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## **THE UTILIZATION OF INTEGRATED PLASMA GASIFICATION COMBINED CYCLE SYSTEM (IPGCC)**

### **WHITE PAPER**

#### **A Patented and Proprietary IPGCC System:**

The Integrated Plasma Gasification Combined Cycle (IPGCC) is a unique process that uses a patented Plasma Gasification Vitrification (PGV) technology for the conversion of low value fuels/feed stocks, such as coal waste, petroleum coke, biomass, and different waste forms (including MSW), into a low heating value synthesis or syngas containing carbon monoxide and hydrogen gases. This gas is then employed as a primary fuel for a gas turbine. The IPGCC can also be viewed as a two-stage processor of an opportunity feedstock. The feedstock is first gasified (partial oxidation) in a gasifier using high-temperature plasma heating systems at atmospheric pressure. The gas is then cleaned and combusted (complete oxidation) in the gas turbine to produce electricity.

The PGV Reactor in essence cleans the solid/liquid and/or dirty fuels/feed stocks by converting them into a valuable by-product fuel gas or “syngas” to power a gas turbine.

This IPGCC system generally consists of four separate processes:

- Feedstock handling;
- Plasma Gasification and Vitrification (“PGV”);
- Gas cooling and clean-up; and
- Gas turbine combined cycle.

The IPGCC system offers significant advantages over standard integrated gasification combined cycle (IGCC). By applying the PGV technology for gasifying the feedstock, the plasma heating system provides an independent and extremely powerful heating source at atmospheric pressure allowing the Gasifier system to be (1) fuel flexible, (2) has high availability for base load power, (3) achieve higher efficiency and (4) provides lower O&M costs.

#### **The PGV Technology:**

The PGV Reactor employs plasma torches to heat the reactor to 4000 – 5000 Degrees Celsius at atmospheric pressure. At this operating temperature, the PGV process uses a carbon based catalyst and oxygen-enriched air to cause the hydrocarbon or organic material to undergo partial oxidation, i.e., the hydrocarbon material is depolymerized into carbon and hydrogen molecules by the plasma generated heat and undergoes partial oxidation to be released as a mixture of H<sub>2</sub> and CO. The syngas has a heating value varying from 150 to 300 BTU/scf, which is

about 1/3 to 1/6, that of natural gas. All inorganic or non-hydrocarbon based material in the feedstock are simultaneously vitrified into an inert glassy slag, suitable for use as construction materials including aggregate, tile, or bricks. Although the PGV reactor can treat most, if not all, feedstock with air alone for the partial oxidation process, this PGV process uses oxygen enriched air in order to optimize thermodynamic reactions and thereby minimize the volume of syngas generated (reducing costs of gas clean up), as well as the specific energy requirements (SER) of the plasma torches (reducing parasitic load). Oxygen will be generated by a VSA (Swing Vacuum Swing Absorption) system, which will also provide nitrogen for use in other parts of the plant (either as a N<sub>2</sub> blanket in the feeding system or as diluent for the turbine). Larger plants may require cryogenic oxygen generation systems.

The syngas from the PGV reactor must be cooled down and cleaned before it can be used as a gas turbine fuel. This cooling and clean-up process typically involves the efficient removal of any sulfur compounds, chlorides, mercury, other volatile metals, acid gas, and any particulate matter in order to reduce air pollution and to meet the gas turbine fuel specifications. Consequently, in the IPGCC process harmful pollutants from the feedstock, particularly when using toxic wastes or coal waste, are removed from the syngas stream (pre-combustion) rather than from the flue gas (post-combustion). Because these pollutants are much more concentrated in the significantly smaller volume of the syngas stream than the exhaust flue gas, the IPGCC clean-up process is more efficient and has a significantly lower cost than the post-combustion clean-up as employed in most steam-boiler plants.

More importantly, because of the PGV reactor's much higher operating temperature, partially combusted short hydrocarbon chains, which typically form precursors to SVOCs (Semi Volatile Organic Compounds) such as dioxins and furans, undergo complete depolymerization into their elemental compounds, rendering the IPGCC process practically free from tar, soot, or SVOCs.

### **This IPGCC System Uses the General Electric (GE) "LCV" Gas Turbines**

GE pioneered the use of standard IGCC almost three decades ago and has developed a broad dedicated IGCC product line of gas turbines and matching steam turbines ranging from 10 to 300 MW. GE special "LCV" gas turbines are proven products with a total of 34 GE IGCC units sold. Of these, 22 units have accumulated over 380,000 hours of operation on syngas similar to that produced in this IPGCC system.

Gas turbines for syngas generated by gasification processes have basic technical and functional requirements that are different from those of a gas turbine powered by natural gas. Therefore, syngas turbines must be modified with features that allow for both efficient and reliable syngas service. These syngas specific features relate primarily to the combustion and fuel systems, but also include some special fire protection, packaging, and controls modifications.

**GE developed the low pressure turbine technology to provide those obtaining power from renewable sources, such as Solena's clean fuel technology, with a complete range of gas turbines that can be efficiently integrated with the gasifier to generate "least cost" electricity while at the same time meeting strict environmental regulatory requirements for air emissions.**

**The core of GE "LCV" syngas turbine design is based on combustion system adaptation and thorough laboratory testing. Combustors must be designed for a wide range of operating conditions with primary syngas, backup fuel, and possible co-firing of both fuels. The multiple can-annular syngas combustor design of GE gas turbines results in excellent flame stability and mixing properties that produce very low emissions. This design also makes it possible for this patented design IPGCC plants to burn multiple fuels, including distillate, naphtha, syngas, methane or natural gas.**

**This important feature provides the process extra capacity and flexibility for projects in a situation where feedstock delivery or availability becomes inconsistent.**

**Because of the high variability of the feedstock using in IGCC systems, a myriad of technical possibilities must be balanced for each gasifier type and each syngas fuel. Therefore, each IPGCC system must be optimized for specific fuel type, site, and environmental conditions. Based on GE's knowledge and experience gained from successful operation of many syngas combined cycle turbine units, this group will work closely with GE Power Systems on all of its projects to integrate in a cost effective and efficient manner GE syngas turbines with these IPGCC systems.**

**GE, with over 380,000 hours of experience in operating syngas turbines, has concluded that a syngas-fueled combined cycle plant can have the same RAM (Reliability-Availability-Maintenance) performance as a natural gas-fueled combined cycle plant and have similar air emissions even if coal is the feedstock of the gasifier.**

#### **This IPGCC Plant's Environmental Performance:**

**The safe and efficient environmental performance of this IPGCC is its leading advantage and allows this group to obtain much faster the necessary permission to "site" and "permit" its renewable energy projects worldwide.**

**This IPGCC process is inherently "greener" than any other combustion/burner technology. As a completely clean system, all harmful pollutants can be removed from the PGV generated syngas before they can reach and possibly damage the gas turbine. Therefore, back-end exhaust gas cleanup is not necessary. The SO<sub>x</sub>, NO<sub>x</sub>, mercury, volatile metals, and particle emissions from a Solena IPGCC plant constitute a small fraction of those emissions from a conventional pulverized coal boiler power plant or incinerator waste- to- energy plant. Consequently, an IPGCC**

plant would require significantly less effort and time to meet the most stringent air emission regulations and to obtain local and other governmental environmental permits.

**Specific Pollutant Considerations (Ash, NO<sub>x</sub>, SO<sub>x</sub>/Sulfur):**

In contrast to conventional PC coal burner or fluidized bed incinerators, this IPGCC process provides opportunity for additional income derived from byproduct recovery and sale. In a conventional burner system, waste products such as ash, sulfur, and scrubber sludge are a major cost factor in terms of operating cost, treatment, transportation, and final disposal.

• • Ash

The PGV Reactor produces no ash. It converts all inorganic material in the feedstock into an inert solid vitreous slag. Unlike a combustion system, the very high plasma temperatures break all fixed carbon bonds. The remaining inorganic materials are melted under high plasma temperatures into molten slag, which is tapped and cooled outside the reactor into a non-leachable and inert vitreous product. Both the US Environmental Protection Agency (EPA) and the European Union (EU) classify the plasma slag as inert. Thus, it can be employed as a construction material. The US EPA has approved plasma slag for such many uses including as construction aggregate for concrete or roadbed, construction fill material, brick making, architectural tile or shingle manufacturing. Hazardous heavy metals are captured and immobilized in the vitreous matrix, so the slag easily passes Toxic Characteristic Leaching Procedure (TCLP) tests. This means that the material, even if it is not employed for construction, can be land filled in non-secure landfills. In all this group's projects, there is no cost for the disposal of slag. This is a cost that must be incurred by the operators of conventional coal burners or incinerators for ash disposal in secure landfills.

• • NO<sub>x</sub>

To moderate NO<sub>x</sub> emissions, steam, water, CO<sub>2</sub> and /or nitrogen are injected into a GE syngas turbine's combustor. Nitrogen is usually available from the SVA unit, so it is conveniently employed in the IPGCC system. Fuel moisturization (using low level process heat) is also often used to reduce NO<sub>x</sub> emissions. NO<sub>x</sub> emissions from this IPGCC process can achieve the range of <10 ppm NO<sub>x</sub>.

In particular, this IPGCC process using a GE syngas H turbine provides lower NO<sub>x</sub> emissions than coal or waste- to -energy plants that have installed both low-NO<sub>x</sub> burners and Selective Catalytic Reduction (SCR) systems. The IPGCC system achieves this through clean gasifying and combustion control in the turbines, rather than attempting end-of-pipe control as do most coal fired power plants. The addition of SCR to this IPGCC process is neither necessary to make it the cleanest solid fuel technology nor is it feasible. According to GE's studies, any unreacted ammonia from the SCR and sulfur will combine to form sticky ammonia

salts. Because IPGCC syngas is particulate-free as opposed to conventional boilers/burners, these salts will plate out on available HRSG surface area or pass through the environment. These salts will then either foul the heat recovery steam generator or contribute salt fume to the particulate loading; or do both. Either outcome is undesirable and are good reasons for not using this method.

- • SOX/Sulfur:

Sulfur is recoverable from the PGV reactor generated syngas as part of the normal off-gas cleanup. With this particular IPGCC system a choice can be made regarding the form of the recovered sulfur: whether as sulfuric acid or elemental sulfur, depending upon the regional industrial or agricultural markets. The sulfur is removed from the syngas stream prior to reaching the gas turbine combustor by using standard processes such as sulferox or Locat system; the resulting elemental sulfur or sulfuric acid are saleable IPGCC process by-products.

Since very little sulfur remains in the syngas (99.99% removal) that enters the gas turbine combustor, SOX emissions from an IPGCC plant are very low when compared to any other coal burner or incinerator plant. In fact, they are similar to those from a natural gas fired plant.

- • Particulate Matter (PM)

The PGV reactor is designed to control the hot gas superficial velocity and maximize thermal cracking time, thereby ensuring minimal amounts of PM or soot/tar exiting in the syngas. In any case and as an additional security measure, any PM is removed from the syngas stream using a cyclone type or other filters and water scrubbers, which produce a virtually PM-free syngas. No back-end flue gas bag-house is required for PM reduction in an IPGCC process plant.

- • Mercury:

Because of its low volatility temperature, mercury present in the feedstock will be volatilized and exit the PGV Reactor in the syngas. If significant amounts of mercury are present in the feedstock, activated carbon bed filters will be used in the IPGCC plant to remove more than 95% of the mercury at relatively low added costs (\$20-\$30 per kw installed). Again, no high cost back-end, flue gas mercury removal system is required for an IPGCC plant.

- • Greenhouse Gas Emissions:

The IPGCC process is approximately 5% more efficient than coal fired power plant technologies and 15%-20% more efficient than incinerators; and, thus, CO<sub>2</sub> emissions per kw generated are also 5% to 20% lower. Additionally, in the IPGCC system, carbon can be removed from the syngas to create a pure hydrogen fuel that effectively eliminates CO<sub>2</sub> emissions.

**This group is currently investigating the possibility of using the high-energy hydrogen gas as a fuel for fuel cell systems. Thereby eliminating all combustion from its plant processes, and fully eliminates all greenhouse gas emissions. Today's stationary fuel cell system is still too small and too expensive for incorporation into an IPGCC plant.**

#### **IPGCC Operational Characteristics:**

**IPGCC plants perform best in base-load applications due to the steady operational requirements of the PGV reactors. IPGCC systems utilize gas turbines that require natural gas or distillate as a start-up fuel, i.e., all IPGCC syngas turbines are dual fuel capable. Consequently, IPGCC plants can switch to the backup fuel when syngas is unavailable or co-fire when syngas is limited. This flexibility increases this IPGCC plant's power availability to levels equivalent to natural gas combined cycle (NGCC) plants.**

**This co-firing of a mixture of fuels is also often desired either to improve the overall economics or to allow the IPGCC plant to more closely follow a required electrical load profile.**

#### **Summary:**

**This IPGCC system provides significant advantages over PC boilers, fluidized bed incinerators or high-pressure gasification processes by producing electricity at competitive pricing while offering superior environmental performance. IPGCC plant emissions are far below any coal or incinerator technologies for all major pollutant categories (NO<sub>x</sub>, SO<sub>x</sub>, metals, mercury, ash, sludge). Because IPGCC plants are "cleaner" than any plants using "burning" technology, new IPGCC plants are significantly easier to site and permit.**

**Additionally, by using the PGV Reactor, this IPGCC plants have the capacity to independently generate and modulate very high process temperature resulting in a gasification process that (1) is fuel flexible; (2) maintains higher availability (up to 90%); (3) achieves higher efficiency; and (4) provides O& M costs lower than all existing "clean" renewable energy production processes.**