Why Plasma?

Evaluating New Energy-from-waste Technologies

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ABSTRACT

The waste that society generates can be converted into various energy products using new conversion technology. This article highlights the benefits of one promising conversion technology known as plasma gasification, which can be used to generate clean fuels, chemicals and clean electric power. A comparison of plasma gasification to conventional gasification technology is also discussed. Implementation of plasma gasification has the potential to dramatically reduce emissions, including greenhouse gas (GHG) emissions, relative to conventional waste disposal and treatment methods. The plasma gasification process is a significant move to a more sustainable approach to waste treatment and renewable energy production.

INTRODUCTION

The waste generated by our society is a resource from which we can extract various forms of energy. As the cost of energy increases, new technologies emerge as potential solutions to both lower the cost of energy and generate energy products from alternative and renewable resources. One such energy resource is the vast quantity of waste created by modern society in all facets of commercial and residential activities. Recycling continues to minimize the disposal of valuable resources, such as plastics, metals and glass. However, there is also great potential to recover significant energy and other resources from the fraction of waste materials that have no recycle value today. One broad technology category for recovering these precious resources being developed and deployed around the globe is waste gasification.

Gasification can be deployed in various configurations, some of which enable greater energy recovery from waste material and produce a broader array of energy products. One gasification technology that has gained significant attention over the past few decades is plasma gasification. S4 Energy Solutions LLC (S4), a new joint venture between Waste Management Inc. (Waste Management) and InEnTec LLC (InEnTec), is developing the next generation of energy from waste technologies based on plasma gasification. The new gasification process known as the Plasma Enhanced Melter™, or PEM™, is now being commercialized by the new S4 joint venture.

PLASMA TECHNOLOGY

To generate a plasma, one most impose an electric potential of sufficient magnitude to cause the breakdown (ionization) of the gaseous medium between the electrodes, and to maintain the gaseous medium in that ionized state. This ionized gas is referred to as the "plasma state," which is often called the fourth state of matter (and anecdotally, is the basis for the S4 name). As electric current flows through the ionized gas, the electric energy is converted into thermal energy as a result of the electrical resistance in the plasma zone between the electrodes. To maintain plasma in a stable state, sufficient electric current must flow between the electrodes to generate enough thermal energy to offset any losses caused primarily by the intense thermal radiation to the cooler surroundings.

Plasma technology can be deployed in many configurations and for many purposes, including surface etching, deposition of high melting point materials, melting of specialty metals, such as titanium and cutting of many types of materials, to name a few. In this article, we will focus on the application of plasma technology to generate the thermal energy required to drive chemical reactions for the conversion of waste into a clean synthesis gas (syngas). Further, we will limit the discussion to what is referred to as thermal plasmas. These are plasmas that generate significant thermal energy at near atmospheric pressure. There are various methods to form thermal plasmas. The most common are the use of a metal plasma torch or the use of graphite arc electrode technology. The former method has generally been deployed in very specialized applications, such as radioactive and certain hazardous waste processing applications.

Plasma torch systems typically use an inert gas as the plasma gas with a water-cooled metal torch configuration, as shown in Figure 1 and Figure 2. Plasma torches are either operated in the non-transferred or transferred mode. The non-transferred mode of operation is the least efficient relative to conversion of input electric power into thermal energy. Typically, 50 percent of the input power is converted into usable thermal energy in the plasma, with the remaining input power lost to the cooling water that is used to maintain the temperature of the metal torch within the working limits of the metals used in the construction of the torch. An alternative configuration for the conventional plasma torch is shown in Figure 3, which is termed a transferred torch. In this mode of operation, the torch electrodes are one polarity and the work piece, or the material being processed, is the counter electrode. This mode of operation is more energy efficient than the non-transferred torch, however the over efficiency for conversion of electric input energy into thermal energy of the plasma is 50 to 60 percent.

Alternatively, a simpler and more robust method of forming a plasma arc is the graphite electrode system depicted in Figure 3. Both of these methods have advantages and disadvantages, however the graphite electrode techniques tends to be much more forgiving and robust in the application of waste gasification.

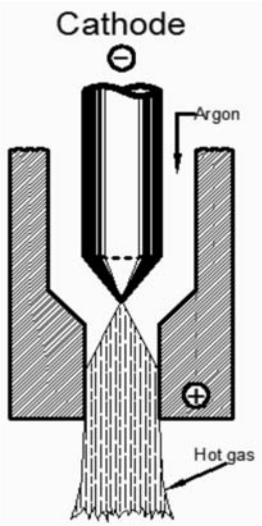

Figure 1. Conventional plasma torch in non-transferred mode.

CONVENTIONAL GASIFICATION

Gasification of waste can be accomplished with different degrees of success using various forms of gasification technology. Apart from plasma gasification technology, more traditional gasification technology, such as fluidized bed systems, shaft furnace systems, updraft and downdraft gasifiers with a number of variations in design, have been used with varying degrees of success. Pyrolysis, which is another form of gasification, has also been commissioned in waste gasification facilities, again with limited success.

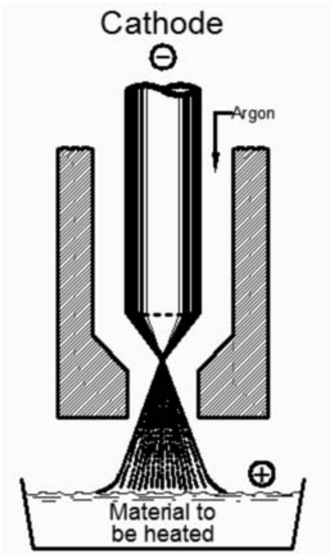

Figure 2. Conventional plasma torch in transferred mode.

The primary issue with most traditional gasification technologies is the quality of syngas that is generated via the gasification process. All gasification systems with counter current flow of the gasification agent (i.e., air, oxygen, steam, carbon dioxide, etc.) relative to the material to be gasified suffer from an inherent problem associated with tars, oils and products of incomplete gasification. This issue of gas contaminants is further compounded when these types of gasifiers are operated at lower temperatures, which is commonly the case. Figure 4 shows the typical configuration of both the primary gasifier chamber and the relative flows of materials in and out of the gasification chamber. Waste or material to be gasified enters at the top of the gasifier and the gasification agent (normally oxygen) enters at or near the bottom. These two primary inputs to the updraft gasifier flow in a counter current flow. The high temperature syngas that is produced in Zone I and II, as depicted in Figure 4, exits the gasifier near the top and comes in contact with the incoming waste material in Zone III, resulting in the partial gasification of the waste into oils, tars and other contaminants, all of which are carried out of the gasifier in the syngas. These contaminants make the subsequent downstream use of the syngas much more costly and technologically difficult. Moreover, when these contaminants are removed from the syngas, it often generates a

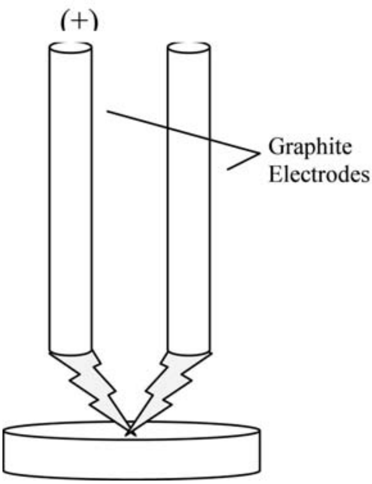

Figure 3. Graphite electrode DC arc plasma.

secondary hazardous waste stream, resulting in higher operating costs.

A second gasifier configuration is what is referred to as a downdraft gasifier. This type of gasifier, as depicted in Figure 5, produces a much cleaner syngas. The produced syngas and the waste material being gasified both move downward in the gasifier. In the upper portion of the gasification chamber, partial oxidation and pyrolysis of the feed material occur as it comes in contact with the gasification agent(s) in Zone I. Further gasification of the solid(s) takes place in Zone II as the high temperature syngas mixture formed in Zone I passes down through the bed of partially gasified material. Both the gas and any solid residual are removed from the lower portion of the downdraft gasifier where the solid residual is largely a carbon char. The syngas exiting in this high temperature zone does not come in contact with raw waste or feed material, so the formation of tars and other contaminants is significantly reduced in the downdraft mode of operation. Even though downdraft technology has been successfully deployed in entrained flow gasifiers for coal gasification, fixed or moving bed downdraft gasifiers have not been successful for various technical reasons, especially when feed material is heterogeneous waste material. The major issue of this type of gasifier is the lack of adequate mixing and therefore the gasification reactions are less controllable. The desired syngas product is therefore not assured when using the downdraft gasifier as the only mode of gasification.

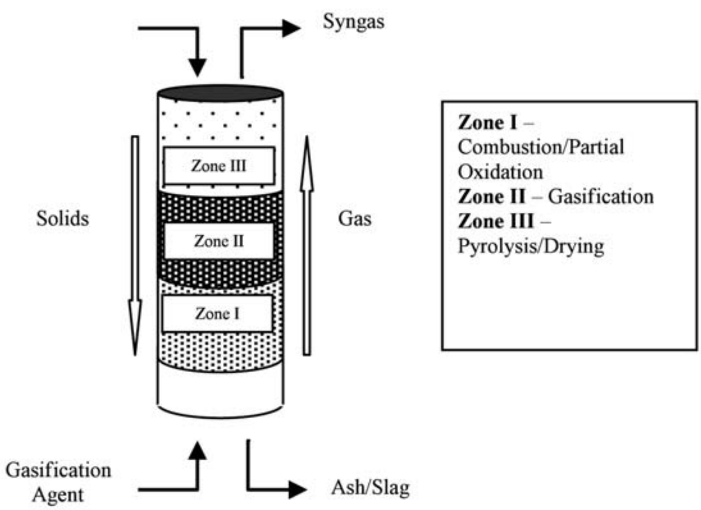

Figure 4. Updraft (counter current) flow gasifier.

PLASMA ENHANCED MELTER TECHNOLOGY

The S4 gasification process has at its core the PEM™ gasification technology. The PEM™ is a plasma gasification system based in part on technology developed for the US Department of Energy (DOE). More than $300 million has been spent on research and development of the predecessor technologies that form the basis for this unique and robust gasification system.

The PEM™ technology had its genesis at the Pacific Northwest National Laboratory (PNNL) operated by Battelle Memorial Institute and at the Plasma Fusion Center at the Massachusetts Institute of Technology (MIT). Researchers at PNNL and MIT collaborated to develop a new technology that could serve as an alternative to incineration for the thermal treatment of many of the waste materials generated in DOE facilities across the country. That effort culminated in the development of the PEM™ technology, which was later commercialized by the technology-based startup InEnTec (formerly known as Integrated Environmental Technologies LLC) in 1995. Since 1995, InEnTec has deployed seven small commercial PEM™ facilities for the specialized treatment of medical, hazardous and industrial waste.

The PEM™ process is a combination of three discrete technologies that work synergistically in an efficient and effective process depicted

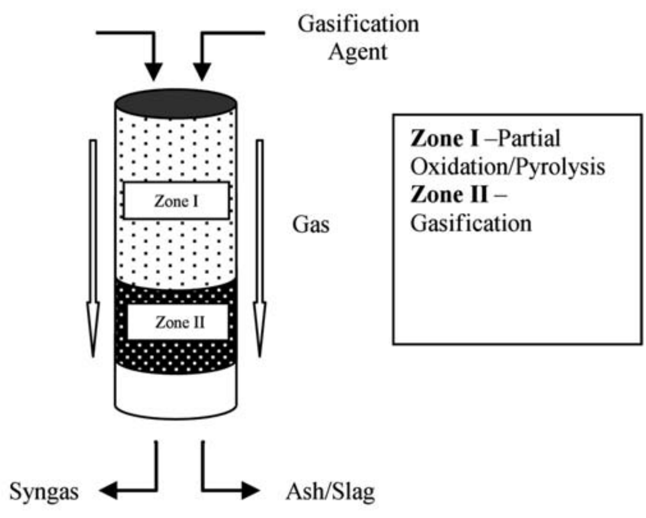

Figure 5. Downdraft (co-current) flow gasifier.

in Figure 6. The first step of the process involves a pre-gasification unit, where feedstock is gasified using a combination of autothermal reformation and steam reforming. The pre-gasifier is a specially configured downdraft gasification unit, as described in the previous section of this article. Carbonaceous materials introduced into the process are converted into synthesis gas and a char-like material rich in carbon. The char moves through the first stage gasification chamber and gravimetrically is transported into the plasma enhanced melter (PEM™) portion of the process. In this second plasma stage, the char is exposed to ultra-high temperatures of 3,000 to 10,000°C. Plasma's are ionized gases that are maintained in the ionized state by imposing an electric potential across a cloud of gas phase ions. The electric arc is generated in the PEM™ through the use of DC graphite electrodes wherein a large electric potential is placed between the electrodes. Finally, any inorganic materials that would otherwise form an ash in a combustion process are converted into a vitreous glass-like material in the third "glass bath" stage of the PEM™ system. This third stage uses a process commonly referred to as joule or resistive heating. Because the glass-like material is molten at the operating temperatures of the PEM™, it can conduct electric current. Therefore, when AC current is passed through the molten glass, thermal energy is produced as a result of the electrical resistance of the glass bath. If any metals are present in the incoming feedstock that are not dissolved into the glass bath as an oxide, they will form a distinct metal

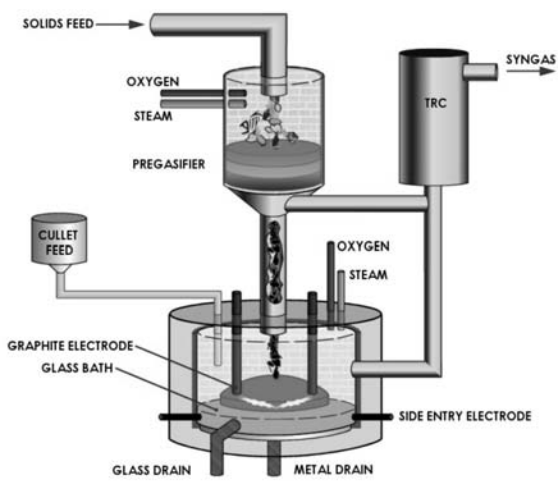

Figure 6. Plasma enhanced melter™ (PEM™) gasifier.

phase at the bottom of the chamber that can be removed and recovered along with the molten glass as a potential recyclable material.

WHY PLASMA GASIFICATION?

Plasma gasification offers distinct advantages over traditional gasification techniques and the PEM™ gasification process offers additional advantages over other plasma technologies. As discussed above, traditional gasification technology comes in a number of configurations, most of which use the updraft or counter current flow of gasification agent to that of the material being gasified. These systems are relatively efficient at converting the solid material into a syngas; however, the produced gas will vary in quality and composition because of the physical configuration and flow of the reactants in the gasifier. The plasma gasification processes operate typically at much higher temperatures than conventional gasification units and therefore produce a much cleaner syngas. The PEM™ gasification system as described above has the added advantage of using the most efficient operating regimes of each of the three technologies incorporating plasma technology to produce an ultra clean syngas. This gas is much more amenable to direct use in downstream fuel conversion units with minimal syngas cleaning.

ENERGY FROM WASTE GASIFICATION

All gasification processes produce synthesis gas, or syngas, of various composition and quality. Because of the high temperatures at which the system operates, the PEM™ process produces an ultra-pure syngas amenable to a multitude of additional downstream energy options, including production of syngas, electric power or hydrogen and a number of liquid fuels and chemicals.

Producing usable fuels from syngas is a substantial benefit. Most simply, syngas can be used directly as a fuel to replace natural gas or other fuels. From a practical standpoint, syngas is a potential fuel substitute in boilers or other large industrial heating applications, where the syngas is being delivered to a small number of end users from a single S4 gasification facility. The syngas can also be used as a fuel in power generation systems, and has been proven as a viable fuel for internal combustion engines, such as gas turbine technology and reciprocating engines. Additionally, certain fuel cell designs, such as solid oxide fuel cells (SOFCs), allow syngas to be used directly as a fuel. When used as a fuel in internal combustion engines, the high hydrogen content of the fuel enables lean operation at high compression ratios, which can dramatically lower NOx emissions in comparison to traditionally fueled internal combustion (IC) engines operating closer to stoichiometric air/fuel mixtures.

More interesting from an alternative energy perspective is the potential to use the syngas formed in gasification systems, like the S4 process, to produce higher-value fuels and chemicals. There is a large demand for industrial hydrogen and potentially a growing demand for hydrogen in fuel cells. Refiners and chemical manufacturers alike use significant quantities of hydrogen in the production of low sulfur transportation fuels and in the synthesis of chemicals, respectively. Some believe hydrogen will eventually serve a critical role as a fuel as we move closer to the so-called "hydrogen economy." In California, a hydrogen highway system is already under development using hydrogen as a transportation fuel. If hydrogen is to ever be a viable alternative fuel, a distributed network of hydrogen generation facilities will need to be deployed, because hydrogen does not lend itself to cost-effective transportation and distribution. The S4 gasification process, because of its inherent ability to be cost-effectively scaled to meet the needs of smaller waste conversion facilities, is ideally suited for such a distributed hydrogen generation network. Because the PEM™ gasification technology produces a very pure syngas, it is optimal for the subsequent production of hydrogen using commercially available shift reactor and pressure swing adsorption (PSA) technology.

Another area of intense interest and development is in the conversion of syngas into liquid transportation fuels and additives. Fischer Tropsch catalysts have been used in large centralized facilities to produce synthetic crude oil and other variations of traditional transportation fuels, such as diesel fuel from syngas. Others have deployed large-scale processes that use a methanol pathway to convert syngas into gasoline. Developers around the world are investigating methods to convert syngas into ethanol as a fuel additive to meet the US government-mandated levels. There are also a number of other synthesis processes where syngas can be converted into useful fuels and chemicals; however, most of these processes are only economically viable at larger scale. Because of the low cost of syngas production in a PEM™ system, the S4 gasification process can cost-effectively use many of the syngas to liquid conversion processes at a smaller scale.

Determining the quantity of fuel or chemical product that can be produced from the conversion of waste or biomass material via the syngas intermediate depends on many factors. The primary factor involves the inherent energy content of the waste feed material. In general, waste materials that have higher heat content produce more synthesis gas. The relative ratios of carbon, hydrogen and oxygen in the feed material will also affect the resultant gas composition and hence, the viability of producing certain end products.

If the waste feed material is municipal solid waste (MSW) that has been pre-processed to remove the majority of the metals, glass and other inorganic constituents such as soil, the waste can be converted into products, as shown in Figure 7.

Although not all-inclusive, Figure 7 represents the possible products that can be sold into existing markets. As shown, for every ton of MSW processed, 650 kWh of electric power can be generated using IC reciprocating engines. This value could exceed 1000 kWh if the plant incorporated gas turbine technology using combined cycle power plants. The amount of syngas, hydrogen and alcohol that could potentially be produced is 10 million Btus, 20,000 standard cubic feet and 100 U.S. gallons, respectively. In general, one of these products would be produced at a given facility because of the additional capital required for equipment and systems for each option. But in some cases, both a liquid product and electric power can be made practical by using byproduct

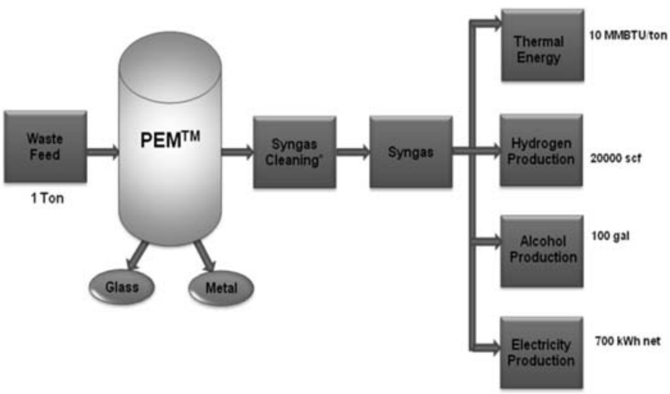

Figure 7. Possible energy products from 1-ton of waste.

streams from the gas to liquids process, yielding significant residual energy value.

The S4 gasification process may enable many of the above mentioned synthesis processes and technologies to be cost-effectively scaled down to be deployable in a distributed network. S4 has chosen to initially deploy its gasification technology in smaller, distributed facilities as opposed to centralized facilities. The distributed model provides for both efficiency in the energy product delivery and minimization of transportation for the waste or biomass materials being processed. Lessening transportation requirements for both feedstock and product can result in significant reductions in greenhouse gas (GHG) emissions. Additionally, the processing of waste containing biomass and other biomass materials inherently reduces emissions of GHG as opposed to the use of fossil fuels for the generation of equivalent energy products.

The environmental attractiveness of a technology is measured both from the direct emissions of what are considered traditional air pollutants, including carbon monoxide, nitrogen oxides and sulfur oxides, and hazardous air pollutants, including dioxins and furans. Of equal concern today is the emission of GHG pollutants, such as carbon dioxide, methane and nitrogen oxides. Technologies such as the PEM™ gasification system can dramatically reduce both traditional and GHG pollutants.

When waste feedstock is processed in a gasification system, these materials are converted into syngas with no direct emissions to the environment. Rather, the syngas is thoroughly cleaned of any contaminants that may be present prior to use in downstream processing. Because the contaminants have been removed, the emissions from the downstream processing units will be significantly lower than if the material was directly combusted. In addition, because of the highly reducing environment in the PEM™ gasification process, the formation of pollutants, such as nitrogen oxides, dioxins and furans, is not promoted.

Waste containing mercury has historically been problematic for waste-to-energy technologies because of the high vapor pressure of mercury at typical operating temperatures. In the PEM™ gasification system, the mercury can be cost-effectively removed from the syngas prior to use as a result of the much lower gas flow rates of a gasification system as opposed to a combustion technology. Mercury is typically removed using specialized packed bed filters loaded with a sulfur-impregnated carbon. This method of mercury removal has been demonstrated to essentially remove all the mercury to levels below the detection limits of

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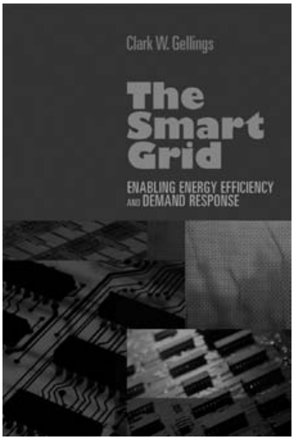

Clark Gellings

The power system has often been cited as the greatest and most complex machine ever built, yet it is predominantly a mechanical system. However, technologies and intelligent systems are now available which can significantly enhance the overall functionality of power distribution, and make it ready to meet the needs the 21st century. This book explains in detail how sensors, communications technologies, computational ability, control, and feedback mechanisms can be effectively combined to create this new, continually adjusting "smart grid" system. You'll gain an understanding of both IntelliGrid^{SM} architecture and EnergyPort^{SM}, as well as how the integration of intelligent systems can be effectively utilized toward achieving the goals of reliability, cost containment, energy efficiency in power production and delivery, and end-use energy efficiency.

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the analytical techniques specified by the US EPA.

The PEM™ gasification technology enables S4 to convert almost any type of waste or biomass into clean, renewable fuels. If all of the waste generated in the US were converted into liquid transportation fuels, such as ethanol or synthetic diesel, over 50 billion gallons of fuel could be produced annually. This could largely eliminate the need for importing fuels from the Middle East, moving the US closer to energy independence.

Initially, S4 will focus on highly segregated waste streams, such as medical and certain industrial waste materials. Through an aggressive commercialization strategy, S4 will first demonstrate the technology at a scale of 25 tons of feedstock per day, which will increase to an operational capacity of 125 tons per day. Once proven at the larger scale, S4 will begin deploying systems into the broader waste conversion markets, including residential and commercial solid waste. Where appropriate and economically feasible, S4 will also process biomass blended with certain waste materials to further reduce the overall carbon footprint of the S4 facility and to minimize the generation of GHGs.

Presently, S4 is completing the full detailed design of its first commercial facility, which S4 plans to deploy at a number of sites over the next several years. S4 is also completing the scaling of its gasification facility design from 25 tons of feedstock per day to 125 tons per day for a single process train. S4 has a number of facilities in the development stage and plans to announce its first commercial demonstration plant. S4 intends to broadly deploy its gasification facilities both in the US and internationally once it has fully demonstrated the technology at scale on various waste and biomass feedstocks.

SUMMARY

The S4 gasification technology is now in full commercialization phase with smaller scale systems in the deployment stage with larger facilities under development. S4 believes it will have a number of PEM™ gasification facilities deployed over the next 3 to 5 years demonstrating the conversion of waste-based materials and biomass into various energy products. With the combination of Waste Management's vast network of assets for the aggregation, handling and transportation of waste and InEnTec's advanced PEM™ technology, S4 is uniquely positioned to successfully commercialize gasification as a source of clean, renewable fuel.

ABOUT THE AUTHOR

Jeffrey Surma is President and Chief Executive Officer of S4 Energy Solutions. Prior to joining S4, Mr. Surma was a senior research engineer with Battelle at the Pacific Northwest National Laboratory (PNNL), where he led multi-million dollar research projects in the area of high-level radioactive waste vitrification, electrochemical processing and plasma processing of waste. Mr. Surma led a multi-institutional team involving the Plasma Fusion Center at MIT to develop plasma technologies that have been commercialized through InEnTec, where he was a founder and CEO. Mr. Surma holds 25 US patents and 15 international patents and is a four-time recipient of the prestigious R&D 100 award for his work on plasma processing and associated technologies. Mr. Surma holds a B.S. in Chemistry from the University of Minnesota and a M.S. in Chemical Engineering from Montana State University. He can be contacted via email at jsurma@s4energysolutions.com.