Fuel Cells

While the fuel cell has been the subject and recipient of considerable interest and focus for several years, the audience to whom this overview is addressed is assumed to have sufficient background knowledge and experience with the technology and thus a primer on this area will not be included However we are including the following brief summarization for the record.

Fuel cells, it is generally known, are not constrained by the Carnot cycle of combustion engines because they do not operate with a thermal cycle. However, unlike the THRUST System, they produce only direct current (DC) which must be used in conjunction with converters and inverters to convert the DC to AC for most end user applications. It is generally known, of course, that an inverter is a device that adapts electrical current produced by a fuel cell to suit the needs of the end use application.

These inverters must in turn work with complementary converters, which, are electronic devices in a fuel cell that changes one level of direct current to another level, that is DC to DC primarily. In an inverter, DC is further changed to AC in a DC to AC transition. Whether the end result is a simple electrical motor or a complex utility grid the Direct Current must be converted to Alternating Current.

By employing the THRUST concept AC will emerge from the generator and plug right into the AC electrical grid and will not of course require the associated cost and complexes and losses due to the converter and inverter interfaces. Thus the THRUST concept and fuel cell might both find useful and productive applications depending upon the end user requirements.

A fuel cell typically converts the chemical energy of its fuel into electricity with an efficiency of about 50%. However there is one problem in this regard. The efficiency is very highly dependent on the current through the fuel cell: the more current drawn, the lower the efficiency. For a hydrogen fuel cell the efficiency (actual power / theoretical power) is equal to cell voltage divided by 1.23 volts, at a temperature of 25 degrees Centigrade. This Voltage, of course, depends on the fuel used, quality and temperature of the cell. A cell running at 0.6V has an efficiency of about 50%, meaning that 50% of the energy content of the hydrogen is converted into electrical energy.

It is also important to accept losses due to production, transportation and storage into account. Fuel cell vehicles running on compressed hydrogen may have a power plant to wheel efficiency of 22% if the hydrogen is stored as high pressure gas storage and 17% if it is stored as liquid hydrogen (efficiency of Hydrogen Fuel Cell, Diesel-SOFC, Hybrid and Battery Electric Vehicles). The round-trip efficiency (electricity to hydrogen and back to electricity) of such plants is between 30 and 40%.

In “combined heat and power” applications, a fuel cell carries with it the requirement that it be placed in a location where considerable heat is also needed. A lower fuel-to-electricity conversion efficiency is tolerated (typically 15-20%), because most of the energy not converted into electricity is utilized as heat.

Theoretical Efficiency

An exhaustive study of this technology clearly points out that the theoretical efficiency of a hydrogen fuel cell has not been obtained to date.

Thermodynamics and the Gibbs free energy play key roles in determining the efficiency of a fuel cell. It is accepted and widely known that the Gibbs free energy only gives the maximum theoretical work produced by a fuel cell. For emphasis, please recall that the Gibbs free energy can be defined as energy available to do external work, not including work done by changes in pressure or volume. In a hydrogen fuel cell this external work is done by moving electrons though the circuit.

There are five types of fuel cells available under study.

Polymer Electrolyte Membrane fuel Cell (PEMFC) – A PEMFC fuel cell employs a solid organic polymer polyperfluorsulfonic acid electrolyte membrane and operates at temperatures of 60 – 100 degrees Centigrade. PEMFC applications include electric utilities, portable power, and transportation. Its main advantages are that the solid electrolyte reduces corrosion, operates at low temperatures, and delivers quick start-up. Its disadvantages are that the cell requires expensive catalysts and the cell is extremely sensitivity to fuel impurities.

Alkaline Fuel cell (AFC) – An AFC employs an aqueous solution of potassium hydroxide soaked in a matrix electrolyte and operates at temperatures of 90-100 degrees Centigrade. AFC applications include military and space and is the technology that has been used by NASA for more *than 25 years*. Its main advantage is that cathode reaction is faster in the alkaline electrolyte, resulting in high performance. Its disadvantage is

the requirement for pure hydrogen, requiring expensive CO2 removal fuel and air streams.

Phosphoric Acid Fuel Cell (PAFC) – A PAFC employs a matrix soaked with liquid phosphoric acid. It operates at temperatures of 175 – 200degrees Centigrade. PAFC applications include electric utility and transportation. Its main advantages are that it has up to 65% efficiency when used in cogeneration of electricity and heat, and it can use impure hydrogen as fuel.

Its main disadvantages are that it requires a platinum catalyst, has low current and power, and requires not only a large size and weight but also requires a long start-up time.

Molten Carbonate Fuel Cell (MCFC) employs a liquid solution of lithium, sodium, and/or potassium carbonates soaked in a matrix. It operates at 600 – 1000 degrees Centigrade. The main MCFC applications are for electric utilities. Its advantages are its high efficiency, fuel flexibility and it ability to use a variety of catalysts. Its disadvantage is that the high temperature enhances corrosion and breakdown of cell components.

The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Research is currently exploring corrosion – resistant materials for components as well as fuel cell designs that increase cell life without decreasing a Teflon – bonded silicon carbide matrix – and porous carbon electrodes containing a platinum catalyst.

We would at this time like to very briefly return to the PACFs

The PAFC is considered the “first generation” of modern fuel cells. Its is one of the most mature cell types and the first to be used commercially, with over 200 units currently in use. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses.

PAFCs are more tolerant of impurities in fossil fuel that have been reformed into hydrogen than PEM cells, which are easily “poisoned” by carbon monoxide – carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell’s efficiency. They are 60% efficient when used for the co-generation of electricity and heat, but less efficient at generating electricity alone (37 to 42 percent). This is only slightly more efficient than combustion – based power plants, which typically operate at 33 to 35 percent efficiency. PAFCs are also less powerful than other fuel

cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. Like PEM fuel cells, PAFCs require an expensive platinum catalyst, which raises the cost of the fuel cell. A typical phosphoric acid fuel cell costs between *$4000 and $4,500 per Kilowatt to operate.*

Solid Oxide Fuel Cell (SOFC) – An SOFC employs a solid zirconium oxide to which a small amount of yttria is added. It operates at 600 – 1000 degrees Centigrade. Its main advantages are its high efficiency, fuel flexibility, ability to use a variety of catalysts and reduced corrosion. Its main disadvantage is that the high temperature spurs breakdown of cell components.

For Transportation application, the three key fuel cell challenges are cost (less than $50/KW of engine power), durability (at least 5,000 hours) and rapid start up (less than 30 seconds).

It is expected that as the THRUST concept is studied there will also be advantages and disadvantages. However allow us to quickly point out that the THRUST concept, unlike fuel cells, should produce usable current in AC standards thus eliminating the need for the several converters and inverters for conversion from DC to AC. Also the tremendous amount of heat generated from the exhaust of a hydrogen powered engine can be used to eliminate the many problems associated with fuel cells. This over and generous abundance used in creative can combat the many problems working with the low temperature fuel. In addition, please return to the home page and click on “Ten reasons why this project should move forward”.

Environmental Considerations

Aircraft gas turbine engines fueled with hydrogen produce no carbon dioxide emissions and cut nitrogen emissions up to 80 percent.

Using hydrogen in fuel cell propulsion systems with low temperature fuel cells completely eliminates all polluting emission. The only byproduct resulting from the generation of electricity from hydrogen and atmospheric oxygen is water.

Hydrogen has a higher energy density than petroleum-based fuels. It supplies more energy per unit volume than gasoline, diesel, or kerosene. Hydrogen is extremely a abundant, thus eliminating U.S. dependence on foreign sources of supply.