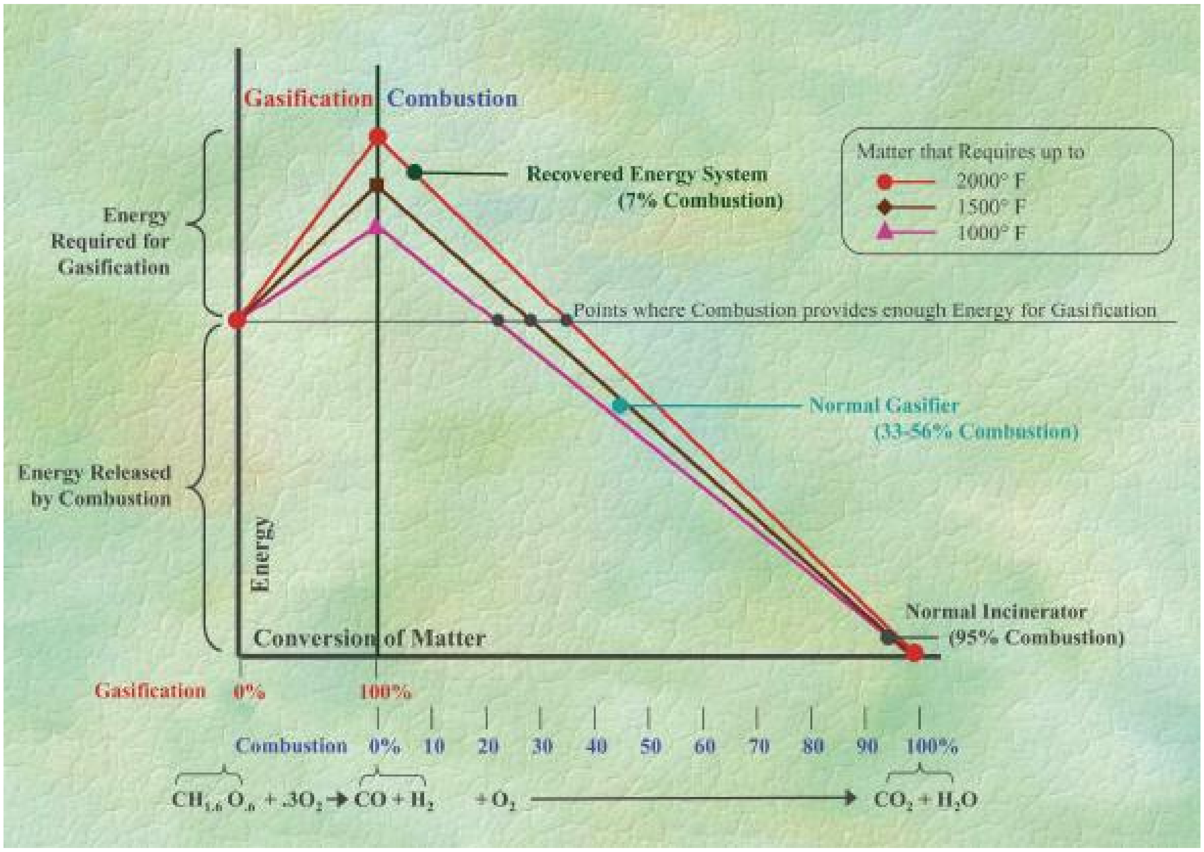
TECHNICAL DISCUSSION OF WHY PLASMA GASIFICATION IS THE ONLY ANSWER



DEFINITION OF COMBUSTION/GASIFICATION

The above chart shows a simplified, representative gasification/combustion curve for typical municipal solid waste (MSW). (Note that every compound has its own curve, the actual curves are not straight lines and the curves will not have the same starting and ending points, however, this chart is intended to be a simplified representation to illustrate a concept.) The X axis shows the progression of MSW to gasification and then combustion. The Y axis shows the initial energy contained in the waste, the energy required to gasify MSW and then the energy released by the combustion of MSW. The chart shows three curves—one representing all matter that will break down at temperatures up to 1000 degrees Fahrenheit, one representing all matter that will break down at temperatures up to 1500 degrees Fahrenheit and one representing all matter that will break down at 2000 degrees Fahrenheit. The formulas for the reactions that are taking place are as follows:

CHEMICAL FORMULAS INVOLVED

Chemical composition of typical MSW:	$CH_{1.6}\,O_{.6}$
Objective of pure gasification	$CH_{1.6}\,O_{.6} + .3O_2 = CO + H_2$
Objective of pure combustion (incineration)	$CH_{1.6}\,O_{.6} + O_2 = CO_2 + H_2O$
Chemical composition of tars	$C_xH_xO_x$ or $C_xH_xN_x$
Chemical composition of hydrocarbon gases	C_xH_x

DESCRIPTION OF THE GASIFICATION/COMBUSTION PROCESSES

Combustion requires three essential elements—combustible matter, an ignition source and oxygen. Combustion cannot occur until the matter is first broken down and then gasified. Think of starting a campfire. In order to start the fire you must use a match or some form of heat source. The match gasifies a portion of the wood or paper, the gas then combusts (ignites) and burns. The heat required to gasify is less than the heat generated by combustion. Therefore, once the fire starts it generates enough of its own heat to gasify and then ignite the rest of the wood and release energy in the form of heat. Without oxygen combustion cannot occur. Gasification, therefore, is a precursor to combustion.

In a perfect world, assuming pure gasification, carbon is combined with limited oxygen in the presence of heat to form carbon monoxide (CO) and hydrogen (H_2). The oxygen required for gasification is less than 30% of the oxygen required for combustion. Once gasification has occurred, three time more oxygen is added to cause combustion. The result is carbon dioxide (CO_2) and water (H_2O).

The objective of a gasification process is to convert the carbon and hydrogen in the waste to a fuel gas composed of CO and H_2 and not to combust any of the waste. The fuel gas still contains most of the chemical and heat energy of the waste. Once cleaned the fuel gas has a variety of uses. The only way to achieve pure gasification is with an external heat source.

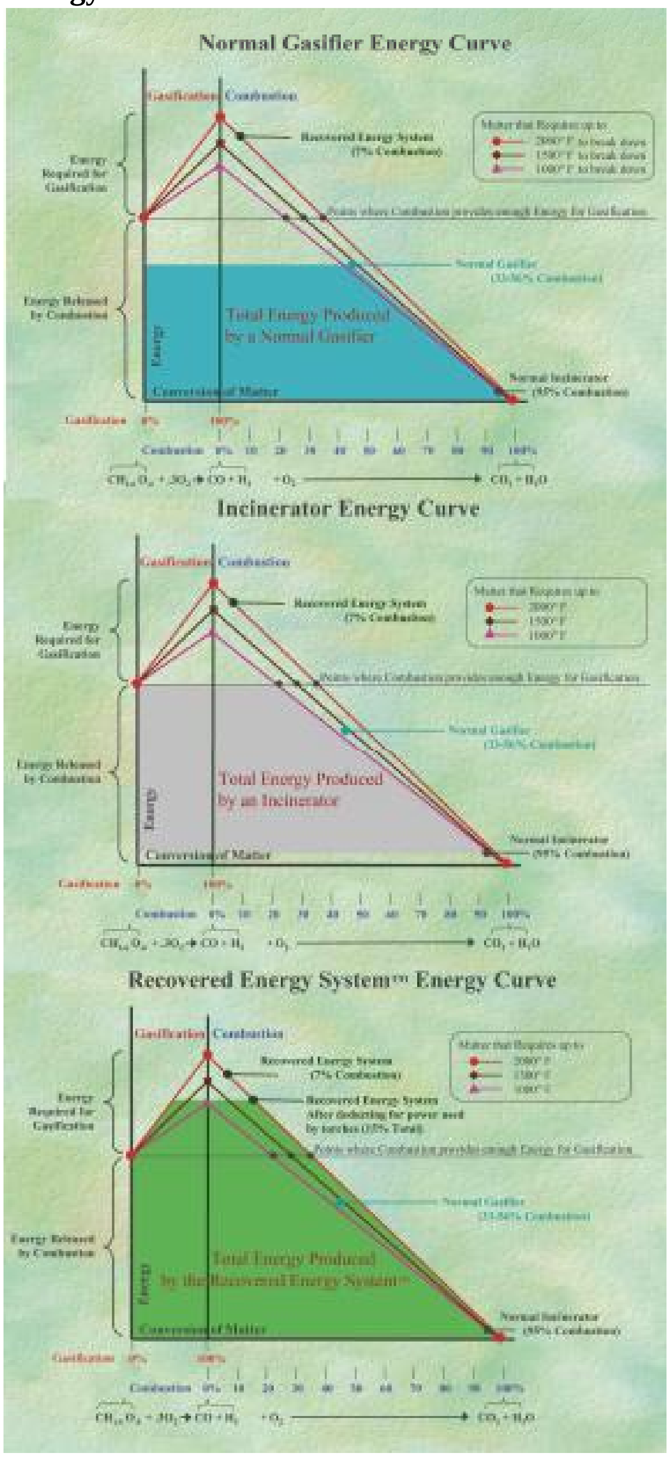
In practicality there is no process that can achieve pure gasification, although the Recovered Energy System™ plasma gasification process comes closer than any other known technology. The Recovered Energy System™ uses a patented plasma torch to provide the energy required for gasification. The equipment design, combined with a proprietary control system allows the process to control the reaction so that there is very little combustion and a high level of control of the reaction. The plasma torch heats air to internal temperatures (inside the torch) as high as 25,000 degrees Fahrenheit and external temperatures (point of contact with the material) as high as 8,000 degrees Fahrenheit. The Recovered Energy System™ produces a clean fuel gas that has a variety of other uses.

Normal gasifiers use partial combustion in order to generate the heat required for gasification. Partial combustion causes the formation of tars and dioxins in the fuel gas and results in the loss of a substantial amount of the energy. The temperatures that can be achieved in the reaction process are much lower than with Recovered Energy System™ and there is much less control of the reaction. Normal gasifiers produce an inferior fuel gas that is high in CO_2 and various contaminants. Most gasifiers have not been successful in cleaning the gas and therefore immediately combust the gas and produce steam that can only fire a steam turbine.

The objective of an incinerator is to achieve complete combustion. The heat from the combustion can only be used to make steam or to go to a steam turbine. In the real world, incinerators fall far short of complete combustion. They also produce tars and dioxins and lose a substantial amount of the chemical and heat energy.

The amount of combustion that takes place in any process is measured by the amount of carbon that is converted to CO_2. Normal gasifiers convert 33-56% of the carbon to CO_2 (based on a study of 15 gasifier processes). Modern incinerators convert 95% of the carbon to CO_2. The Recovered Energy System™ converts less than 7% of the carbon to CO_2 —just enough to ensure full gasification. With the Recovered Energy System™ some of the energy produced is required to operate the plasma torches. The amount of the energy used to generate the electricity for the torches is equivalent to less than 8% of the carbon, leaving a net amount of carbon converted to CO_2 in the Recovered Energy System™ of 15%--less than half the carbon used by normal gasifiers.

Energy Produced:



The total energy produced by plasma gasification, normal gasification and incineration can be measured by the area under the curve. The charts to the left show the energy produced by each of these processes.

The normal gasifier curve shows the chemical energy left assuming perfect combustion, which is not possible. It is possible for a normal gasifier to recover part of the energy generated by combustion by converting the sensible heat from the discharge of the reactor to steam. However, most gasifiers do not recover this energy.

The curve for incinerators shows the energy that is generated by combustion. Incinerators can never recover the energy that is contained in the noncom-busted matter.

The curve for the Recovered Energy System™ factors in the carbon converted into electricity that is needed for the plasma torches. The small amount of energy that comes from combustion is partially recovered by converting the sensible heat from the discharge of reactor to steam. The Recovered Energy System™ recovers almost all of the sensible heat in the fuel gas. Our process produces higher energy because (a) we are on a higher curve, (b) we recover most of the sensible heat (c) we lose very little to combustion and (d) we can use a more efficient gas turbine system.

The bottom line is as follows:

Net electricity produced by the Recovered Energy System >1 mWh/ton of waste

Net electricity produced by gasifiers and incinerators .4 to .6 mWh/ton of waste

FORMATION OF TARS, CHAR AND HYDROCARBON GASES

Before either gasification or combustion (incineration) can take place the organic matter has to be broken down. The breakdown of the matter produces tars (defined as any hydrocarbons that will condense—including furans, phenols, etc.), char (residual unburned carbon), hydrocarbon gases (such as methane, ethane, etc.) and dioxins.

Tars:

Tars are various molecules of carbon, hydrogen and oxygen or nitrogen. Tars are formed at various temperatures starting at 450 degrees Fahrenheit up to 1800 degrees Fahrenheit. Tars can be classified as Primary and Secondary tars. Primary tars begin forming at approximately 450 degrees Fahrenheit and have been broken down and destroyed by time the temperature reaches 1500 degrees Fahrenheit. Secondary tars begin forming at approximately 900 degrees Fahrenheit and have been broken down and destroyed until the temperature exceed 1800 degrees Fahrenheit. The key temperature is not the temperature at the hot spot of the flame but the average temperature in the reactor. The average temperatures in gasifiers and incinerators are not high enough to break down all the tars.

In a normal gasifier or an incinerator some of the tars stay in the gas stream and contaminate the fuel gas. These tars attach to the equipment, fouling the equipment and are difficult to remove from the gas stream. Some of the tars attach to the ash and char, thereby contaminating the residual ash and rendering it toxic.

Because of the high temperatures, the Recovered Energy System™ hinders the formation of tars and fully breaks down any tars that are formed. There are no tars remaining in either the fuel gas or the vitrified glass using the Recovered Energy System™.

A list of the typical Primary and Secondary tars that will be formed by various wastes follows:

Primary Tars:

Acids: Formic (CH_2O_2), Acetic ($C_2H_4O_2$), Propanoic ($C_3H_6O_2$), Glycolic ($C_2H_4O_3$), Butanoic ($C_4H_6O_2$), Pentanoic ($C_5H_{10}O_2$), Hexanoic ($C_6H_{12}O_2$), Benzoic ($C_7H_6O_2$) and Heptanoic ($C_7H_{14}O_2$)

Sugars: D-Xylose ($C_5H_{10}O_5$), Levoglucosan ($C_5H_{10}O_2$), alpha-D-Glucose ($C_6H_{11}O_5$), Fructose ($C_6H_{12}O_5$) and Cellobiosan ($C_{12}H_{20}O_6$).

Alcohols: Methanol (CH_4O) and Ethanol (C_2H_6O).

Ketones: 2-Butenone (C_4H_6O), Cyclopentanone (C_5H_8O), Cyclohexanone ($C_6H_{10}O$), Dimethylcoclopentanone ($C_7H_{12}O$) and Trimethylcyclopentenone ($C_8H_{14}O$).

Aldehydes: Formaldehyde (CH_2O), Acetaldehyde (C_2H_4O) and Acrolein ($C_3H_4O_2$).

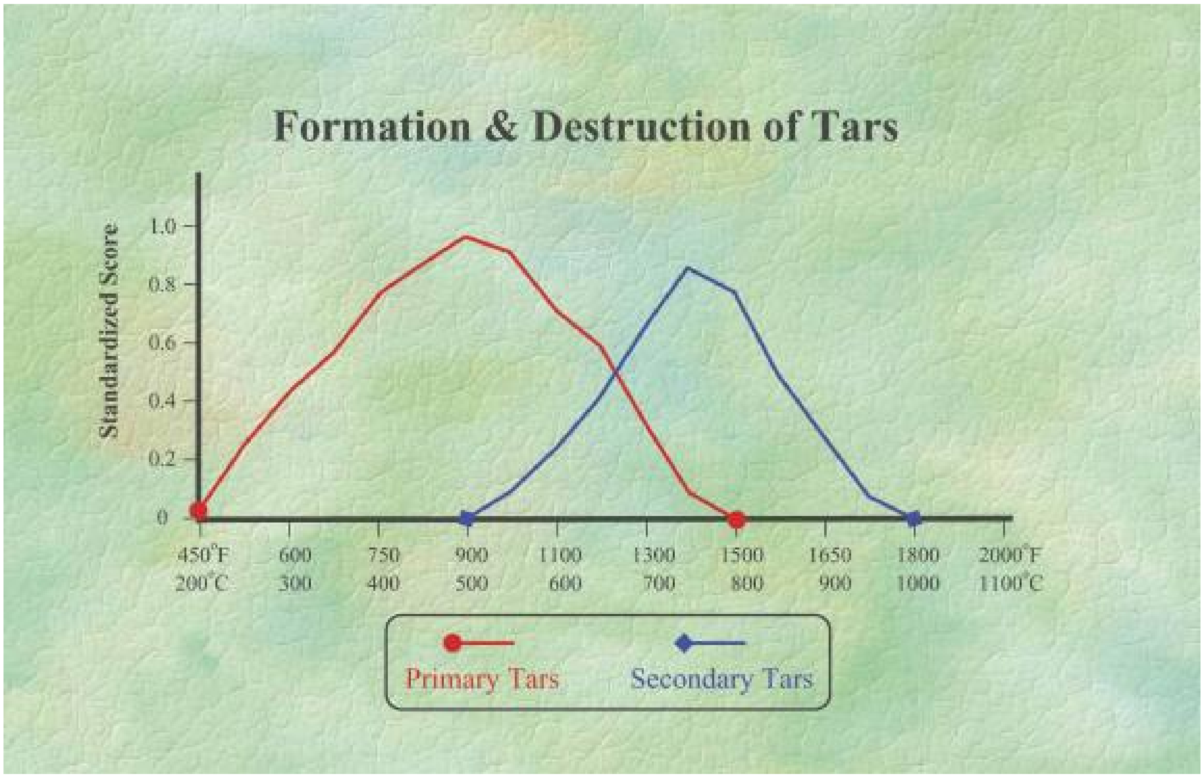
Phenols: Phenol (C_6H_6O), Cresol (C_7H_8O), Xylenol ($C_8H_{10}O$) and 2-Ethylphenol ($C_8H_{10}O$).

Furans: Furfuran (C_4H_4O), 2-Methylfuran (C_5H_6O), Furanone ($C_4H_4O_2$), Furfural ($C_5H_4O_2$), Furfural alcohol ($C_5H_6O_2$) and 5-Methylfurfural ($C_6H_6O_2$)

Mixed Oxygenates: Glyoxal ($C_2H_2O_2$), Hydroxyethanal ($C_2H_4O_2$), Acetol ($C_3H_6O_2$), Methanolacetaldehyde ($C_3H_6O_2$), 1,2-Dihydroxybenzene ($C_6H_6O_2$), Resorcinol ($C_6H_6O_2$) and Hydroquinone ($C_6H_6O_2$).

Secondary Tars:

1H-Pyrrole (C_4H_5N), Pyridine (C_5H_5N), Methylpyridine (C_6H_7N), Phenol (C_6H_6O), Benzaldehyde (C_7H_6O), Dimethylpyridine (C_7H_9N), Cresol (C_7H_8O), Dihydroxy-benzene ($C_6H_6O_2$), Benzofuran ($C_8H_6O_{2.3}$), Vinylphenol (C_8H_8O), Trimethylpyridine ($C_8H_{11}N$), Dimethylphenol ($C_8H_{10}O$), Dihydorxytoluene ($C_7H_8O_2$), Quinoline (C_9H_7N), Methylbenzofuran (C_9H_8O), Propenylphenol ($C_9H_{10}O$), Dimethylethyl-pyridine ($C_9H_{13}N$), Propoxybenzene ($C_9H_{12}O$), Methylethylphenol ($C_9H_{12}O$), Quinaldine ($C_{10}H_7N$), Dimethylbenzofuran ($C_{12}H_{10}O$), Creosole ($C_8H_{10}O_2$), Dimethyl-ethylphenol ($C_{10}H_{14}O$), Dibenzofuran ($C_{12}H_8O$), Naphthofuran ($C_{12}H_8O$), Benzo-quinoline ($C_{13}H_9N$), Phenylbenzaldehyde ($C_{13}H_{10}O$),



Char:

Char is carbon that has not been converted to CO. In a normal gasifier or incinerator process the tars condense out and attach to the char. The contaminated char becomes part of the bottom ash and renders the entire ash toxic. In order to completely convert the char to CO the temperature must exceed 2000 degrees Fahrenheit. Without an external heat source neither gasifiers nor combustors (incinerators) can reach the temperatures required to destroy the char. Normal gasifiers have a high level of char. Modern incinerators have significantly reduced the amount of char left but still have some. Whatever char is remaining represents wasted carbon. The Recovered Energy System™ has no char remaining.

Hydrocarbon Gases:

Hydrocarbon gases are various molecules of carbon and hydrogen. These hydrocarbon gases can include Methane (CH_4), Acetylene (C_2H_2), Benzene (C_6H_6), Toluene (C_7H_8), Styrene (C_8H_8), Fluorene ($C_{13}H_{10}$) and other carbon-hydrogen molecules. These gases are high in energy and will be converted cleanly into electricity by the gas turbine. The hydrocarbon gases can form at higher temperatures beyond the normal operating range of most gasifiers or incinerators. The formation of these gases is also a function of how the process reaction is controlled. Most normal gasifiers and incinerators have very little control of their reaction process because they are locked into a specific curve. However, with our plasma torches the reaction can be controlled to maximize the production of the higher value hydrocarbon gases. The Recovered Energy System™ produces an average C_2H_4 hydrocarbon gas, adding as much as 10% to the output of electricity.

Dioxins:

The commonly accepted, though chemically imprecise, name for dioxin is 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). TCDD is one of more than 70 members of the family of chlorinated dioxins. Dioxins are formed when plastics, chlorinated solvents and other chlorinated chemicals are combusted. Dioxins are destroyed at temperatures in excess of 1800 degrees Fahrenheit. Normal gasifiers and incinerators form dioxins in their operating temperature range and do not have high enough temperatures to destroy the dioxins. The Recovered Energy System™ breaks the matter down at very high temperatures, blocks the formation of dioxins and has enough temperature to completely destroy the few dioxins that may already be present or that happen to form in the process.

CONCLUSION

Plasma gasification is the ONLY proven process that:

1. Breaks down all the tars
2. Leaves no char
3. Produces no toxic ash
4. Generates enough external heat source to gasify any type of waste
5. Minimizes the loss of chemical energy
6. Utilizes all the sources of energy
7. Leaves no dioxins

The Recovered Energy System™ is the ONLY plasma gasification system that has combined proven technologies to handle large-scale waste of any type economically. If you want a COMPLETE solution to your waste problem the Recovered Energy System™ is not just the best answer—it is the ONLY answer.