Greening Fossil Energy

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A Highly Efficient Process for Producing Electricity and Hydrogen from Coal, Oil, Natural Gas and Biomass

The Integrated Plasma Fuel Cell process is a new method for generating electricity and hydrogen. It has lower calculated costs, higher efficiencies and less pollution than the most advanced methods employing combustion. It has the potential to create two times the amount of electricity from coal than is possible with current technology. It creates a concentrated stream of hydrogen gas, a concentrated stream of carbon dioxide and a stream of synthetic gas, which can readily be converted into gasoline and diesel fuel using the well-known Fischer Tropsch process.

The hydrogen gas can be used in a variety of commercial applications, e.g., in the production of synthetic gasoline and diesel fuel, in petroleum refining and as a future fuel for hydrogen fuel cell powered motor vehicles.

The carbon dioxide can also be used for a variety of commercial applications, for example, injection into oil and natural gas wells for enhanced production and injection into coal beds to release methane. It can also be used as a clothing and equipment-cleaning agent, as a food grade gas for carbonation of popular bottled soft drinks like Pepsi and Coca-Cola and the production of dry ice.

The process can be installed on the sites of existing power plants enabling the use of existing coal infrastructure, or it can be newly constructed at appropriate sites. The plants are expected to scale from tens of megawatts to hundreds of megawatts.

Highest Thermal Efficiency Attained with the Non-burning IPFC Process

Current power plants (Rankine Cycle) create electricity by burning fossil fuels using atmospheric oxygen. The heat released from the converts water to steam, which drives a turbine.

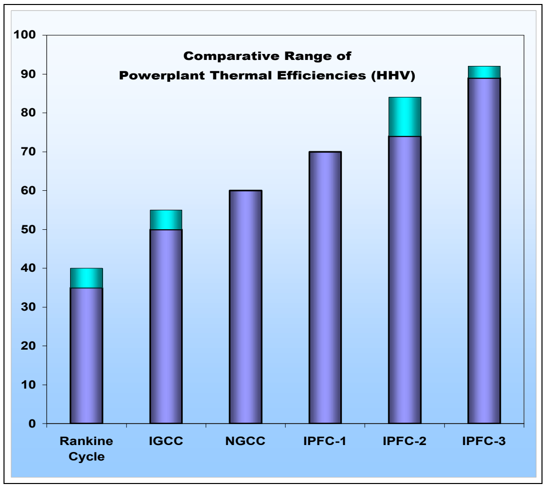
Unfortunately, a major portion of the fuel's heat energy in traditional plants is lost because the process is only about 38% efficient. In addition, the usual pollution gases from combustion are released to the environment (e.g., NOx, SOx, Hg, As, F and CO_2 and particulates).

Comparison of IPFC to Power Generating Processes

Over the past two decades, improved electric power generating plants have been built in an effort to improve efficiency and to reduce pollution. In two of the best design alternatives, the heat of combustion is more thoroughly used to increase *efficiency* up to 60%. This process is known as a *combined cycle*.

Two combined cycle plants have been constructed. They burn natural gas in compressed air and the hot gases are used directly to rotate a turbine-generator and a compressor. The hot exhaust from the turbine goes to a conventional Rankine cycle plant where a secondary turbine generates electricity. This is called the Natural Gas Combined Cycle (NGCC), which typically achieves 60% thermal efficiency for electricity production.

Integrated Gasification Combined Cycle (IGCC) plants use coal fuels. In order to produce the compressed gas for burning the coal, a gasifier is used, which partially burns the coal in air and steam. These IGCC plants typically achieve 50 - 55% thermal efficiency for electric power generation. Pollution reduction has been largely improved by gasifying coal and then cleaning the combustion gases and burning natural gas.

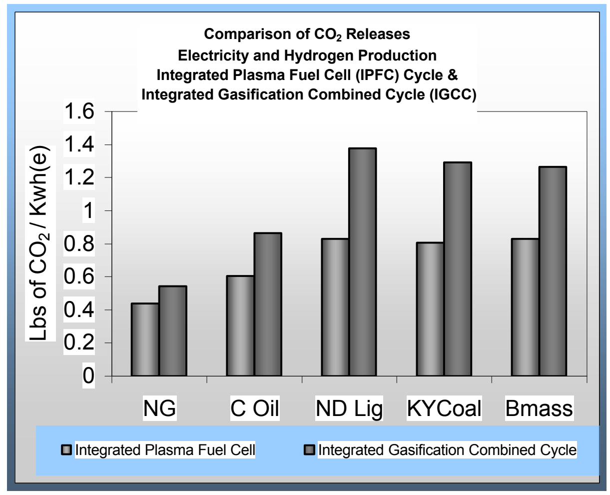


In comparison, as the figure above shows, the IPFC process can achieve much higher thermal efficiencies ranging from *a low of 70% to a high of 92%.* Values vary depending upon the type of fuel, the amount of hydrogen produced in relation to the amount of electricity, and the heating value of the fuel. Typically, lower thermal efficiencies (IPFC-1) are for biomass (wood) fuel, and the highest thermal efficiency value (92%) is obtained using petroleum fuel (IPFC-3).

IPFC-2 in the *Thermal Efficiencies Chart* reflects calculated thermal efficiencies of burning various grades of coal: 75% to 84% thermal efficiencies for electricity production compared to the efficiencies of 35% to 40% achievable in the typical Rankine cycle power plant and 50-55% efficiency in an NGCC plant. In an IPFC plant producing electricity and hydrogen, the thermal efficiency using coal fuels increases to a range of 87% to 91%. There is thus an economic benefit derived from producing both electricity and hydrogen.

IPFC Pollution Reduction

In a new IPFC plant, pollution emissions would be reduced because of increased thermal efficiency. In comparison to an Integrated Gasification Combined Cycle, which is a low emissions process, the IPFC is much lower as the figure below shows.



The IPFC process produces concentrated streams of hydrogen, and carbon dioxide. These gases are collected for use in commerce as mentioned earlier. The collected excess carbon dioxide gas can also be sequestered in the ground and thus release of this global warming gas to the atmosphere is prevented.

The IPFC empowers a Hydrogen Economy

One roadblock to a hydrogen economy is that producing hydrogen from fossil fuels may cause more pollution than directly using the fossil fuel. The IPFC process removes this roadblock and produces hydrogen from fossil fuels with much less pollution than if the fuel were used directly or in combined cycle plants. Furthermore, if the hydrogen is used in a Syngas process to produce gasoline and diesel fuel, hydrogen storage and pipeline requirements are reduced or eliminated.

How the IPFC process works

The basic *IPFC process* for electricity production integrates two technologies, the Hydrogen Plasma Black Reactor and the Molten Carbonate Direct Carbon Fuel Cell. (See Figure 1)

The integration of these two technologies creates an entirely new and innovative chemical process for extracting the maximum amount of energy and commercial products from the fuel source. It generates electricity without burning while efficiently extracting useful byproducts such as hydrogen, and pure carbon dioxide, from the fuel, rather than producing the highly wasteful products of conventional combustion.

The *IPFC process* can also be adapted to provide feed stock for a process that will produce synthetic gasoline and diesel fuels (Fischer-Tropsch process). (See Figure 2)

The highest efficiency for electricity production is obtained by supplementing the basic IPFC process with a Solid Oxide Fuel Cell and a back-end Rankine cycle plant in the IPFC combined cycle. The cited efficiencies (70% to 92%) for the IPFC do not include credit for the efficiency improvements provided by these additional components. (See Figure 3)

Integration of the Hydrogen Plasma Black Reactor with the Direct Carbon Fuel Cell
In the basic IPFC cycle, a Hydrogen Plasma Black Reactor thermally decomposes any carbon containing fuel, typically coal, to elemental carbon, hydrogen, carbon monoxide and a reduced amount of pollution products. High temperature hydrogen plasma is used to crack the fuel into its elemental components.

The elemental carbon is then captured in a molten carbonate working fluid and transferred to the Direct Carbon Fuel Cell, wherein the elemental carbon is chemically consumed to produce electrical power and concentrated carbon dioxide gas. About 90% of the electrical power is available for sale, while the remainder is fed back to the electrodes in the Plasma Black Reactor.

In an enhanced *IPFC Process* configured to maximize production of electricity, the hydrogen gases from the Hydrogen Plasma Black Reactor are used in a Solid Oxide Fuel Cell, which also produces electricity.

A Water Gas Shift Reactor consumes the carbon monoxide from the Hydrogen Plasma Black Reactor to produce concentrated streams of hydrogen and carbon dioxide.

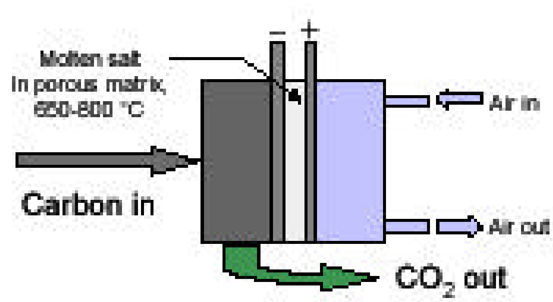
A back-end Rankine plant uses the hot gases from the Solid Oxide Fuel Cell and the Direct Carbon Fuel Cell to produce additional power.

The attractiveness of the *IPFC Process* is that it can be configured to produce only electricity or to produce some combination of electricity, hydrogen and liquid motor fuels. Preliminary economic analyses based on the projected capital cost of the Direct Carbon Fuel Cell achieves considerable savings in power production and hydrogen costs compared to conventional and combined-cycle power plants.

The flexibility of co-products creates an economically attractive power generation, hydrogen-production, and synthetic transportation fuels.

Hydrogen Plasma Black Reactor
The Hydrogen Plasma Black Reactor was developed by Aker Kvaerner and was used on an industrial scale to produce carbon black for tires. See photograph of Karbomont Montreal Hydrogen Plasma Black Reactor plant. The Karbomont Plant produced Hydrogen at the rate of 2.5 Billion Cubic Feet/per year and 20,000 Tons/Day of Carbon Black from two reactors.

An Operational Direct Carbon Fuel Cell
In the Integrated Plasma Fuel Cell (IPFC) process, the Direct Carbon Fuel Cell operates using a recirculating molten carbonate electrolyte as a carbon transfer medium.

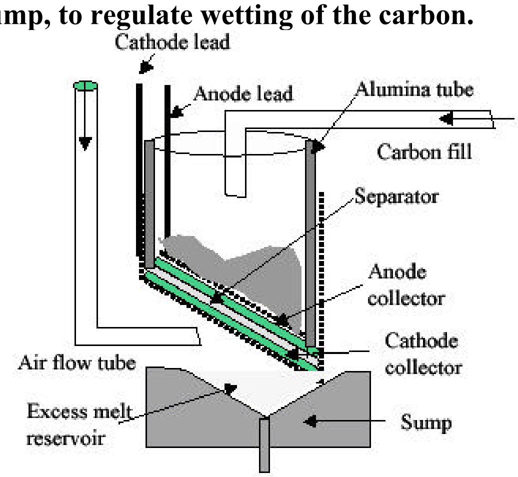


Experience using molten carbonate electrolytes in megawatt-scale hydrogen fuel cells is directly applicable to this process.

The laboratory scale Direct Carbon Fuel Cell (shown in the photograph to the right) has been operated at the U.S. Department of Energy's Lawrence Livermore National Laboratory.
The photo shows a laboratory cell of 60 square centimeters.

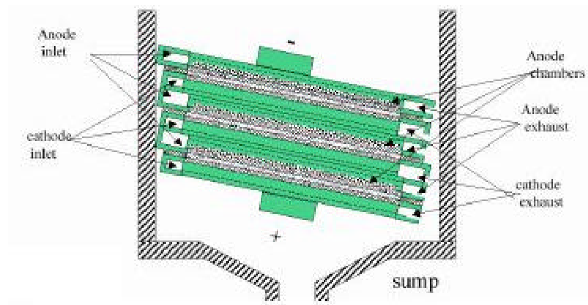
The electrode assembly is placed at an angle of 45 degrees from horizontal. The tilted orientation helps drain excess electrolyte from the cell from the cell that might otherwise collect in depressions in a horizontal electrode and shut off access of oxygen to reactive cathode sites. It also prevents flooding of the metallic cathode and corrosion to Ni_2CO_3 during startup that would prevent development of a compact, defect-free film with the desired catalysis. Finally, the tilt allows the electrolyte to be exchanged between the separator, electrodes, and an adjacent reservoir, to maintain sufficient electrolyte during progressive consumption of the carbon inventory.

Schematic of a cell tilted to allow exchange of melt between the cell and an underlying sump, to regulate wetting of the carbon.



Status of Development
The critical engineering path for building an IPFC process plant is the scaling-up of the Direct Carbon Fuel Cell and the integration of the Fuel Cell with the Hydrogen Plasma Black Reactor.

One conceptual approach to an industrial scale Direct Carbon Fuel Cell suggested by the lab-scale is shown in the following schematic of a cell cross-section which would maintain orientation in a bipolar stack of rectangular cells and provide for a flow of carbon saturated molten salt.



The electrode assembly is placed at an angle of 5-45° from horizontal. This tilted orientation helps drain excess electrolyte

A functioning pilot plant is expected to take 3 years to complete. This would be followed by a completion of a full-scale demonstration plant in an additional 3 years.

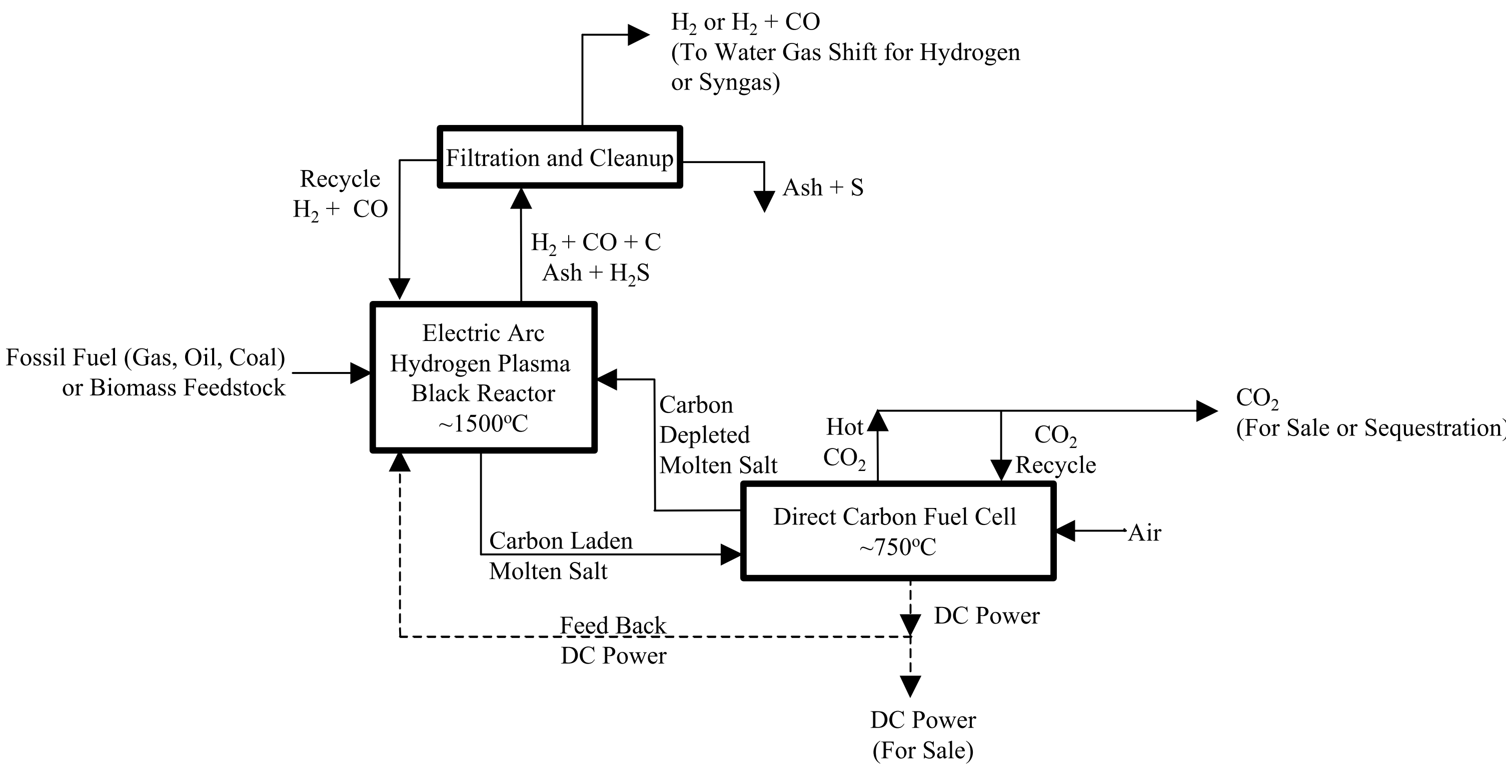


FIG. 1 -- Hydrogen Plasma Black Reactor Integrated with Direct Carbon Fuel Cell for Conversion of Fossil Fuels or Biomass to Electric Power and Hydrogen or Syngas. (IPFC)

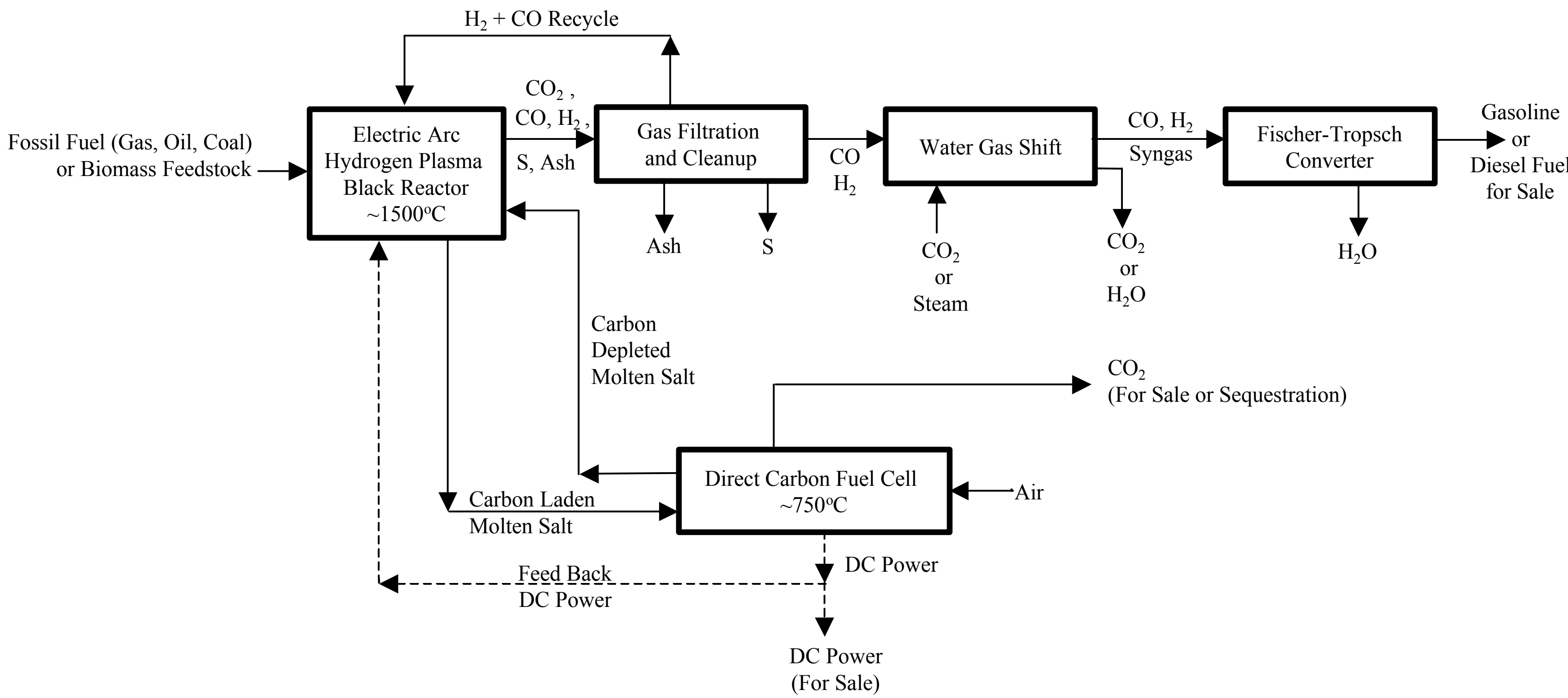


FIG. 2 -- Integrated Plasma Fuel Cell Plant for Producing Power and Transportation Fuels (IPFC – FT).

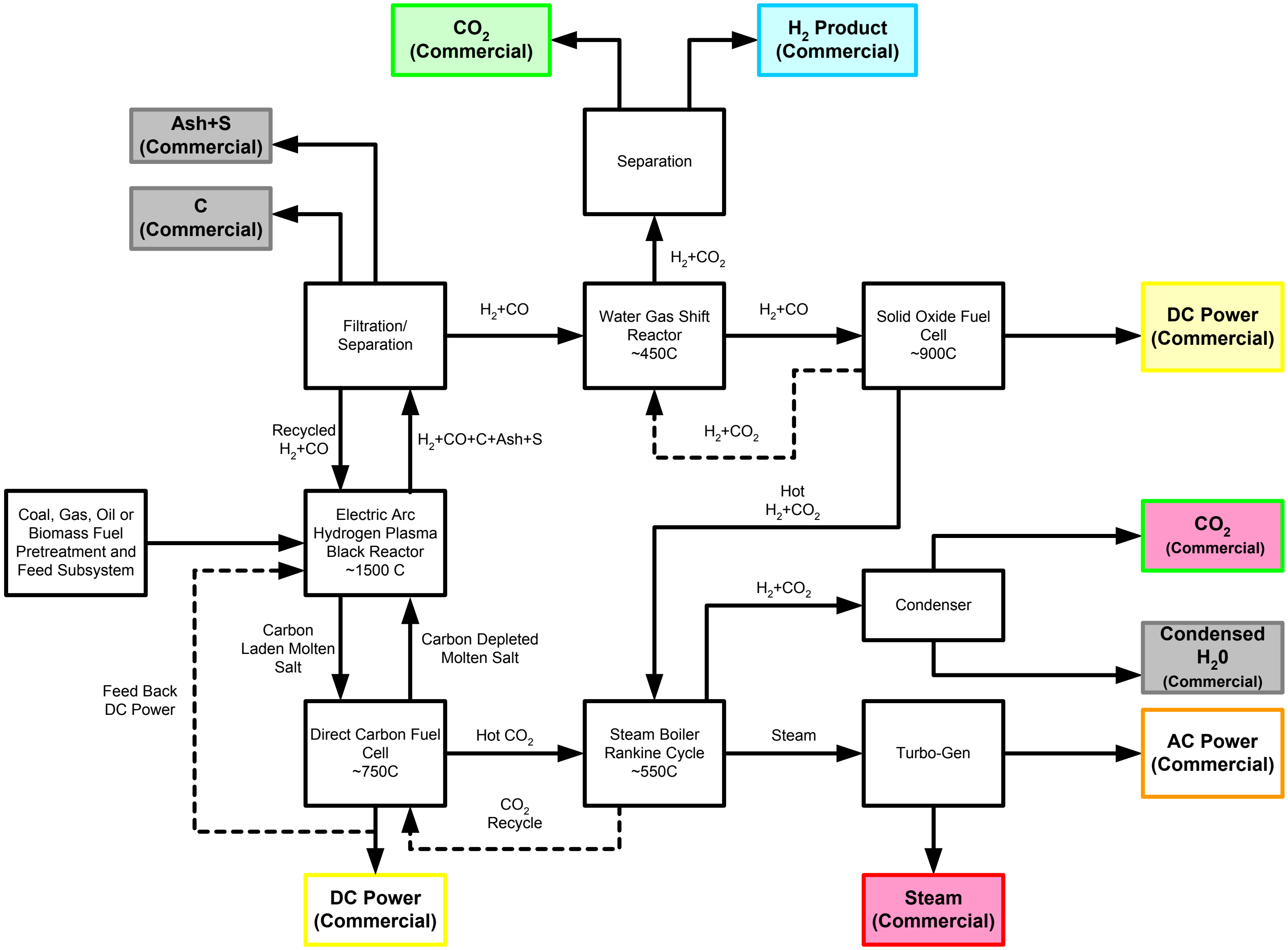


Fig. 3 -- Enhanced HCE-IPFC Process for Electrical Power and Hydrogen Production