIRONMENTAL ASPECTS OF GASIFICATION-BASED POWER GENERATION TECHNOLOGIES Final Report 2002, Table 3-10.

[3] Harrison, et al, "Organic Chemicals in Sewage Sludge", Science of the Total Environment 367 (2006) 481–497

smokestack scrubbers offer no operational benefit and are put in place primarily to meet legal requirements. The ash from incinerators is also highly toxic and is disposed of in landfills, while the slag from plasma gasification is safe because all of the ash is melted and reforms in tightly bound molecular structure. One of the main uses for plasma torches in the hazardous-waste-destruction industry has been treating incinerator ash by melting it.

Mihama-Mikata Plasma Gasification Pilot Plant, Japan
Systems Test Report, 2003

Emission Limits (Stack)

Item	Unit	Regulation value	Target	Measured value1	Measured value2
Dust	g/m3N	0.15	0.02	0.003 under	0.003 under
HCL	ppm	430	100	39	22
NOx	ppm	250	150	62	82
SOx		K-value = 17.5	———	0.02 under correspondence	0.03 under correspondence
	ppm	———	———	1ppm under	2ppm
CO	ppm	———	30	29 under	27 under
Dioxins	ng-TEQ/m3N	5	0.05	0.00059	0.00067

Provided by: Westinghouse Plasma

Low Emissions

The EPA does not have very thorough regulations regarding the gasification of municipal waste, because it has never been done on a large scale in the United States. Proposed facilities have instead been subject to emissions standards for waste incinerators. In practice, gasification systems employing proper scrubbers have extremely low emissions and have no trouble meeting and beating the most stringent emissions targets.

Emissions are mitigated through a combination of engineering that reduces the formation of certain compounds such as dioxins and NOx, and also by a suite of scrubbers and filters that remove other pollutants such as sulfur and mercury. The objective of gasification systems is to produce a clean gas that can be used for downstream processes that require specific gas chemistry free of acids and particulate matter.

Slag Leachability

Metal	Permissible Concentration (mg/l)	Measured Concentration (mg/l)
Arsenic	5.0	< 0.1
Barium	100.0	< 0.5
Cadmium	1.0	< 0.02
Chromium	5.0	< 0.2
Lead	5.0	< 0.2
Mercury	0.2	< 0.01
Selenium	1.0	< 0.1
Silver	5.0	< 0.5

* Test results from Georgia Tech

The glassy slag residue from high-temperature gasification is subject to EPA Toxicity Characteristic Leaching Procedure (TCLP) regulations which are designed to measure eight elements of harmful leachates. Data from existing facilities, even those processing highly hazardous waste has shown them to be well below regulatory limits.

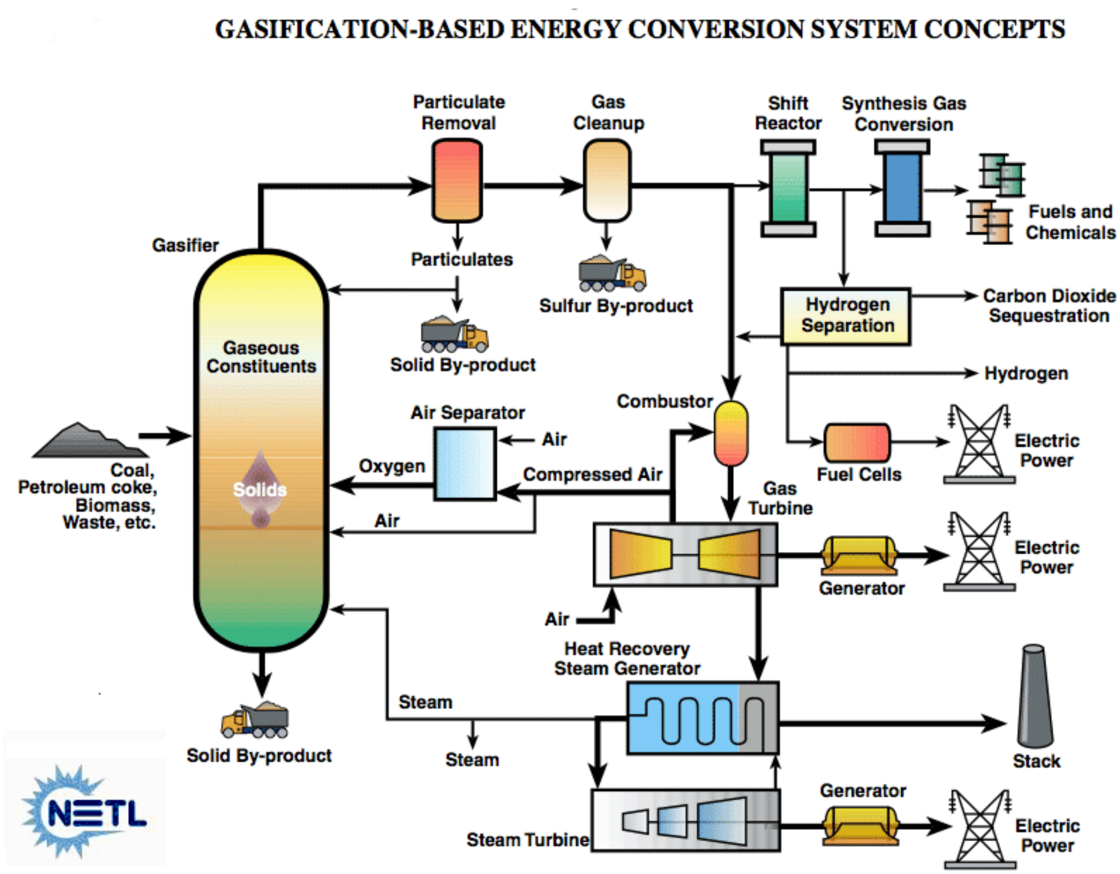
Carbon Sequestration

Gasification is an important enabling technology for carbon sequestering. Gasification is at its heart a carbon processing technology; it transforms solid carbon into gas form. The US Department of Energy has identified gasification through its clean coal projects as a critical tool to enable carbon sequestration. Syngas is a combination of carbon monoxide and hydrogen, which are readily separated, allowing the carbon to be sequestered or utilized for useful products. Carbon sequestering can be profitable when utilized to enhance oil recovery from abandoned wells. The engineering and economics of sequestering projects that seek to dump carbon into underground deposits simply to get rid of it are challenging and difficult. Researchers and entrepreneurs are actively developing new processes that will turn carbon monoxide and carbon dioxide into useful products such as polymers and ethanol. Novomer of Ithaca, N.Y., is a start-up company that is using carbon dioxide to produce biodegradable plastics and polymers. Lanzatech of New Zealand is a company working to produce ethanol from carbon monoxide in smokestacks via enzymatic conversion. Such innovations promise to find useful avenues for carbon. Carbon is a basic building block of life and all plants and animals are made from it. By finding productive uses for carbon, industry can work toward environmental sustainability.

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 study of the waste markets shows the alternative to be true. The economics of waste-to-energy heavily favor 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 that do not clean the gasses and instead use afterburners to immediately combust the dirty syngas. Such systems are essentially two-stage burners and are not recommended in this report. There are many variations of combustion, pyrolysis, and gasification used in different combinations. Proper engineering is required to achieve positive environmental performance.

4. Technology



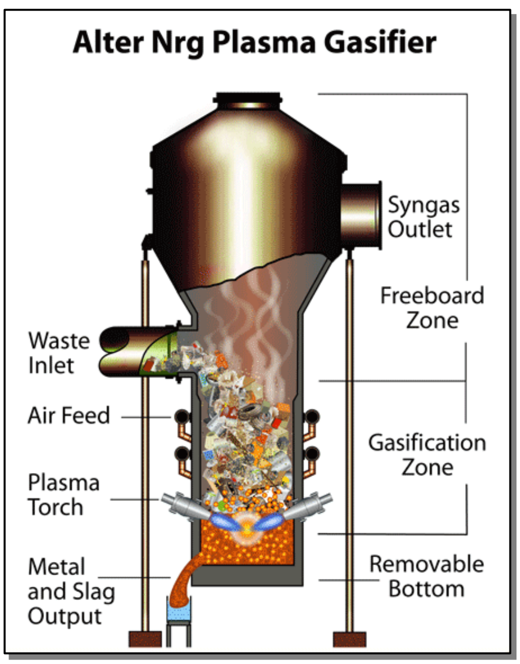
Plasma gasification for treatment of municipal solid waste is a fairly new application that combines well-established subsystems into a new system. The subsystems are waste processing and sorting, plasma treatment, gas cleaning and energy production. The integration of these systems is rapidly maturing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

Preprocessing

Waste sorting and processing is a mature industry for recycling. A wide range of drying technologies is commercially available, including rotary dryers, rotary kilns and fluid-bed dryers. Mechanical separation and size reduction is utilized for the removal of textiles, glass, paper, grit, plastic bags, recyclables and large items, including appliances. These devices include: shredders, trommel screens, sieves, grizzlies, vibrating screens, centrifuges, air classifiers, magnetic separators (for ferrous materials) and eddy-current separators (for non-ferrous materials). 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, but there is a balance to be struck with paper and plastics that are carbon-based and have value as fuel. In practice, any recyclables that are easily identified and removed should be removed, but at a certain point it is no longer economical to do additional sorting. MSW in this form is often called RDF, refuse-derived fuel. Odors are controlled by using negative air pressure, meaning that air is drafted through the facility and then used in the gasification process.

Plasma Gasification

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 MSW to energy is still in its infancy, but it has great potential to operate more efficiently than other pyroysis 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.



There are many different approaches to gasification; it is a technology that is as much art as it is science and it must be closely tuned to the feedstock being used. Coal gasification and biomass gasification both have long histories and there are many types of systems in existence. Plasma gasification is unique among all gasification technologies because it produces the highest temperatures and can deal with the most difficult and heterogeneous feed stocks.

Westinghouse Corporation began building plasma torches with NASA for the Apollo Space Program to test the heat shields for spacecraft at 5500˚C (10,000˚F). Westinghouse invested more than $100 million in the development of the technology before selling the division in 1989. The Westinghouse plasma torches are among the largest built. They operate at up to 2MW per torch and effectively convert more than 70% of that power to heat at temperatures up to 10,000˚F. They have been reliably used over the years to melt metals in foundries, destroy hazardous waste, and other industrial applications such as applying diamond coatings. In the late 1990's 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 the U.S., India, Turkey and other countries. The Westinghouse Plasma Corp. was independent until 2007 when it was purchased a Canadian energy firm named AlterNRG that intends to use the plasma gasification technology to convert tar-sands, coal, and MSW into energy.

Plasma gasification is advantageous because of the high temperatures produced and its ability to utilize mixed feed stocks. Garbage and sewage can be mixed with coal and biomass in any combination. Requirements for the output gas will determine the precise recipe of the feed going in. Gasification is an oxygen-controlled reaction where the air mix inside the reactor is carefully controlled. Steam may be injected to induce water-shift reactions and raise the ratio of hydrogen to carbon in the syngas. It is desirable to limit nitrogen in order to reduce formation of nitrogen oxides. Nitrogen is reduced by using an Air-Separator Unit (ASU), which separates oxygen from regular air and injects it into the gasifier. Oxygen ratios are very important to manage in gasification because some oxygen is required to create syngas, but if there is too much then combustion occurs instead of gasification and oxides form. In practice, a small of amount of combustion is utilized in gasification reactions to provide heat. Gasification of MSW requires temperatures above 1200˚C (2200˚F) and systems are targeted to operate around 1500˚C. As the hot gasses 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 multiple purposes including generating electricity, injection into the gasification reaction, or facility heating. There are however, engineering challenges in using heat exchangers at 1500˚C; as such temperatures strain steel and other materials. The heat exchanging subsystem is one of the areas that can benefit from further development and maturity so that maximum efficiencies can be achieved in the overall system.

Net Output of Thermal Processes for Municipal Solid Waste (MSW) to Energy Using Boiler Systems

	Type of Process	**Net Energy Production to Grid**
1.	Mass Burn (Incineration)	544 kWh / ton MSW
2.	Pyrolysis	571 kWh / ton MSW
3.	Pyrolysis/Gasification	685 kWh / ton MSW
4.	Conventional Gasification	685 kWh / ton MSW
5.	Plasma Arc Gasification	816 kWh / ton MSW

1 ton MSW = 3,150 kWh, heating value

Reference:
The Regional Municipality of Halton, ON
Step 1B: EFW Technology Overview,
May 30, 2007

Gary C. Young, Ph.D., P.E.
GYCO, Inc.
Cedar Rapids, IA 52402

Scrubbing

Once the gasses are cooled, they pass through a series of gas cleaning operations that are tuned to the requirements of downstream processes as well environmental regulations. There are many different designs for scrubber systems and it is a mature industry. Scrubbers are routinely used in cleaning smokestack exhaust in power plants and industry. Improvements and innovations continue to be made to improve the cost, reliability and integration with other processes. Scrubbers used in gasification are similar to those used for combustion systems, but with some optimizations. Gasification systems are at an advantage over combustion systems because there are fewer oxides formed in gasification and that makes the gasses easier to clean. The basic system concepts involve the removal of particulate matter, acid gasses and sulfur, mercury, and perhaps nitrogen using SCR (selective calalytic reduction). Particulate matter is treated using water quench, cloth filters or venturi cyclones. Activated carbon beds are used to remove mercury and other vaporized metals such as lead and cadmium, some of which also gets caught in the cloth filters. Sulfur is removed a variety of different techniques, but the basic idea is to use an activated lime that reacts with the sulfur to form either hydrochloric acid or an elemental sulfur. The sulfur products have some commodity value and may be used in fertilizers. Dioxins and furans are avoided through the use of very high temperatures in the gasification stage and then quickly cooling the gasses before scrubbing.

ENVIRONMENTAL CONTROL METHODS FOR IGCC			
Sulfur Control and Sulfur Byproducts	Greater than 98% sulfur control. H_2S and COS are removed from the syngas in an amine-based scrubber prior to combustion and recovered as elemental sulfur or sulfuric acid. Both are valuable industrial commodities.	**Trace Substance Control (Metals and organics)**	Most semi-volatile and volatile trace metals condensed and removed in syngas cleaning equipment. Elemental mercury emissions may exit with flue gas. Other metals exit with wastewater blowdown and wastewater treatment material. Trace organic emissions are extremely low. Activated carbon beds have been commercially demonstrated to remove more than 90% of syngas mercury.
Nitrogen Oxides Control	Fuel nitrogen mainly converted to N_2 and small amount of NH_3 and HCN, with the latter removed via syngas cleaning. Diluents, such as nitrogen and steam, are used in the gas turbine to lower the combustion flame temperature to minimize NOx generation. Use of add-on control technologies, such as SCR, have not been demonstrated for syngas-fired turbines.	**Solid Waste Disposal/ Utilization**	Slag material is environmentally benign and can be safely landfilled. Slag can also be safely utilized for various applications, such as drainage material or roofing granules. Similar to material produced by wet-bottom PC plants.
Particulate Control	Virtually all particulate is removed. Fly ash entrained with syngas is removed downstream in wet scrubber. No acid mist problem.	**Carbon Dioxide Control**	Higher thermodynamic efficiency of IGCC cycle minimizes CO_2 emissions relative to other technologies. High pressure and high CO_2 concentration in synfuel provides optimum conditions for CO_2 removal prior to combustion, if required.

Source: NETL, National Energy Technology Laboratory, US Department of Energy
MAJOR ENVIRONMENTAL ASPECTS OF GASIFICATION-BASED POWER GENERATION TECHNOLOGIES Final Report 2002

Energy Production

Electricity is produced in one of three ways; through the use of boilers and steam turbines, gas engines, or gas turbines. Engines and turbines require very clean gasses. Straight combustion to fire a boiler can use dirtier gasses and has the lowest cost of all the options. Steam turbine systems may generate 500-600kwh per ton of MSW. Gas turbines in a combined cycle may generate 1000-1200kwh per ton of MSW.

Integrated Gasification Combined Cycle (IGCC) is considered the state of the art and most efficient means to generate power from carbon resources and is the model used for modern clean coal power plants. In IGCC the syngas is combusted in an advanced turbine (similar to a jet engine) such as those manufactured by GE. The turbine produces electricity, and additionally the hot turbine exhaust is captured in a heat recovery steam generator (HRSG) to produce electricity from a steam turbine. The combination of a steam turbine with the gas turbine is the combined cycle. Gas turbines are very large pieces of equipment that produce from 40MW to over 200MW of power. For MSW gasification, the plant needs to handle a minimum of 750 tons per day to be able to utilize IGCC. Smaller systems could utilize banks of engines that operate from 1MW-4MW each, such as the GE Jenbacher engines that can be run in combined cycle mode. The simplest systems use boilers and steam turbines. Steam turbines range in size from the smallest at just a few KW to the very largest at 500MW and above such as those used for nuclear power plants and large coal power stations.

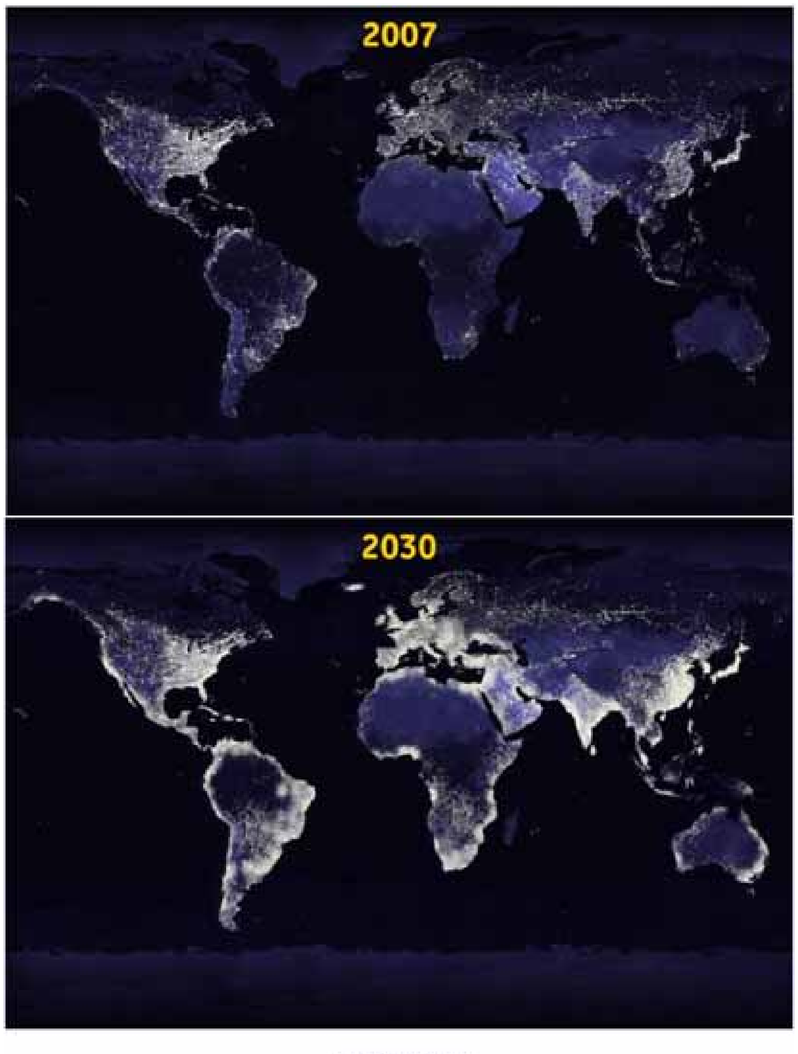
Gasification is very intense thermal process and there is a lot of heat to be captured and used. Heat-recovery steam generators can power the torches using the captured heat from the gasses. The gasses pass out of the reactor at around 1200˚ C and need to be cooled quickly to prevent the formation of dioxins and furans as well as to enable the scrubbing processes. Heat exchangers are used in the gas cooling to generate significant energy for the facility. Overall, the torches and the facility consume approximately 25% of the energy produced, leaving 75% available for sale.

Liquid fuels are produced by subjecting the syngas to catalytic conversions. Through the use of specially engineered catalysts, chemical reactions occur that convert gas molecules into new formations. Catalytic conversions have very specific requirements for the chemistry of the gas to maximize conversion efficiencies.

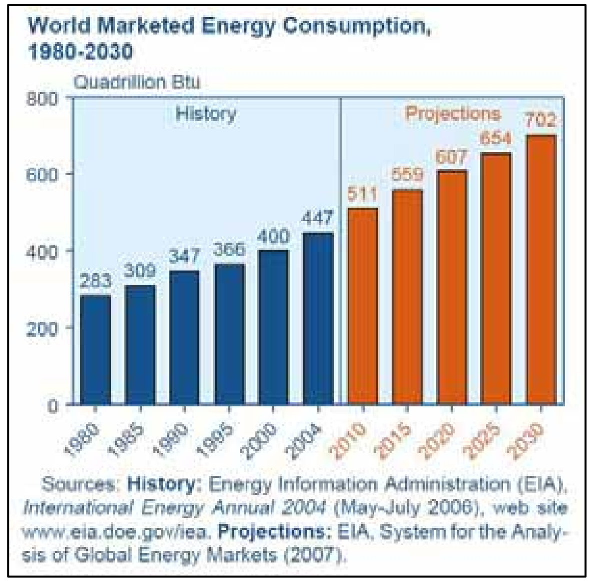
5. Conclusions

Growing Demand for Power

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. Political, business and community leaders are looking for solutions. 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 town budgets and provide a hedge against future increases in energy prices.

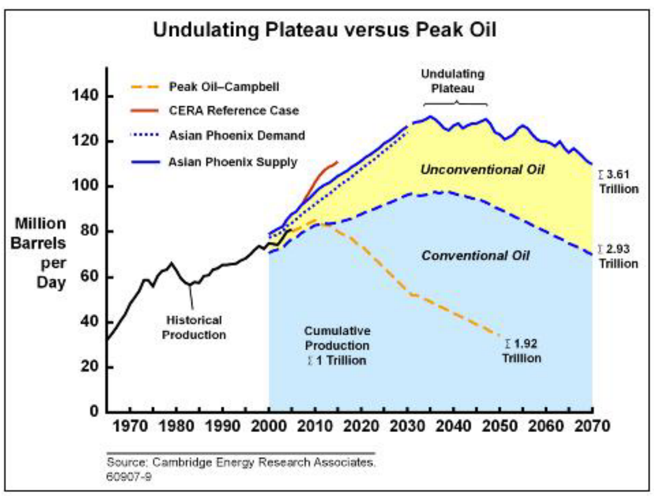


Global energy consumption is only going to rise over the next few decades as heavily populated countries such as China, India, Brazil and Indonesia modernize and embrace more consumer technologies. Efforts at conservation in the developed world are very important in maximizing the value of fuels, but conservation alone will not dampen the need for net supplies of energy to rise. Conventional petroleum resources are not going to be able to meet the rising demand. While there is much debate about the notion of Peak Oil, it does seem clear from recent events that petroleum supplies are at least going to plateau and that supplies needed to meet growing demand will have to come from new sources. The complete portfolio of renewable energy solutions, including wind, solar, geothermal, waste-to-energy, and others are going to be needed to meet growing demand. Gasification enables the use of unconventional fossil fuels, whether waste coal or Canadian tar sands, in a manner that keeps harmful emissions to a minimum. Extraction of fossil fuels needs to be managed for its environmental impact. Many practices, such as mountaintop removal for coal, or fracking for natural gas, are very harmful to the environment. At least by using gasification the emissions from combustion can be minimized and these resources can be utilized to help meet growing demand.



Landfills can be a Resource

In modern times, human society has developed an incredible capacity to waste. We use mineral and fossil resources from under the ground for single-use disposable products such as cheap plastic goods and electronics, and after a short time these goods are unceremoniously heaved into the local (or not-so-local) dump. Mineral resources need to be used again and again rather than one single time. People are starting to realize that mines and wells are not unlimited, and that the hydrocarbons and minerals they offered up are becoming increasingly difficult to find.



Fortunately many of those wasted resources are still available to us in the landfills. If it is economically viable to mine tons of ore to extract ounces of gold, it may well prove to be viable to mine landfills to recover metals and minerals. Landfills mostly fill up with organic materials from food and greenery that then mixes with chemicals, paints, solvents and oils to form a toxic stew. This stew is very harmful to the air, land and water, and to humans and animals, yet this stew could be converted into useful fuels. Virtually all of the material in the landfills can be recovered for some useful purpose, and now the technology and economics are making the practice viable.

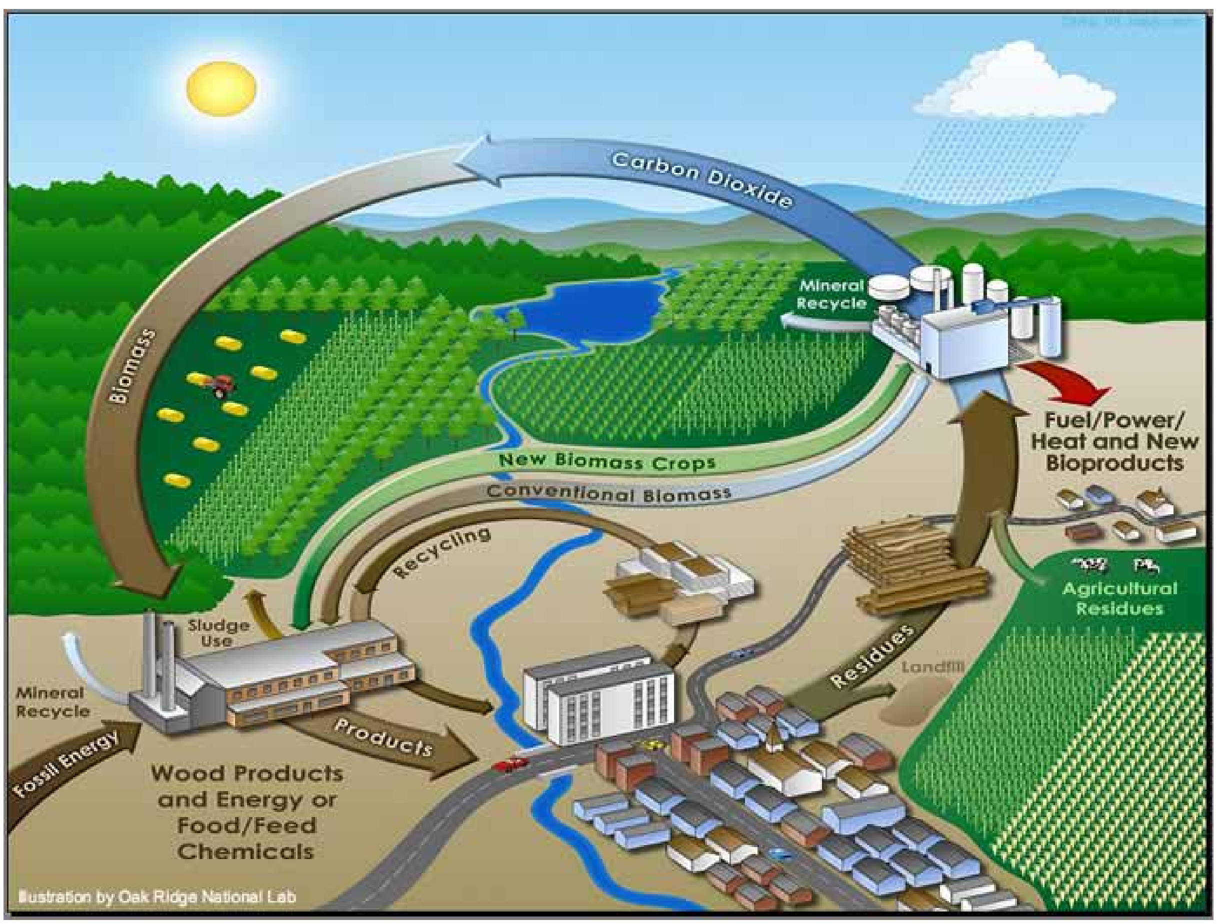
The economics of transforming liabilities into commodities has obvious value. Current methods of waste disposal and landfilling cost society many millions of dollars in administrative fees alone, and the environmental impacts of the pollution are difficult to quantify in dollar terms. There is a compound economic effect in the transformation from liability into commodity that is not simply a matter of moving sums across the accounting ledger. The effects are multiplicative when one problem can be used to solve another and both get solved at the same time.

If waste gasification were to be developed on a wide scale, very profound changes would occur in society. All garbage becomes valuable, the litter from a candy wrapper on the ground could have economic value, so someone would pick it up, similar to the way bottle deposits ensure that those bottles are not left on the ground. Illegal dumping can be minimized by providing useful means to collect common hazardous wastes found in many people's homes, such as motor oil, paints and solvents. These hydrocarbon-based chemical products can have great value as gasification fuels but are currently nuisances to most people.

Bridging the Gap

The technologies needed to make waste gasification work are coming along fast. The most encouraging aspect of plasma gasification is that the individual subsystems 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, gasification and gas cleaning is also well understood. Energy production from syngas can be done profitably today by producing electricity, and tomorrow ethanol will hopefully 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 cold be producing significant quantities of renewable fuels by using landfill waste and in doing so cleaning up the environment at the same time.

Plasma gasification can help bridge the gap between fossil fuels and biomass resources. Anything that is made from hydrocarbons can be made from carbohydrates. Any of the products made from petroleum can be made from the green earth. All the petroleum-based fuels, chemicals and plastics that modern society has embraced can be made from renewable resources of forests, farms, grasses, and algae. Gasification is a technology that enables this transformation because hydrocarbon and carbohydrate materials can be used together to make syngas and then refined into green products. Land-use policies that encourage the growth of greenery everywhere will help to sequester carbon dioxide while cultivating new resources. Plasma gasification is special because it allows difficult and contaminated materials to be made useful, which helps to clean the environment and grow our economy.



6. Appendix

Additional Financials

Capital Cost		
	Cost	% of Total
Feed Stock Handling		
Waste Recycling	$8,220,000	5.3%
Gasification		
ASU (Air Separator Unit)	$8,750,000	5.7%
Gasifier	$6,300,000	4.1%
Plasma Torches	$1,500,000	1.0%
Quench, Heat Exchange, Pre-Heat	$750,000	0.5%
Slag & Metal Handling	$2,000,000	1.3%
Gas Cleanup		
Venturi Water Quench	$220,000	0.1%
Process Water Treatment	$4,080,000	2.7%
LOCAT (Sulfur Removal)	$1,860,000	1.2%
Active Carbon Bed (Mercury Removal)	$430,000	0.3%
Cloth Filter - Bag House	$1,000,000	0.7%
Electricity Production		
Turbines	$38,000,000	24.7%
HRSG	$2,100,000	1.4%
Steam Turbine	$4,070,000	2.6%
Rest of Plant		
Service Water & Water Supply	$3,010,000	2.0%
Ancillary Systems	$4,870,000	3.2%
Electrical Supply	$5,720,000	3.7%
Instrumentation & Controls	$6,440,000	4.2%
Excavation, Concrete & Buildings	$8,300,000	5.4%
Piping	$4,870,000	3.2%
Equipment Installation	$5,010,000	3.3%
Total Construction Cost	**$117,500,000**	**76.4%**
Development		
15% Contingency	$17,625,000	11.5%
Plant Startup Equipment	$1,666,667	1.1%
Operator Training	$2,500,000	1.6%
Site Purchase	$4,000,000	2.6%
Legal & Permitting	$2,300,000	1.5%
Construction Finance (Interest/Bond)	$8,242,000	5.4%
Total Soft Cost	**$36,333,667**	**23.6%**
Grand Total - Capital Cost	**$153,833,667**	**100.0%**

Cash Flows									
		2010	2011	2012	2013	2014	2015	2016	2017
	Period	1	2	3	4	5	6	7	8
Revenue	Notes								
Electric Revenue	2% rise	**$13,230,000**	13,494,600	13,764,492	14,039,782	14,320,577	14,606,989	14,899,129	15,197,111
Tipping Fee for MSW	Fixed	**$9,187,500**	9,187,500	9,187,500	9,187,500	9,187,500	9,187,500	9,187,500	9,187,500
Recycling Earnings	2% rise	**$8,568,375**	8,739,743	8,914,537	9,092,828	9,274,685	9,460,178	9,649,382	9,842,370
Slag	2% rise	**$315,000**	321,300	327,726	334,281	340,966	347,785	354,741	361,836
Sulfur	Fixed	**$1,750**	1,750	1,750	1,750	1,750	1,750	1,750	1,750
Total Annual Revenue		**$31,302,625**	31,744,893	32,196,005	32,656,140	33,125,478	33,604,203	34,092,502	34,590,567
Operating Expenses	2% Rise								
Salaries and wages - 40 Employees		$2,750,000	2,805,000	2,861,100	2,918,322	2,976,688	3,036,222	3,096,947	3,158,886
Other Employee Benefits		$2,500,000	2,550,000	2,601,000	2,653,020	2,706,080	2,760,202	2,815,406	2,871,714
Building Services		$10,283	10,489	10,698	10,912	11,131	11,353	11,580	11,812
Office Supplies		$8,617	8,789	8,965	9,144	9,327	9,514	9,704	9,898
Overtime Premium (20% / 5% of Salaries)		$165,000	168,300	171,666	175,099	178,601	182,173	185,817	189,533
Auto, Truck, Rolling Stock (includes fuel, oil)		$95,125	97,028	98,968	100,947	102,966	105,026	107,126	109,269
Contract Testing Services		$550,000	561,000	572,220	583,664	595,338	607,244	619,389	631,777
Plasma Torch Electrodes		$750,000	765,000	780,300	795,906	811,824	828,061	844,622	861,514
Maintenance-Routine		$1,250,000	1,275,000	1,300,500	1,326,510	1,353,040	1,380,101	1,407,703	1,435,857
Water Services - Lab Tech		$64,880	66,178	67,501	68,851	70,228	71,633	73,065	74,527
Utilities		$100,000	102,000	104,040	106,121	108,243	110,408	112,616	114,869
Insurance		$750,000	765,000	780,300	795,906	811,824	828,061	844,622	861,514
Travel		$50,000	51,000	52,020	53,060	54,122	55,204	56,308	57,434
Telecom		$32,240	32,885	33,542	34,213	34,898	35,596	36,307	37,034
Legal Services		$55,000	56,100	57,222	58,366	59,534	60,724	61,939	63,178
Computer Systems/Services		$6,885	7,023	7,163	7,306	7,453	7,602	7,754	7,909
Security		$85,000	86,700	88,434	90,203	92,007	93,847	95,724	97,638
Training and Development		$55,300	56,406	57,534	58,685	59,858	61,056	62,277	63,522
Management Fee		$550,000	561,000	572,220	583,664	595,338	607,244	619,389	631,777
Total Operating Expenses		**$9,828,330**	10,024,897	10,225,395	10,429,902	10,638,500	10,851,270	11,068,296	11,289,662
Operating Income (before debt)		**$21,474,295**	21,719,996	21,970,611	22,226,238	22,486,978	22,752,932	23,024,206	23,300,905
Capital Cost	$153,833,667								
Interest Rate	7%								
Bond Maturity	20								
2 payments per year	($7,203,613)								
Annual Payments	($14,407,225)								
Debt Payment (Amor. over 20 years)		**($14,407,225)**	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)
Operating Income (after debt)		**$7,067,070**	$7,312,771	$7,563,386	$7,819,013	$8,079,753	$8,345,707	$8,616,981	$8,893,680

2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
9	10	11	12	13	14	15	16	17	18	19	20
15,501,054	15,811,075	16,127,296	16,449,842	16,778,839	17,114,416	17,456,704	17,805,838	18,161,955	18,525,194	18,895,698	19,273,612
9,187,500	9,187,500	9,187,500	9,187,500	9,187,500	9,187,500	9,187,500	9,187,500	9,187,500	9,187,500	9,187,500	9,187,500
10,039,217	10,240,001	10,444,801	10,653,697	10,866,771	11,084,107	11,305,789	11,531,905	11,762,543	11,997,794	12,237,749	12,482,504
369,073	376,454	383,983	391,663	399,496	407,486	415,636	423,949	432,427	441,076	449,898	458,896
1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750
35,098,593	35,616,780	36,145,331	36,684,452	37,234,356	37,795,259	38,367,379	38,950,941	39,546,175	40,153,314	40,772,595	41,404,262
3,222,063	3,286,505	3,352,235	3,419,279	3,487,665	3,557,418	3,628,567	3,701,138	3,775,161	3,850,664	3,927,677	4,006,231
2,929,148	2,987,731	3,047,486	3,108,436	3,170,604	3,234,017	3,298,697	3,364,671	3,431,964	3,500,604	3,570,616	3,642,028
12,048	12,289	12,535	12,786	13,041	13,302	13,568	13,840	14,116	14,399	14,687	14,980
10,096	10,298	10,504	10,714	10,928	11,147	11,370	11,597	11,829	12,066	12,307	12,553
193,324	197,190	201,134	205,157	209,260	213,445	217,714	222,068	226,510	231,040	235,661	240,374
111,454	113,683	115,957	118,276	120,642	123,054	125,515	128,026	130,586	133,198	135,862	138,579
644,413	657,301	670,447	683,856	697,533	711,484	725,713	740,228	755,032	770,133	785,535	801,246
878,745	896,319	914,246	932,531	951,181	970,205	989,609	1,009,401	1,029,589	1,050,181	1,071,185	1,092,608
1,464,574	1,493,866	1,523,743	1,554,218	1,585,302	1,617,008	1,649,348	1,682,335	1,715,982	1,750,302	1,785,308	1,821,014
76,017	77,538	79,088	80,670	82,284	83,929	85,608	87,320	89,066	90,848	92,665	94,518
117,166	119,509	121,899	124,337	126,824	129,361	131,948	134,587	137,279	140,024	142,825	145,681
878,745	896,319	914,246	932,531	951,181	970,205	989,609	1,009,401	1,029,589	1,050,181	1,071,185	1,092,608
58,583	59,755	60,950	62,169	63,412	64,680	65,974	67,293	68,639	70,012	71,412	72,841
37,774	38,530	39,300	40,086	40,888	41,706	42,540	43,391	44,259	45,144	46,047	46,968
64,441	65,730	67,045	68,386	69,753	71,148	72,571	74,023	75,503	77,013	78,554	80,125
8,067	8,228	8,393	8,561	8,732	8,906	9,085	9,266	9,452	9,641	9,833	10,030
99,591	101,583	103,615	105,687	107,801	109,957	112,156	114,399	116,687	119,021	121,401	123,829
64,793	66,089	67,410	68,759	70,134	71,536	72,967	74,427	75,915	77,433	78,982	80,562
644,413	657,301	670,447	683,856	697,533	711,484	725,713	740,228	755,032	770,133	785,535	801,246
11,515,455	11,745,764	11,980,679	12,220,293	12,464,699	12,713,993	12,968,273	13,227,638	13,492,191	13,762,035	14,037,275	14,318,021
23,583,138	23,871,016	24,164,651	24,464,159	24,769,658	25,081,266	25,399,106	25,723,303	26,053,984	26,391,279	26,735,319	27,086,241
(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)	(14,407,225)
$9,175,913	$9,463,791	$9,757,426	$10,056,934	$10,362,432	$10,674,041	$10,991,881	$11,316,078	$11,646,759	$11,984,054	$12,328,094	$12,679,016

U.S. Government Opinions

Gasification of hazardous waste "has the potential to convert hazardous materials into energy and products in an environmentally sound way. Beneficial properties: preventing pollution due to higher efficiency, breakdown of pollutants into basic components, capture of problem materials like halogens as products, reduction in air emissions over some other technologies."
--Rick Brandes, Chief Waste Minimization Branch, U.S. EPA Office of Solid Waste.

"The U.S. Department of Energy (DOE) has promoted the continued development of gasification technology because of the superior energy efficiency and environmental performance of the process for energy production applications. Specifically, DOE has focused its efforts on the Integrated Gasification Combined Cycle (IGCC) systems which replace the traditional coal combustor with a gasifier and gas turbine. Exhaust heat from the gas turbine is used to produce steam for a conventional steam turbine, thus the gas turbine and steam turbine operate in a combined cycle. The IGCC configuration provides high system efficiencies and ultra-low pollution levels. SO2 and NOx emissions less than one-tenth of that allowed by New Source Performance Standards limits have been demonstrated."
-- US DOE NETL, *A Comparison of Gasification and Incineration of Hazardous Wastes Final Report*, March 30, 2000.

"Gasification is the most environmentally attractive alternative for producing power, fuels, and chemicals from solid feedstocks."
-— US Dept. of Energy, 2002.

"*Gasification is proving to be the most effective and efficient means for dealing with various carbonaceous wastes, such as refinery bottoms and hazardous organic wastes. Gasification can convert these wastes into commercially valuable products, such as electricity, fuels, synthesis gas, and hydrochloric acid. By doing so, gasification serves as a means of source reduction and of recycling, both of which are preferred to either waste treatment or disposal. With some R&D in enhancing the methods of processing and injecting organic sludge, MSW can become a candidate for gasification-based source reduction and recycle in lieu of landfill disposal.*"
--US DOE NETL, *Gasification Technologies - Gasification Markets and Technologies — Present and Future- An Industry Perspective*, July 2002.

Japanese Waste Gasification Plants

The 'Top 10' Waste Gasification Plants in the World

Location	Capacity kTpa	Process	Date	Type
SVZ, Germany	250,000	Envirotherm BGL	2001	Gasification + Melting
Karlsruhe, Germany	225,000	Thermoselect	2001	Gasification + Melting
Ibaraki, Japan	135,000	Nippon Steel	1980	Gasification + Melting
Aomori, Japan	135,000	Ebara	2001	FB gasification + Combustion + Melting
Kawaguchi, Japan	125,000	Ebara	2002	FB gasification + Combustion + Melting
Toyohashi, Japan	120,000	Mitsui	2002	Pyrolysis + Combustion + Melting
Akita, Japan	120,000	Nippon Steel	2002	Gasification + Melting
Oita, Japan	115,000	Nippon Steel	2003	Gasification + Melting
Chiba, Japan	100,000	Thermoselect	2002	Gasification + Melting
Hamm, Germany	100,000	Techtrade	2002	Pyrolysis + Combustion

Juniper

Source: Juniper database

Kawaguchi, Japan, Ebara TIFG, 2002, 125,000 kTpa

Toyohashi, Japan, Mitsui R21, 2002, 120,000 kTpa

Westinghouse Plasma Pilot Facilities

Kinuura, Japan ash vitrification facility, neutralizes ash from an MSW incinerator

The Mihama-Mikata plasma gasification WTE facility processes 20 tpd of MSW & 4 tpd sewage sludge and produces steam

The Utashinai plasma gasification facility processes up to 280 tpd of MSW & auto shredder residue and produces electricity

Projects under Development with Westinghouse Plasma Corp.

Geoplasma's St. Lucie WTE Project

When completed, Geoplasma's WTE plant in Florida will be the largest plasma gasification facility in the world, and will use WPC plasma gasification technology. Located on an existing landfill site, it will process up to 3,000 tons-per-day of MSW and producing 120 MW of electricity. The first phase will process 1,500 tons-per-day and produce 60 MW or enough electricity to power 60,000 homes. The only other output from the facility will be an inert slag, which can be used for aggregate in road construction.

Sun Energy WTE Project, New Orleans

Sun Energy is intending to build a large WTE facility in New Orleans that will use WPC plasma gasification technology to convert 2,500 tpd of garbage to 138 MW of power. The company has acquired a site located in the industrial sector of eastern New Orleans and is near completion of its environmental permit applications.

Coronal WTE Project, International Falls, Minnesota

The Koochiching County, International Falls project will use approximately 150 tpd of municipal solid waste to produce a syngas which will be directed to the kilns at a neighboring paper mill, reducing the mill's usage of natural gas. The WPC plasma gasification process will convert the MSW to syngas and a glass slag material which could be sold as a building aggregate, greatly reducing the amount of garbage Koochiching County and neighboring counties send to landfills. Coronal, the consulting and development firm for the project, is currently coordinating a feasibility study to be completed as the first step in the project permitting process. Upon completion of the feasibility study, project permitting will begin mid-year 2008.

Green Power Systems, WTE project, Tallahassee, Florida

Renewable Fuels of Tallahassee LLC, a subsidiary of Jacksonville-based Green Power Systems LLC will install a system in Tallahassee to convert municipal solid waste into clean energy, including electricity. Financing for the project will be provided through a $182 million funding agreement with the Controlsud International Group, based in Luxembourg, which is composed of more than 70 companies. The deal was announced November 5, 2007 by Gov. Charlie Crist, who led a delegation of more than 200 business and government leaders on a trade mission to Brazil. Renewable Fuels will install a WPC-designed plasma gasification system that uses WPC plasma torches to convert landfill waste into syngas, which can be injected into a combustion turbine for the production of electricity. It is anticipated that the project will generate sufficient power to supply 22,000 homes and produce ethanol. (Source: Tampa Bay Business Journal, November 6, 2007)

Fuel Frontiers, Inc. (FFI), Muhlenberg County CTL Project, Kentucky

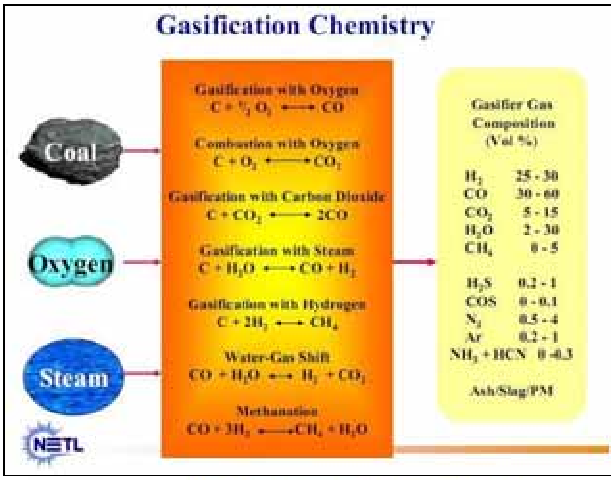
Fuel Frontiers, Inc. (FFI), through its parent corporation Nuclear Solutions, Inc., has contracted with Westinghouse Plasma Corporation (WPC) for the WPC Plasma Gasifier to be designed and incorporated in the FFI Muhlenberg County, Kentucky CTL (Coal-to-Liquid) Diesel Fuel Production Plant. The plant will operate at coal feedstock levels of 400 to 450 tons per day, producing in the range of 72 million gallons per year of ultra-clean diesel fuel. FFI has Letters of Intent from Phoenix Coal Corporation for plant locations for the CTL Ultra-Clean Synthetic Diesel production facility close to Phoenix Coal producing areas. At the same time, FFI has Letters of intent with Phoenix Coal for coal supply. FFI plans to work with Stone & Webster Ltd of Milton Keynes, England to do the design integration of the WPC Plasma Gasifier and the Fischer Tropsch system and to design the gas cleanup system and balance of plant systems.

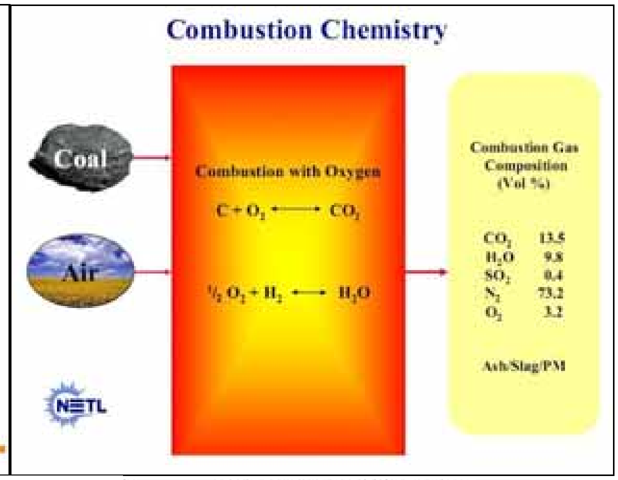
Stone & Webster Ltd, in concert with WPC, will assist FFI in selecting the Fischer Tropsch system supplier. Stone & Webster Ltd and its parent corporation, Shaw Stone & Webster, will assist FFI in selecting the best plant site for the Diesel Fuel Production Plant. FFI anticipates plant startup in year 2010.

SMS Infrastructures Limited, India

In India, SMS Infrastructures Limited has begun construction of two 68 ton-per-day hazardous-waste disposal plants utilizing the WPC technology. The plants, located in Pune and Nagpur, are projected to produce up to five megawatts of electricity and are expected to open in the fall of 2007.

Chemistry

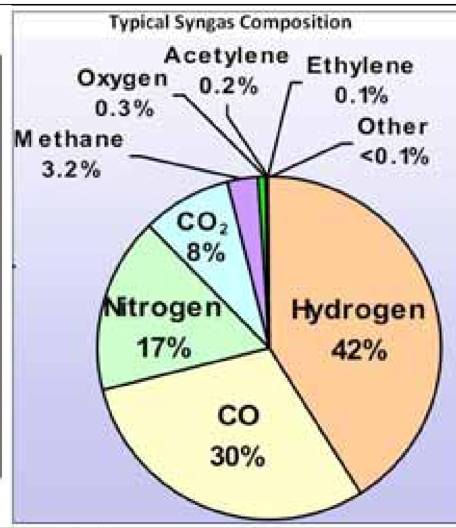


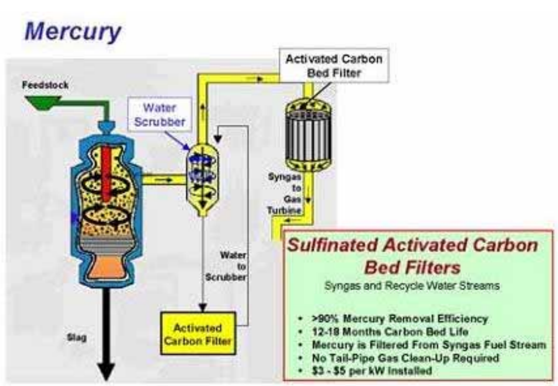


Environmental Contrasts

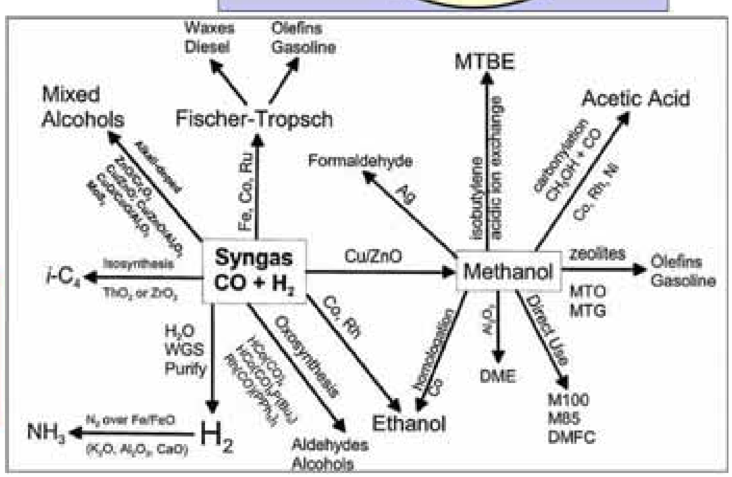
	Combustion	Gasification
sulfur converted to…	SO_2	H_2S
sulfur capture	flue gas scrubbers, boiler limestone injection	absorbed in physical or chemical solvents
sulfur disposal	gypsum sold for wallboard	sold as H_2SO_4 or elemental S
nitrogen converted to…	NOx	traces of NH_3 in syngas (syngas combustion produces low levels of NOx)
NOx control	required (e.g., low-NOx burners, staged combustion, SCR/SNCR)	currently not needed for IGCC (but tighter regs could require SCR)
C is converted to…	CO_2	mostly CO in syngas
CO_2 control	post-combustion removal from diluted stream	pre-combustion removal from concentrated stream
water requirements	much more steam cycle cooling water needed	some water needed for slurry, steam cycle and process needs

NETL





Mercury removal from IGCC



Waste for Fuel Resources

Waste Coal Pile Reclamation

- There is a compelling need to reclaim billions of tons of coal wastes that for decades have polluted our nation's watersheds.
- 120 million tons per year of coal waste are produced nationally.
- The Gilberton Coal-to-Clean Fuels and Power demonstration plant and two larger-scale commercial plants (in Illinois and Kentucky) could collectively reclaim over 30 million tons of waste product per year.

- National commercialization of this technology offers a much larger potential for waste coal reclamation.

NETL

Gilberton Coal-to-Clean Fuels and Power Project

- An Integrated Gasification Power and Clean Fuels Demonstration Plant co-producing 41 MW_e and 5,000 barrels per day of ultra-clean transportation liquids utilizing Shell Gasification technology and SASOL's Fischer-Tropsch liquefaction technology.
- To be constructed near Gilberton, Pennsylvania.
- Will process (reclaim) 1.4 million tons per year of anthracite coal waste (culm) as feed to the gasifier.
- Project Cost: $612,000,000
  DOE Share: $100,000,000 (16%)

NETL

Estimated Generation of Municipal Solid Waste for the 38 Largest U.S. Metropolitan Areas (weights in thousands of tons)

City	Population, millions	Municipal Solid Waste, 1000 tons/year	% of Gasifier Thermal Input
New York, NY	15.000	7005	332
Los Angeles, CA	13.000	6071	288
Chicago, IL	8.008	3740	177
Philadelphia, PA	4.95	2312	110
Dallas–Ft. Worth, TX	4.910	2293	109
Washington, D.C.	4.740	2214	105
Detroit, MI	4.475	2090	99.1
San Francisco–Oakland, CA	4.035	1884	89.4
Houston, TX	4.011	1873	88.8
Atlanta, GA	3.857	1801	85.4
Miami–Ft. Lauderdale, FL	3.711	1733	82.2
Boston, MA	3.297	1540	73
Seattle–Tacoma, WA	3.260	1522	72.2
Phoenix–Mesa, AZ	3.014	1408	66.7
Minneapolis–St. Paul, MN	2.872	1341	63.6
San Diego, CA	2.821	1317	62.5
St. Louis, MO	2.569	1200	56.9
Baltimore, MD	2.491	1163	55.2
Pittsburgh, PA	2.331	1089	51.6
Tampa–St. Petersburg, FL	2.278	1064	50.4
Cleveland, OH	2.221	1037	49.2
Denver, CO	1.979	924	43.8
Portland, OR–Vancouver, WA	1.846	862	40.9
Kansas City, MO	1.756	820	38.9
San Jose, CA	1.647	769	36.5
Cincinnati, OH	1.628	760	36.1
Sacramento, CA	1.585	740	35.1
San Antonio, TX	1.565	731	34.7
Norfolk–Virginia Beach, VA	1.563	730	34.6
Indianapolis, IN	1.537	718	34
Orlando, FL	1.535	717	34
Columbus, OH	1.489	695	33
Milwaukee, WI	1.462	683	32.4
Charlotte–Gastonia, NC	1.417	662	31.4
Las Vegas, NV	1.381	645	30.6
New Orleans, LA	1.305	609	28.9
Salt Lake–Ogden, UT	1.275	595	28.2
Hartford, CT	1.147	536	25.4
Total Metropolitan United States	123.968	57893	

US DOE NETL, US Department of Energy- National Energy Technology Laboratory, February 2003

Estimated Generation of Undigested Sewage Sludge for the 38 Largest U.S. Metropolitan Areas

City	Population, millions	Sludge, thousand dry tons/year	% of Gasifier Thermal Input
New York, NY	15.000	684	56.1
Los Angeles, CA	13.000	593	48.6
Chicago, IL	8.008	365	30.0
Philadelphia, PA	4.95	225	18.5
Dallas–Ft. Worth, TX	4.910	224	18.4
Washington, D.C.	4.740	216	17.7
Detroit, MI	4.475	204	16.7
San Francisco–Oakland, CA	4.035	184	15.1
Houston, TX	4.011	183	15.0
Atlanta, GA	3.857	176	14.4
Miami–Ft. Lauderdale, FL	3.711	169	13.9
Boston, MA	3.297	150	12.3
Seattle–Tacoma, WA	3.260	149	12.2
Phoenix–Mesa, AZ	3.014	138	11.3
Minneapolis–St. Paul, MN	2.872	131	10.7
San Diego, CA	2.821	129	10.6
St. Louis, MO	2.569	117	9.6
Baltimore, MD	2.491	114	9.3
Pittsburgh, PA	2.331	106	8.7
Tampa–St. Petersburg, FL	2.278	104	8.5
Cleveland, OH	2.221	101	8.3
Denver, CO	1.979	90.3	7.4
Portland, OR–Vancouver, WA	1.846	84.2	6.9
Kansas City, MO	1.756	80.1	6.6
San Jose, CA	1.647	75.1	6.2
Cincinnati, OH	1.628	74.3	6.1
Sacramento, CA	1.585	72.3	5.9
San Antonio, TX	1.565	71.4	5.9
Norfolk–Virginia Beach, VA	1.563	71.3	5.8
Indianapolis, IN	1.537	70.1	5.7
Orlando, FL	1.535	70.0	5.7
Columbus, OH	1.489	67.9	5.6
Milwaukee, WI	1.462	66.7	5.5
Charlotte–Gastonia, NC	1.417	64.7	5.3
Las Vegas, NV	1.381	63	5.2
New Orleans, LA	1.305	59.5	4.9
Salt Lake–Ogden, UT	1.275	58.2	4.8
Hartford, CT	1.147	52.3	4.3
Total Metropolitan United States	123.968		

US DOE NETL, US Department of Energy- National Energy Technology Laboratory, February 2003

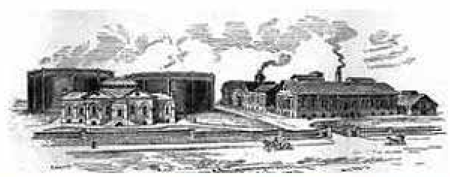
Gasification History

History of Gasification
Town Gas

Town gas, a gaseous product manufactured from coal, supplies lighting and heating for America and Europe.

Town gas is approximately 50% hydrogen, with the rest comprised of mostly methane and carbon dioxide, with 3% to 6% carbon monoxide.

- First practical use of town gas in modern times was for street lighting
- The first public street lighting with gas took place in Pall Mall, London on January 28, 1807
- Baltimore, Maryland began the first commercial gas lighting of residences, streets, and businesses in 1816



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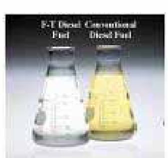
History of Gasification

- Used during World War II to convert coal into transportation fuels (Fischer – Tropsch)
- Used extensively in the last 50+ years to convert coal and heavy oil into hydrogen – for the production of ammonia/urea-based fertilizer
- Chemical industry (1960's)
- Refinery industry (1980's)
- Global power industry (Today)



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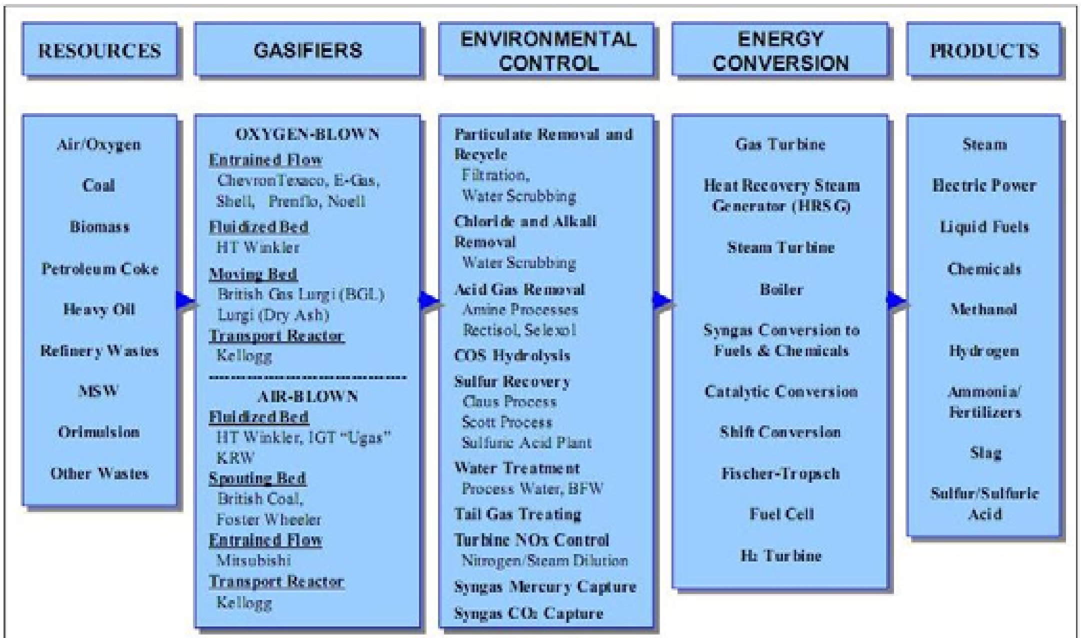
Different Types of Gasifiers



US DOE NETL , US Department of Energy -National Energy Technology Laboratory, MAJOR ENVIRONMENTAL ASPECTS OF GASIFICATION-BASED POWER GENERATION TECHNOLOGIES, Final Report, DECEMBER 2002

Gasifier Types

Flow Regime	Moving (or "Fixed") Bed	Fluidized Bed	Entrained Flow
Combustion Analogy	grate fired combustors	fluidized bed combustors	pulverized coal combustors
Fuel Type	solids only	solids only	solids or liquids
Fuel Size	5 - 50 mm	0.5 - 5 mm	< 500 microns
Residence Time	15 - 30 minutes	5 - 50 seconds	1 - 10 seconds
Oxidant	air- or oxygen-blown	air- or oxygen-blown	almost always oxygen-blown
Gas Outlet Temp.	400 - 500 °C	700 – 900 °C	900 – 1400 °C
Ash Handling	slagging and non-slagging	non-slagging	always slagging
Commercial Examples	Lurgi dry-ash (non-slagging), BGL (slagging)	GTI U-Gas, HT Winkler, KRW	GE Energy, Shell, Prenflo, ConocoPhillips, Noell
Comments	"moving" beds are mechanically stirred, fixed beds are not	bed temperature below ash fusion point to prevent agglomeration	not preferred for high-ash fuels due to energy penalty of ash-melting
	gas and solid flows are always countercurrent in moving bed gasifiers	preferred for high-ash feedstocks and waste fuels	unsuitable for fuels that are hard to atomize or pulverize

Note: The "transport" gasifier flow regime is between fluidized and entrained and can be air- or oxygen-blown.

NETL

Gasification and Clean Coal Technologies Conference, Tampa, FL / 2005

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Russian Plasma Gasifier

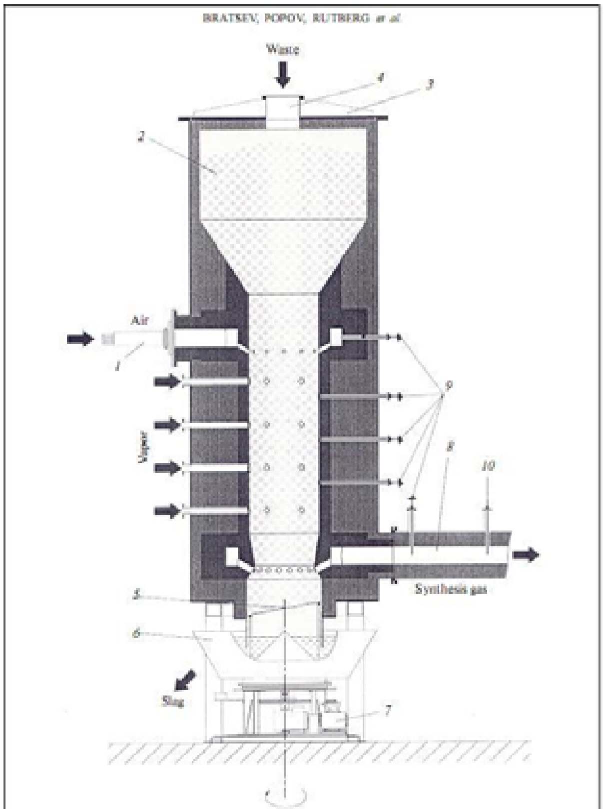
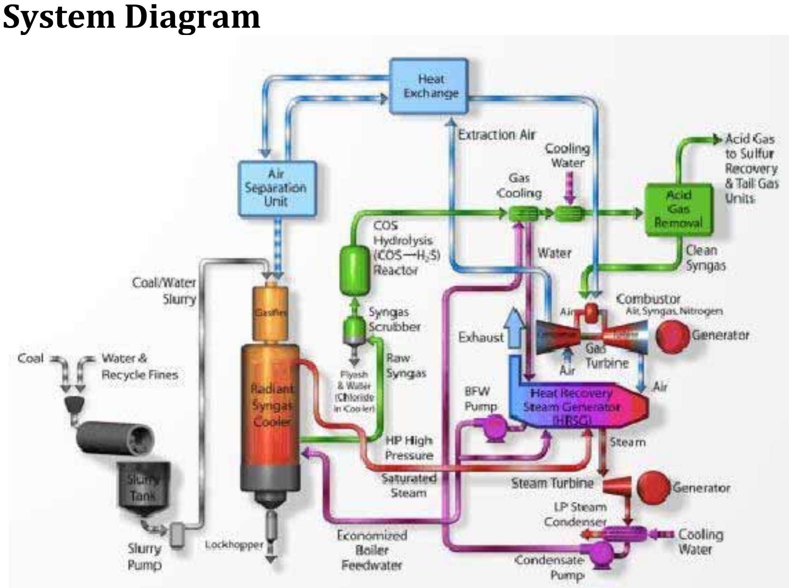


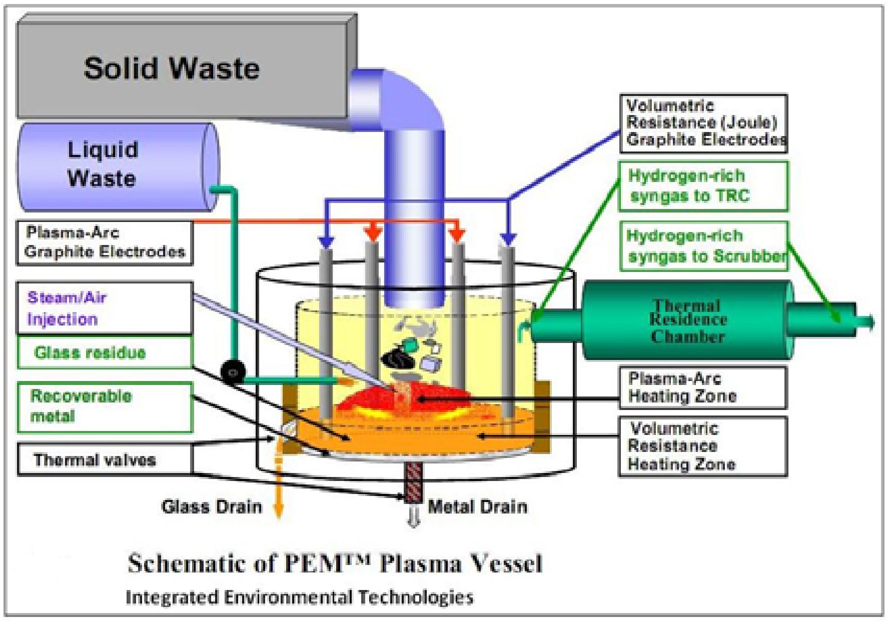
Fig. 3. Gasifier reactor: (1) plasma generator, (2) bin with waste, (3) cover, (4) charging hatch, (5) fire grate, (6) bath with water for quenching the slag, (7) fire grate rotation drive, (8) gas duct, (9) temperature sensors, (10) gas sampling.

Russian Plasma Gasifier

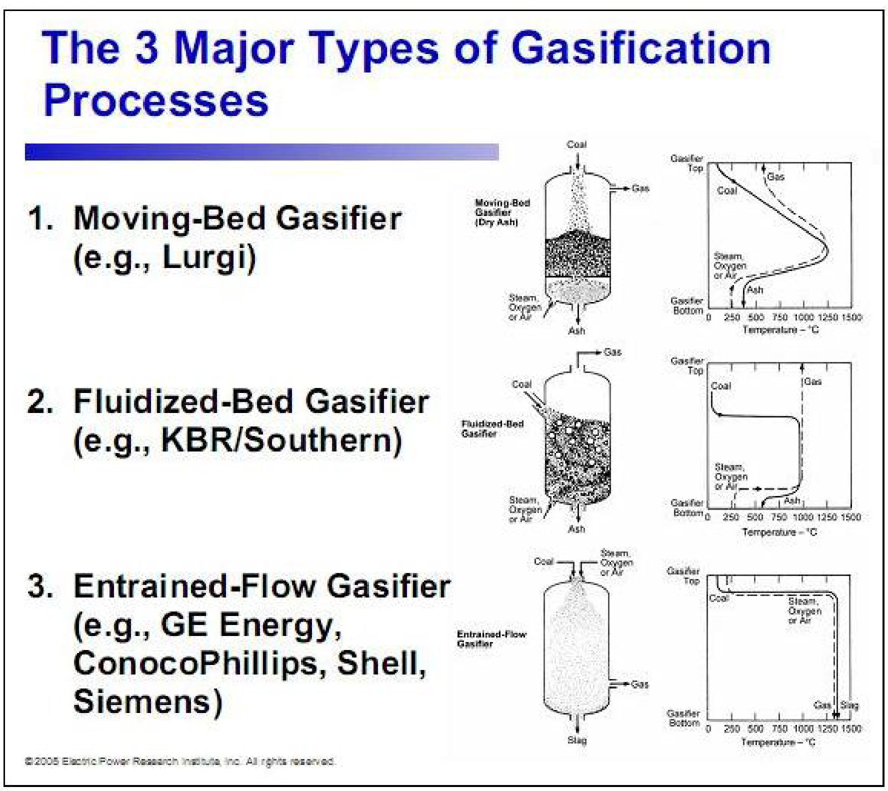
GE Gasification System Diagram



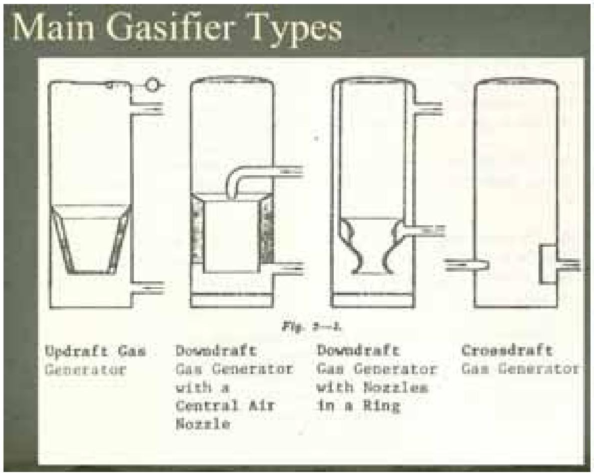
Electric Arc Furnace Gasifier

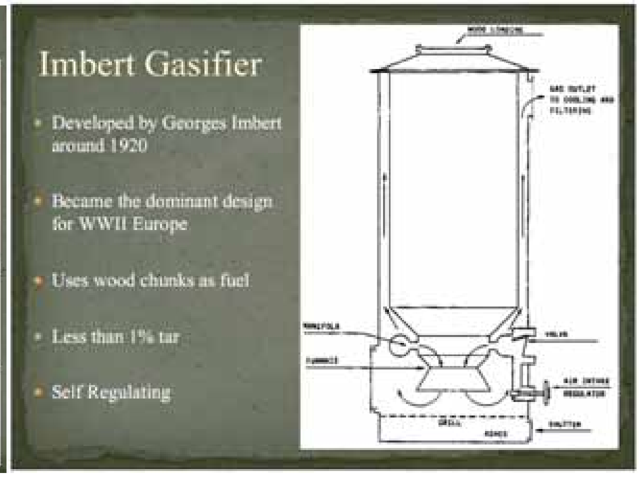


Coal Gasification



Biomass Gasifiers

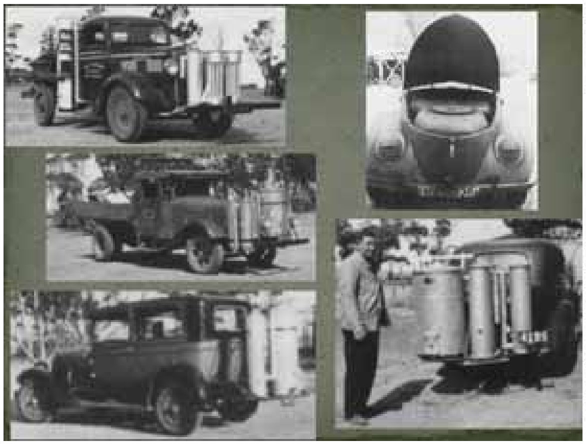


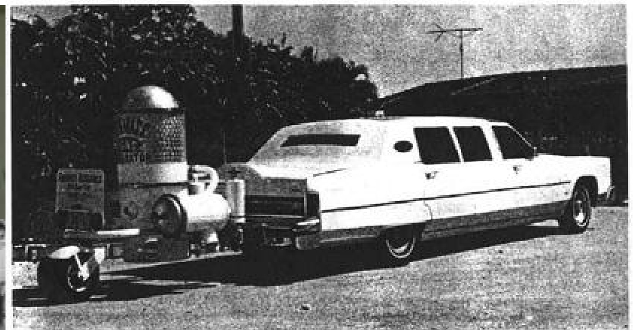


Wood Downdraft Gasifier, South Africa

Biomass of many varieties can be successfully gasified and there is a rich history in the practice. Gasifiers come in a seemingly infinite variety and it seems no two are the same. There is as much art as science in gasification. Gasifiers vary dramatically in scale from small table-top wood stoves and Third World producer gas systems. Wood-gas cars were used extensively in Europe after WWII to get thousands of vehicles on the road when gasoline was in short supply. Large-scale biomass systems have been studied for decades by the US Government and many others.

Woodgas Cars





Miami, Florida, 1981. A charge of 110 lb of wood in the generator of this wood-powered 8,000-lb Lincoln Continental limousine takes it 85 miles or so on flat Florida terrain. In 1981, under a contract from the Department of Energy, its owner toured many southern universities demonstrating producer gas technology, especially to engineering students. (H. La Fontaine, 1995 Keystone Boulevard, Miami, Florida 33181, USA)

WWII era

Modern

Photos from:
Bill Olsen, St. Lawrence University
Engine Operation Using Wood Gas (Presentation)

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