PLASMA GASIFICATION – THE WASTE-to-ENERGY SOLUTION FOR THE FUTURE

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Abstract. Plasma WtE is currently subject of extensive research and a number of companies across the globe are trying to develop a suitable, eco-friendly and efficient WtE technology for the future. While all of these companies are still working on concept designs or small-scale prototypes, there is one company already building large industrial scale plasma gasifiers around the globe to treat MSW, Industrial and Toxic waste all together. In 1999 in Japan, Hitachi Metals and Westinghouse Plasma Corp ("WPC") built the World's First commercial demonstration plasma WtE plant. Hitachi Metals operated the plant for one year on municipal solid waste and obtained a certification from the Japan Waste Research Foundation (JWRF). Subsequently, Hitachi Metals leveraged this success into the two commercial plants at Mihama-Mikata and Utashinai in Japan, both having at the very core the now proven Westinghouse Plasma gasification technology. For more than 20 years, Westinghouse Plasma Corp (WPC) has been leading the technology platform for converting the world's waste into clean energy for a healthier planet. The WPC technology makes landfills obsolete and replaces *Incineration* as the primary process for WtE. The WPC technology already operates in three reference plants around the world and other three new commercial plants are under construction (two plants of 1000 tons/day in UK and a 650 tons/day in China), all three designed to convert municipal solid waste to electricity and district heat, in the most efficient and environmental-friendly manner.
Keywords: plasma gasification, waste, energy.

GAZIFICARE ÎN MEDIU CU PLASMĂ -- DEŞEURI în ENERGIE (WtE) PREZINTĂ SOLUŢIA PENTRU VIITOR

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Rezumat. Energia din Deseuri prin gazificare cu plasmă constituie în prezent obiectul unei ample cercetări şi, o serie de companii din întreaga lume încearcă să dezvolte o tehnologie de Energie din Deseuri adecvată, ecologică şi eficientă pentru viitor. În timp ce toate aceste companii încă lucrează la proiectele de concept sau prototipuri de laborator, există deja o companie care construieşte gazificatoare cu plasmă la scara industrială, care tratează deşeuri solide urbane, industriale şi, chiar deşeuri toxice, toate concomitent. În 1999 în Japonia, Hitachi Metals şi Westinghouse Plasma Corp ("WPC") au constuit împreună prima instalaţie de demonstrare din lume, funcţională la scară industrială pentru Energie din Deseuri prin gazificare cu plasmă. Hitachi Metals a operat fabrica pentru timp de un an, procesând deşeuri solide urbane şi a obţinut o certificare de la Fundaţia Japoneză de Cercetare a Deşeurilor (JWRF). Ulterior, Hitachi Metals a utilizat acest succes în cele două fabrici comerciale la Mihama-Mikata şi Utashinai - Japonia, la baza cărora se află procedeul şi tehnologia de gazificare a Westinghouse Plasma Corp. De mai bine de 20 de ani, Westinghouse Plasma Corp ("WPC") conduce dezvoltarea platformei tehnologice pentru transformarea deşeurilor din lumea întreagă în energie curată, pentru o planetă mai sănătoasă. Tehnologia WPC face ca depozitele de deşeuri să devină o practică învechită şi înlocuieşte incinerarea ca procedeu primar pentru Energie din Deşeuri. Tehnologia WPC funcţionează deja în trei fabrici de referinţă în întreaga lume şi alte trei noi instalaţii comerciale se află în construcţie (două dintre ele cu o capacitate de procesare de 1000 de tone pe zi în Marea Britanie şi una de 650 de tone pe zi în China), toate trei concepute pentru a transforma deşeurile municipale solide în electricitate şi căldură, în modul cel mai eficient şi ecologic posibil.
Cuvinte-cheie: gazificare plasmică, energie, deşeuri.

ПЛАЗМЕННАЯ ГАЗИФИКАЦИЯ – ОТХОДЫ В ЭНЕРГИЮ (WtE)- РЕШЕНИЕ ДЛЯ БУДУЩЕГО

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Аннотация. Плазменные технологии WtE в настоящее время являются предметом обширных исследований ряда компаний, стремящихся разработать экологически чистые и эффективные технологии WtE. Большинство из этих компаний работают над концепцией конструкции или лабораторных прототипов, но есть одна компания, которая уже строит в промышленном масштабе плазменные газогенераторы для утилизации твердых бытовых, промышленных и токсичных отходов. В 1999 году в Японии, Hitachi Metals и Westinghouse Plasma Corp ("WPC"), построили первую в мире коммерческую установку, реализующую технологию WTE. Установка на предприятии Hitachi Metals работает в течение одного года на твердых бытовых отходах и получила сертификацию от

Японского научно-исследовательского фонда отходов (JWRF). Впоследствии, Hitachi Metals использовала этот успех в двух коммерческих установках в Mihama-Mikata и Утасинай в Японии, которых работают на проверенные технологии газификации предложенной Westinghouse Plasma. На протяжении более 20 лет, Westinghouse Plasma Corp ("WPC") была ведущей технологической платформы для преобразования отходов в мире в чистую энергию для здоровой планеты. Технология WPC делает свалки устаревшими и заменяет их сжиганием отходов по технологии WtE. Технология WPC уже работает в трех контрольных установках и в трех новых строящихся коммерческих предприятий, (двух заводов по 1000 тонн /сутки в Великобритании и 650 тонн / сутки в Китае). Все эти предприятия предназначены для преобразования твердых бытовых отходов в электричество и осуществления теплоснабжения наиболее эффективным и экологически безопасным способом.
Ключевые слова: Плазменная газификация, отходы, энергия.

1. Introduction to Westinghouse Plasma Gasification technology

Plasma is a highly concentrated form of energy, generated by a stream of air passing thru an electric arc. The result is an ionized flux of gas with intense temperature that reaches up to 5000 °C at the core. In nature, plasma is produced by lightning when it superheats the air around the lightning bolt converting the air to plasma with a temperature of about 20,000 °C.   Because plasma behaves differently than the three common states of matter; solid, liquid and gas, plasma is sometimes referred to as the fourth state of matter.

Westinghouse Plasma Corp creates plasma using their proprietary design plasma torch systems. An electric arc similar to lightning is created inside the torch and then high speed air is being pushed through the electric arc to create plasma. The plasma, with temperatures close to 5000 °C, is controlled and directed into the reactor. Although it sounds simple, the Plasma torches are sophisticated devices, involving a high degree of complexity to feed, control, and cool the device and the process. A WPC plasma torch in operation is shown in Figure 1, next to the schematic representation of a Westinghouse Plasma Reactor for gasification of Municipal Solid Waste into energy-reach SYNGAS.

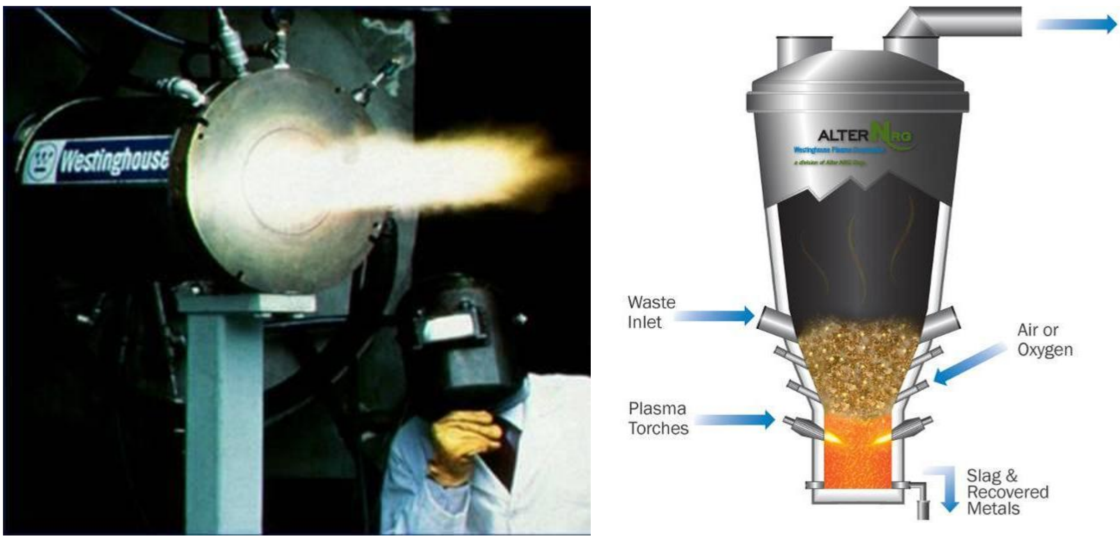


Fig.1. *Westinghouse plasma torch and gasification reactor*

A plasma reactor is an oxygen starved vessel that is operated at the very high temperatures achievable with plasma. Because the environment inside the vessel is deprived of oxygen, feedstock that is processed in the reactor is not combusted. Instead, the intense plasma heat breaks down the feedstock into elements like Hydrogen and simple compounds like Carbon Monoxide (CO) and water. The resulting gas is called synthesis gas or “SYNGAS”, is highly combustible and has a Low Heating Value (LHV) that depends on the feedstock (the better the feedstock, the higher the LHV).

As opposed to Incineration or other types of gasification, such as Pyrolysis - which can only process certain types of waste, non-toxic and pre-sorted, the Westinghouse Plasma Reactor has the versatility to allow simultaneous processing of virtually any type of waste, whether regular, toxic or hazardous _and_ combinations of such waste streams. This unique ***"one solution that fits all problems"*** of the WPC technology, offers the great advantage of only one reactor solution to process all possible waste streams, such as; ***municipal solid waste, hazardous waste from hospitals, toxic waste from industry, used tires, oil, paint, solvents and even incinerator ash and sludge from the city's water treatment station***.

Most feedstocks, including municipal solid waste and specially the incinerator ash or the sludge from the water treatment station, contain both organic and inorganic components. The organic components are converted into syngas. The inorganic components, like glass, metal, concrete or sand, are melted inside the reactor and flow out of the bottom as a non-toxic vitrified molten slag which can be used safely as aggregate. The slag is then quenched and granulated upon exiting the reactor. The resulting vitreous granules are conveyed and loaded onto trucks for export to customers off-site.

The reactor is equipped with Westinghouse plasma torch systems that ensure the internal temperatures in the reactor are high enough to guarantee complete conversion of inorganic material to syngas and to melt all the inorganic material. Also, the heat from the plasma torch systems and the relatively long residence time inside the reactor (longer than the minimum of 2 seconds at 1,100 °C, as required by the 2000/76/EC DIRECTIVE on the incineration of hazardous waste) ensures complete destruction of the feedstock and allows for the processing of high moisture feedstock or feedstock containing hazardous materials or high levels of inert materials like glass and metals.

On the top part of the reactor, the syngas is partially quenched with atomized water prior to exiting the reactor at a temperature of approximately 850 °C, then undergoes a clean-up process that eliminates all dust particulates and other undesirable. The syngas clean-up process is tailored to meet the requirements for each project, but in most cases, especially where MSW is the feedstock, the syngas clean-up will include particulate removal, sulphur removal and mercury/heavy metals removal. Syngas is cooled through a caustic venturi quench and scrubber system and then proceeds through a wet electrostatic precipitator (WESP). The primary purpose of the venturi quench and WESP is to remove the particulate matter entrained in the syngas. The cooled and particulate free syngas then proceeds through a series of syngas cleaning processes to remove chlorine, sulphur, lead, cadmium, zinc and mercury. Intermediate compression and cooling steps remove moisture from the gas.

The clean syngas is then compressed in a multi-stage compressor and fed into a gas-burning turbine to produce electrical power. The turbine flue-gas heat is recovered by a heat recovery steam generator ("HRSG"). The steam from the HRSG is combined and fed again to a multi-stage steam turbine to generate more power.

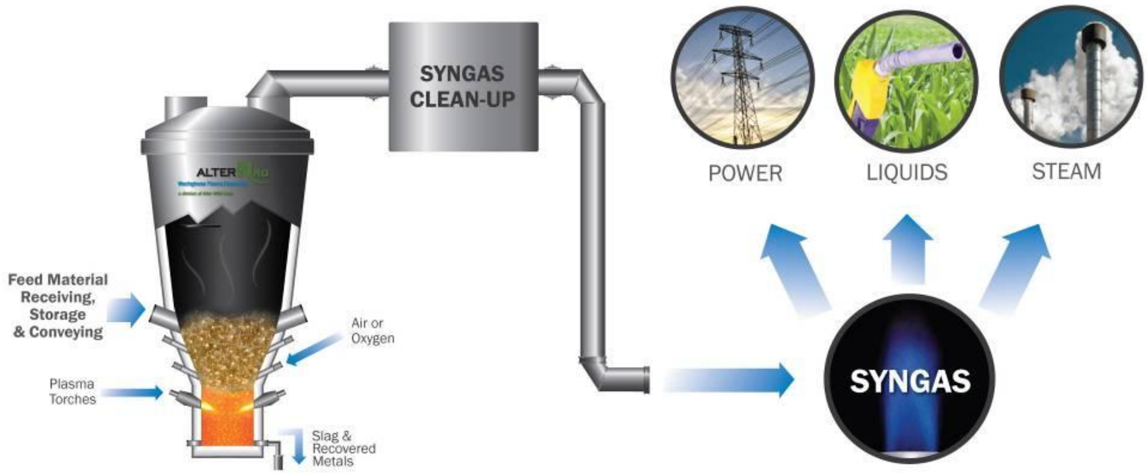


Fig. 2. *Westinghouse plasma Waste-to-Energy system and end products*

Alternately, the cleaned syngas can be used in reciprocating engines or gas turbines to make power or it can be converted to liquid fuels using a number of available or emerging SYNGAS to Power conversion technologies and turned into liquid fuels, as shown in Figure 2.

2. Development history and commercial advantage of WPC technology

Westinghouse Plasma Corporation's plasma technology was developed over more than 30 years and with over $100 million in Westinghouse R&D funding. The WPC technology was initially developed in collaboration with NASA for use in the Apollo space program to simulate space vehicle re-entry conditions of over 5,500°C (10,000°F). Between 1983 and 1990, Westinghouse and the Electric Power Research Institute (EPRI) developed a reactor using plasma for reclaiming fragmented scrap metal. Between 1988 and 1990, Westinghouse extended the plasma cupola technology for the treatment of hazardous wastes including contaminated landfill material, PCB-contaminated electrical hardware, transformers and capacitors, and waste from the steel industry.

In the mid 1990's WPC in cooperation with Hitachi Metals completed an R&D program and pilot testing program to confirm the capability of the plasma cupola to treat municipal solid waste (MSW) and other waste materials to produce a syngas which could be used in a power plant for the production of steam and electricity. A series of tests were completed at the WPC Plasma Center in Madison, Pennsylvania using a variety of feed materials and at varying moisture contents. The success of these tests provided the technical basis for the design and installation of a pilot scale 24 ton/day MSW gasification plant in Yoshii, Japan.

Hitachi Metals and WPC's combined efforts culminated in the demonstration to the Japanese government that the Yoshii WTE facility was capable of using plasma energy to reliably and economically gasify waste materials for energy production. In September 2000, The Japanese Waste Research Foundation awarded a process certification of the technology and the Westinghouse Plasma Reactor was born.

The lessons learned at Yoshii were applied to other two full scale facilities also in Japan, in Mihama-Mikata and Utashinai, which both began commercial operation in 2002 and 2003. The experience gained at the two Japanese facilities was then used to create the next generation reactor which was commissioned in 2009 by SMSIL in Pune, India, a WtE facility that treats various hazardous wastes from over 40 different industries. The Westinghouse Plasma gasification reactor technology development and commercial history is shown in Figure 3.

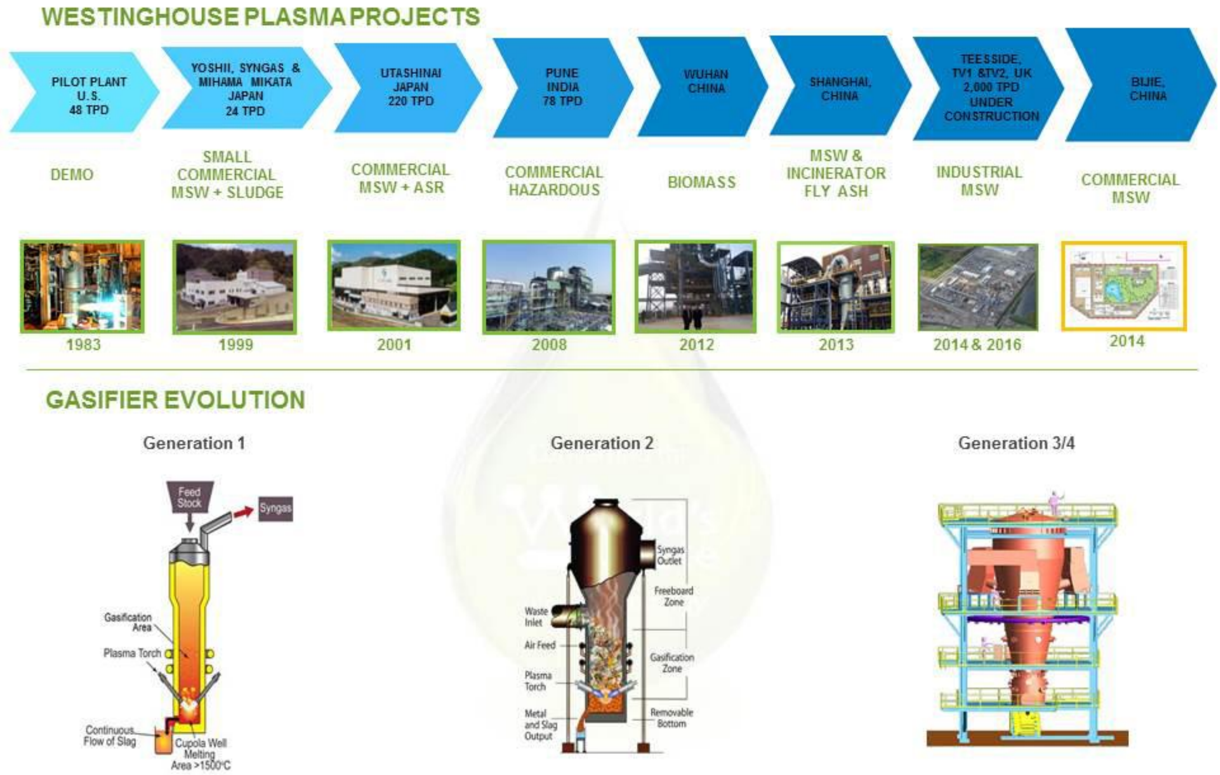


Fig.3. *WPC gasification reactor technology development and commercial history*

The Westinghouse Plasma Reactors size, capacity and overall dimensions are shown in Table 1 and were designed to be economically competitive for a specific range of applications. While all of them have the capacity to process any type of solid or liquid waste, with low energy or low cost waste they become economically viable at higher volume. This is why Westinghouse Plasma ha sdesigned three basic types of reactors. The small-range P5 reactor was designed for the destruction of Hazardous and Toxic waste, which usually carry a higher processing fee. The mid-range W15 reactor was designed to turn the Municipal Solid Waste and Hazardous Waste in useful electric-power and heat for larger communities of up to one million inhabitants, or to serve the needs of larger Industrial Toxic Waste processing facilities. Finally, the high-range G65 reactor was designed for the gasification of Municipal Solid Waste or Coal in large industrial power-plants, to provide large communities of over one million people with green electricity and district heat.

Table 1. Westinghouse plasma reactor models, capacity and dimensions

<table>
<tr><th rowspan="3">Reactor Model</th><th rowspan="3">Feedstock</th><th colspan="4">Capacity (tpd)</th><th rowspan="3">Syngas Produced (Nm^3/hr)</th><th colspan="4">Dimensions (meters)</th></tr>
<tr><th colspan="2">Air Blown</th><th colspan="2">Oxygen Blown</th><th rowspan="2">Top Dia.</th><th rowspan="2">Bottom Dia.</th><th rowspan="2">Vessel Height</th><th rowspan="2">Installed Height[3]</th></tr>
<tr><th>Low</th><th>High</th><th>Low</th><th>High</th></tr>
<tr><td rowspan="2">G65</td><td>MSW</td><td>540</td><td>620</td><td>1000</td><td>1000</td><td rowspan="2">65,000</td><td rowspan="2">9</td><td rowspan="2">4</td><td rowspan="2">24</td><td rowspan="2">30</td></tr>
<tr><td>Haz Waste</td><td>430</td><td>720</td><td>830</td><td>1000</td></tr>
<tr><td rowspan="2">W15</td><td>MSW</td><td>120</td><td>140</td><td>240</td><td>290</td><td rowspan="2">15,000</td><td rowspan="2">6</td><td rowspan="2">2.5</td><td rowspan="2">15</td><td rowspan="2">18</td></tr>
<tr><td>Haz Waste</td><td>100</td><td>160</td><td>190</td><td>300</td></tr>
<tr><td rowspan="2">P5</td><td>MSW</td><td>40</td><td>50</td><td>80</td><td>100</td><td rowspan="2">5,000</td><td rowspan="2">4</td><td rowspan="2">2</td><td rowspan="2">10</td><td rowspan="2">13</td></tr>
<tr><td>Haz</td><td>30</td><td>50</td><td>60</td><td>100</td></tr>
</table>

	Waste									

Figure 4 shows the world's largest plasma reactor delivered by Westinghouse Plasma Corp to Air Products in UK (http://www.airproducts.com/), who purchased two plasma gasification reactors for their two (2) Waste-to-Energy power-plants being built at Tees Valley in England. Each facility will process 1000 tpd of pre-sorted MSW and will produce electricity through a combined cycle power island configuration, for a total installed electrical power of 2 x 64 MW. A combined cycle power island is the combination of a gas turbine(s), a heat recovery steam generator and a steam turbine and is considered the most efficient technology for converting gas to power.

Fig.4. *The largest plasma reactor in the world - 1000 tpd G65 WPC reactor before installation at Air Products' location in Tees Valley, Northeastern England*

3. Energy efficiency and environmental advantage of WPC technology

Plasma gasification differs from non-plasma gasification in one key area - temperature. Non plasma gasifiers typically operate between 800 and 900 °C. The temperatures inside Westinghouse Plasma's Reactor reach *over 3000 °C*. The syngas exits the gasifier at 950 °C. The slag flows out of the reactor at 1650 °C. The higher temperatures inside our plasma reactor result in the complete destruction of tars, something that is not achievable with non-plasma technologies. It is not feasible to remove tars downstream of the reactor and therefore the utility of the syngas produced by non-plasma gasifiers is very limited. It can be burned immediately but it cannot be conditioned for conversion into liquid Bio-Fuels, used in gas turbines or reciprocating engines, which are more efficient and increase the energy yield of the system.

The conversion efficiency from MSW to Electricity can be as high as 40%, with the remaining energy being recovered in the form of heat and exported as steam (~50%) and the inherent heat losses. Of the electrical energy produced by the reactor, 1/3 is being used by the plant for internal consumption and 2/3 exported to the power grid. Table 2 shows some examples of the form of energy output and quantities that can be exported from a WPC gasification plant processing MSW.

Table 2. Westinghouse plasma reactor models, capacity and production output

Reactor Model	Capacity (tons per	Syngas Produced	Syngas Chemical	Installed electric	FT Liquids	Fossil Fuel

	day of MSW)	(NM^3/hr)	Energy, HHV (GJ/yr)	power and net to grid (MW)	BPD / BPY	Replacement (bbls/year)
G65	1000	65,000	4,100,000	58 / 39	785 / 287,000	670,000
W15	290	15,000	976,000	14 / 9	188 / 68,000	160,000
P5	100	5,000	323,000	4.5 / 3	62 / 23,000	50,000

The environmental benefits of the Westinghouse plasma gasification facility include lower emissions, lower greenhouse gas footprint, recovery of the energy stored by waste, useful byproducts and a significant reduction in the amount of material that ultimately must be landfilled.

3.1. Lower emissions

A WPC plasma gasification power plant is completely different than an incineration plant from an emissions perspective. Where incineration technology literally burns MSW to create energy, WPC's technology uses extreme heat to break down the MSW to its molecular constituents including hydrogen and carbon monoxide, the two building blocks of syngas. ***The syngas is cleaned up to a specification similar to Natural Gas before being burned in a gas turbine or reciprocating engine to make power.*** *Emissions from this sort of plant will be very similar to a natural gas fired power plant.*

3.2. Reduction of the waste amount that ultimately must be landfilled

A WPC gasification plant produces vitrified slag as a byproduct. The slag is inert and safe to use as aggregate or in other applications and 100% of the slag from the Mihama Mikata plant in Japan is used as aggregate for concrete products and was proven not to contaminate soil or drinking water. Slag from the Mihama Mikata plant has been tested against several Japanese standards including JLT-46, NEN-7341 and TCLP analysis. These tests were conducted by two independent laboratories *Shimadzu Techno-Research Inc. and ALS Laboratory Group*. The results show that the Mihama-Mikata slag components ***are below the test detection limits and the slag is considered non-leaching***.

A WPC plasma gasification plant also produces particulate which is removed from the syngas downstream from the reactor. However, the particulate can be recycled back into the reactor for destruction and therefore does not become a byproduct that needs to be disposed of. Instead of slag, incineration plants produce bottom ash and fly ash. The fly ash requires special disposal and in many jurisdictions is considered hazardous waste.

Assuming that particulate is recycled back into the reactor, only about 2-4% of the material introduced into a WPC plasma gasification plant needs to be sent to landfill. In comparison, about 20% to 30% of the waste processed in an incinerator must be sent to landfill.

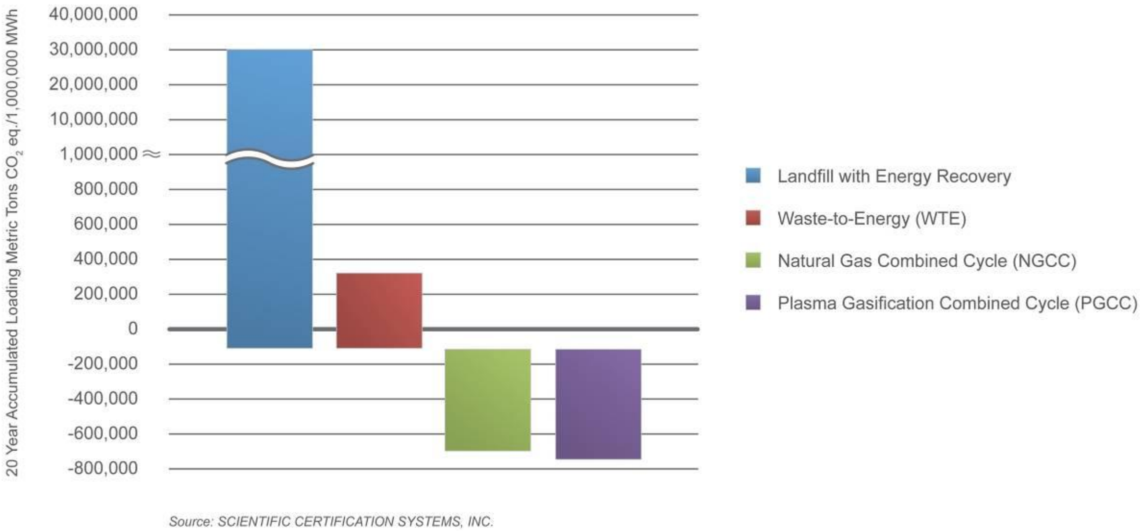
3.3. Lower Greenhouse Gas Footprint

Scientific Certification Systems ("SCS"), an independent consultancy, produced a report in 2010 that compared the lifecycle greenhouse gas emissions of a plasma gasification combined cycle power plant with the emissions from a state of the art incineration facility and a landfill with energy capture facility.

In their report SCS states

"The results of this analysis show that the Plasma Gasification Combined Cycle ("PGCC") system provides the lowest greenhouse gas emissions of the evaluated systems for waste disposal". Figure 6.1, from the SCS study, shows a comparison of the greenhouse gas emissions from the three scenarios plus the greenhouse gas emissions from a state of the art natural gas fired combined cycle facility.
The SCS study also concluded that the lifecycle greenhouse gas emissions were almost equivalent to the state of the art natural gas combined cycle power plant.

Reduced emissions, reduced amounts of solid wastes that need to be landfilled and reduced greenhouse emissions – plasma gasification has better environmental performance in all areas (Figure 5)."



Notes:
1) Twenty year accumulated GHG loading for four power generation options.
2) Results compared on a basis of 1,000,000 MWh.
3) Northeast Power Coordinating Council region. Zero on Y-axis represents average greenhouse gas emissions from power plants per 1 million MWhs in the region.

Fig. 5. *Greenhouse gas emissions comparison by technology*

Overtime, a series of global independent energy and environmental development companies have done performance and emissions assessments of the Westinghouse Plasma Gasification technology. You can find these reports at www.westinghouse-plasma.com.

Summary

Westinghouse Plasma Corp has a long-standing proven expertise in both plasma torch systems and plasma gasification. The WPC plasma gasification technology was developed over more than 30 years and uses a long standing expertise in plasma industrial applications, to build the Westinghouse Plasma Reactor which enables processing of difficult feedstock, like Municipal Solid Waste, Toxic Industrial, Hazardous Hospital waste or even Water Treatment Sludge.

The end product is a clean and useful syngas that can be stored, transported, converted into a large variety of products such as Ethanol, Biofuels, Hydrogen, or simply used into a gas turbine to produce electricity and heat. The inorganic ash residue is turned into a vitrified slag, which is also useful as construction aggregate. In doing so, the WPC technology reduces the total amount of waste to landfill to only 5% by weight, as it converts both organic and inorganic components of waste into useful market products.

The Westinghouse Plasma gasification plant is much more efficient in all aspects and much more environmentally friendly than any state of the art incineration plant. As the SYNGAS is cleaned of all contamination prior to energy production, the flue-gas emissions of the power plant are cleaner than flue-gas of the Natural Gas. The WPC plasma gasification is the energy of the future, much more efficient and much cleaner than any other form of WtE. The future of the WPC plasma gasification technology is to power the emerging Hydrogen fuel cells technology, with syngas from the reactor.

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