Innovative Applications of Hydrogen Fuel Cells

Firouz Shahrokhi[1*], Ahad Nasab[2] and Rocco Guarnaccia[1]
[1]PowerAvenue Corporation, 4215 Harding Rd, Nashville, TN 37205, USA
[2]Middle Tennessee State University, Murfreesboro, TN 37132, USA
www.PowerAvenueCorp.com and *e-mail: PowerAvenueCorp@gmail.com

Abstract

The practical application of fuel cells to a variety of engineering devices requires innovative systems integration, assembly, and manufacturing. Consumer applications can be divided into two categories of mobile and stationary applications. In the mobile application market sector, zero emission systems with nominal powers between 50 W to 100 kW can be designed to compete with other alternative fuel schemes. This will require innovation in fuel storage and precision power matching technology. The stationary power stations range from 1 kW to several megawatts. EPRI has recently released specific guidelines and market forecast for such systems for the next ten years. In this document we will discuss the various innovative techniques of manufacturing, device operation and integration as well as issues such as modularity, security, reliability, and efficiency for mobile and stationary systems. We will also present the concept of decentralized power generation which may be an essential step in ensuring the successful utilization of hydrogen fuel cells in the mobile market.

Keywords: *hydrogen, fuel cell, power generation, mobile generators, stationary generators*

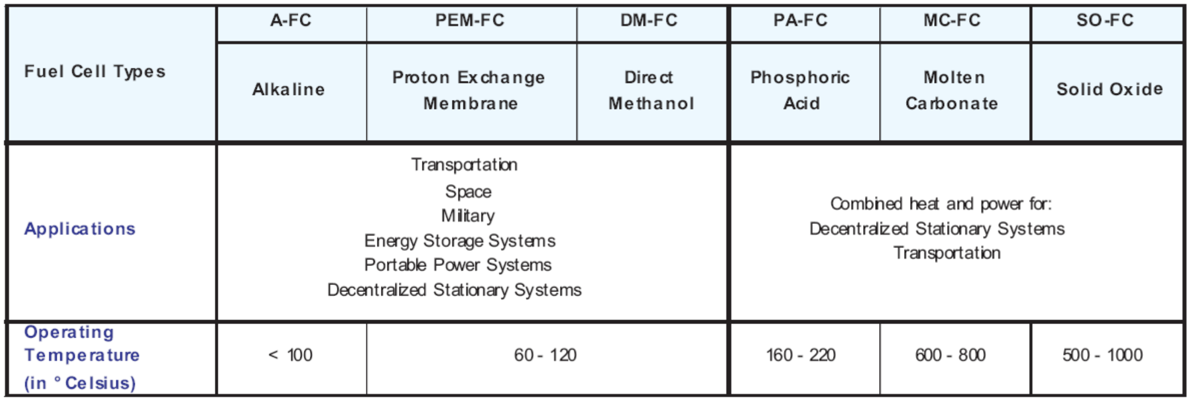
1. Introduction

A fuel cell is a device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity by an electrochemical process. A single fuel cell consists of an electrolyte and two catalyst-coated electrodes (a porous anode and cathode). While there are different fuel cell types, all work on the same principle:

- Hydrogen or hydrogen-rich fuel is fed to the anode where a catalyst separates hydrogen's negatively charged electrons from positively charged ions (protons).
- At the cathode, oxygen combines with electrons and, in some cases, with species such as protons or water, resulting in water or hydroxide ions, respectively.

- For polymer electrolyte membrane and phosphoric acid fuel cells, protons move through the electrolyte to cathode to combine with oxygen and electrons, producing water and heat.
- For alkaline, molten carbonate, and solid oxide fuel cells, negative ions travel through the electrode to the anode where they combine with hydrogen to generate water and electrons.
- The electrons from the anode side of the cell cannot pass through the electrolyte to the positively charged cathode; they must travel around it via an electrical circuit to reach the other side of the cell. This movement of electrons is an electrical current.

The efficiency of fuel cells could reach 70 to 85 percent which is far higher then those of steam turbine or combustion engines (20 to 35 percent).



Fuel Cell Types	A-FC	PEM-FC	DM-FC	PA-FC	MC-FC	SO-FC
	Alkaline	Proton Exchange Membrane	Direct Methanol	Phosphoric Acid	Molten Carbonate	Solid Oxide
Applications	Transportation Space Military Energy Storage Systems Portable Power Systems Decentralized Stationary Systems			Combined heat and power for: Decentralized Stationary Systems Transportation		
Operating Temperature (in ° Celsius)	< 100	60 - 120		160 - 220	600 - 800	500 - 1000

Figure 1: Types and characteristics of various fuel cells – not included are Zinc Air, Regenerative, and Protonic Ceramic: Source: Fuel Cell 2000

2. Types of Fuel Cells

Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, catalysts required, temperature range in which the cell operates, fuel required, and other factors. These characteristics affect the applications for which these cells are most suitable. Several types of fuel cells are currently in development, each with its own advantages, limitations, and potential applications. These types include, Polymer Electrolyte Membrane (PEM), Direct Methanol, Alkaline, Phosphoric acid, Molten Carbonate, Solid Oxide, and Regenerative fuel cells. Summary of these cell types are shown in Figure 2.

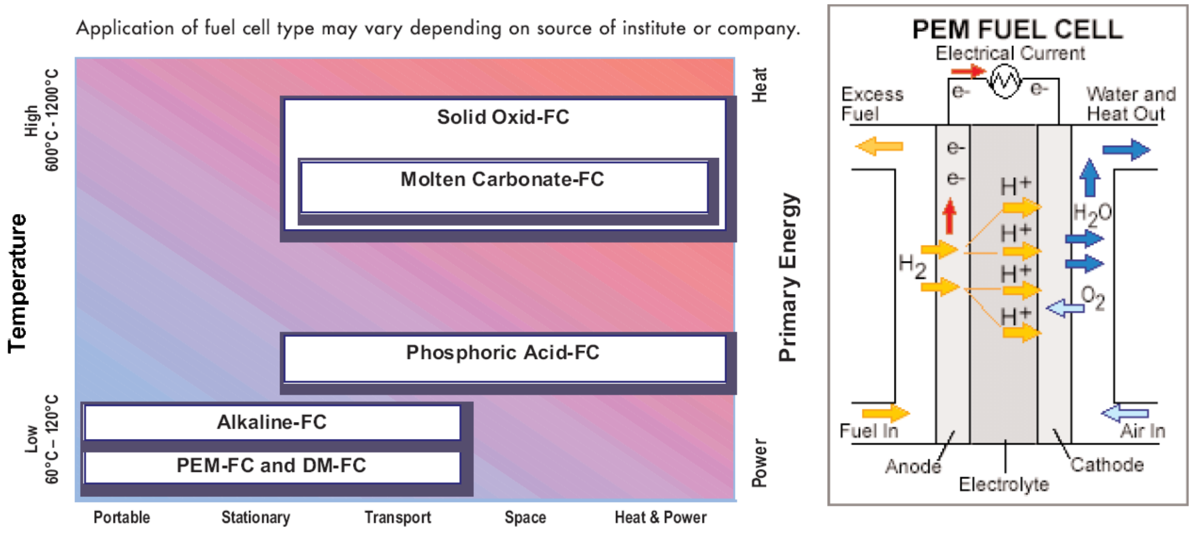


Figure 2: Fuel cells classified based on their applications and the operating temperatures.

3. Products

Fuel cells are classified in two broad categories of portable and stationary systems. The portable systems range in power from a few watts to 1 kW, while stationary fuel cells systems typically range from 1 kW to several megawatts.

3.1 Portable Fuel Cells

The fuel cells that typically serve this market had sales exceeding $250 million in 2004, Figure 3. Applications include any system that requires power and is not connected to an electrical outlet such as cameras, cell phones, laptop computers, radios, electronic devices, power tools, etc. The portable market has diverse requirements:

- Long run times
- Low weight
- Short response times
- Long life
- Low cost
- Small physical size
- Safety and reliability

Fuel cells have lacked commercialization due to high cost and identification of a proper market application. We believe that the new emerging handheld video communication and multimedia devices that demand more power and energy will be a prime market for fuel cell based portable power products as opposed to batteries. There are, however, many current opportunities for the application of fuel cells in small vehicles such as bikes and motor scooters. Our tests have resulted in development of benchmarks for mass productions of fuel cells power systems for this growing transportation market. Specifications and power characterization of two of these systems are shown in Figure 4.

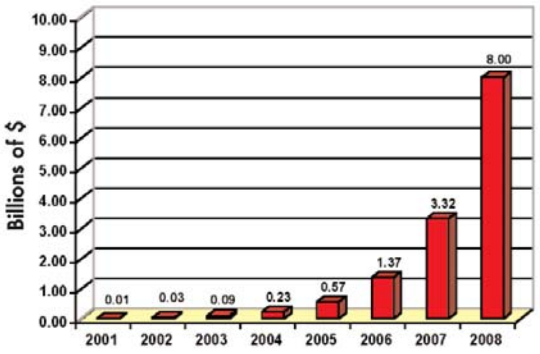


Figure 3: Projected portable fuel cell power market

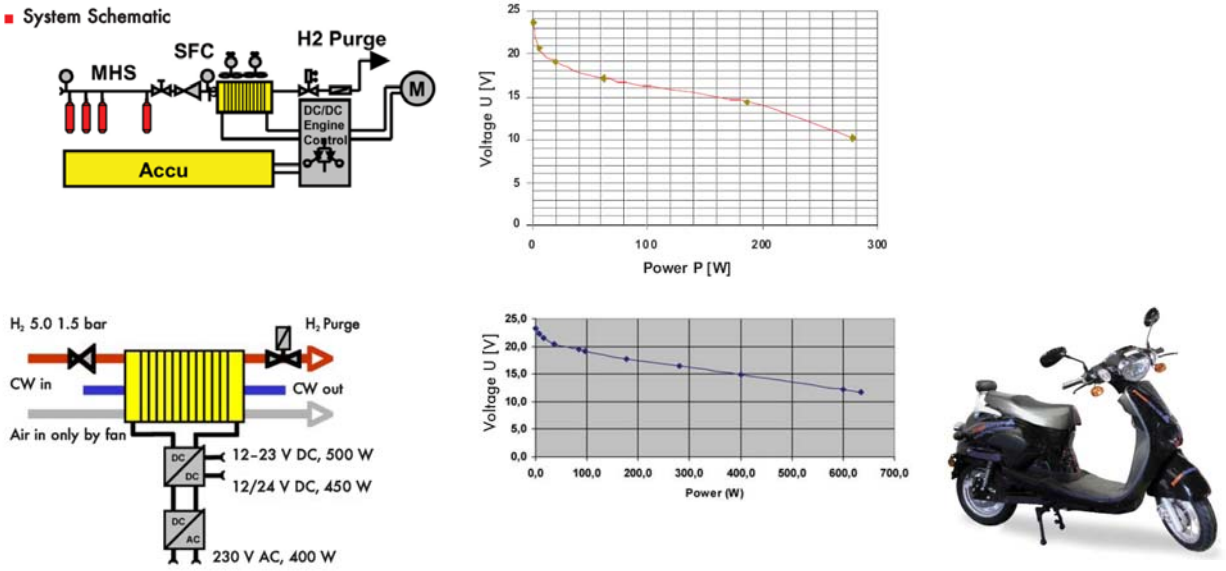


Figure 4: Power characteristics and system schematics of two systems developed for the personal transportation market

Fuel cells can be readily stacked to generate powers from few watts to a few hundred kilowatts. Power Avenue's special design make this process economically feasible as shown in Figure 5. Various portable and stationary applications of the Power Avenue fuel cells are depicted in Figure 6.

500 W TECHNICAL SPECIFICATIONS

Design:	FFC Foil-Fuel Cell
Air Supply:	Fan only
Cooling:	Water cooling
Nominal Power:	500 Watt
Nominal Voltage:	23-12 V DC without DC/DC
Active Area:	119 cm^2
Dimensions:	260 x 130 x 106 mm^3
Weight:	3 kg

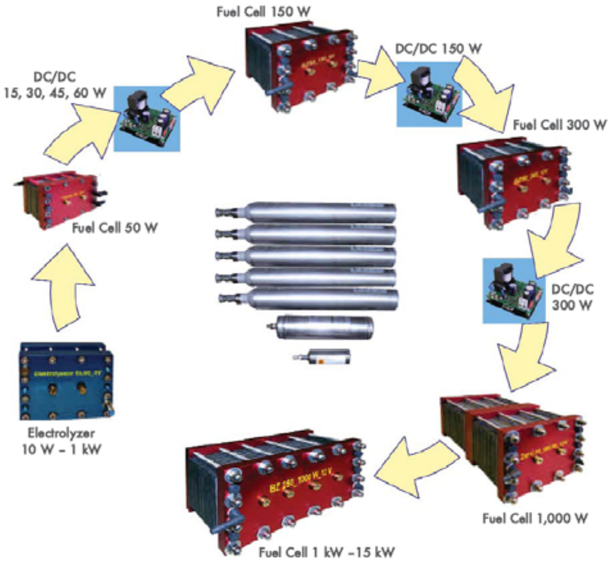


Figure 5: Array of possible fuel cell configurations of Power Avenue systems with specifications included for a 500 W unit.

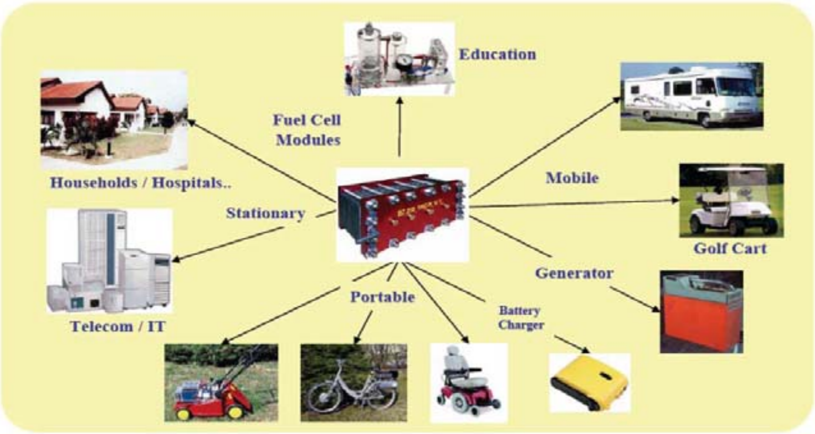


Figure 6: Portable and stationary applications of Power Avenue fuel cells.

3.2 Stationary Power Systems

Stationary power products range from 1 kilowatt to several megawatts. Applications include any place we expect electrical power today: homes, businesses, schools, hospitals, etc. These markets are typically served by central generation.

Due to the increased interest shown by electric utility companies in distributed fuel cell power systems, the EPRI released a detailed specification document for such a system in 1998 and estimates a market size of more than 134 million units over the next 10 years. In a July 1999 Scientific America article, it was estimated that the global market for such units would be $51 billion per year by the year 2030, Figure 7.

Based on our market research and that of EPRI, it will be feasible to develop stationary fuel cell power systems in the 1 to 25 kW range to service the small stationary power system market. The initial application will be for already identified niche markets such as UPS, followed by the emerging industrial, commercial, and home emergency markets.

3.3 Stationary Power Systems – Hydrogen Turbines

Another technique to serve the stationary market is the employment of hydrogen turbines. The only byproduct of burning hydrogen in oxygen is water that is free from CO2, NOx and SOx emissions. Using hydrogen as fuel, novel combustion technology for a 1,973K-class (1,700°C) turbine is expected to eventually achieve 71% gross thermal efficiency (LHV) with no emissions other than water. Toshiba is developing such technology under WE-NET (World Energy Network). The project's goal is to establish a feasible hydrogen-energy network that can eventually be applied on a worldwide scale.

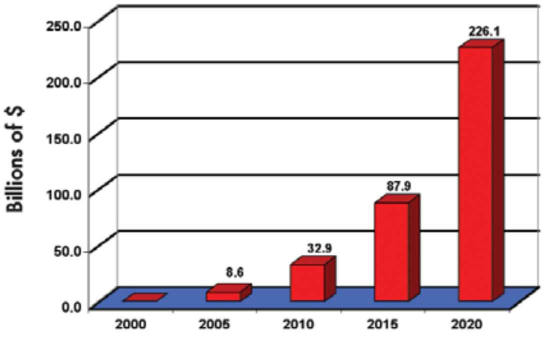


Figure 7: Projected stationary fuel cell power market

Hydrogen will be produced from various sustainable-energy sources such as water, solar, geothermal, and wind power in global areas abundant with such sources. Hydrogen will be used as a transportable source of sustainable energies to consuming areas or other nations. Obviously, it is essential to raise the thermal efficiency of such a hydrogen turbine system to minimize not only its total construction cost but also the cost of generating electricity.

It is expected that a hydrogen turbine's efficiency could reach 71% (LHV, gross) if its firing temperature can be raised to 1,973K (1,700°C). In addition to its higher efficiency, a hydrogen-fuel turbine would also provide superior environmental performance as its only byproduct is clean water. Hydrogen turbines can be manufactured in the power ranges of 1-100 MW for local and industrial usage and 250 MW to 1000 MW for power stations. A 1-MW local power generator will consume approximately 30 kg of hydrogen per hour. This amount of hydrogen can be extracted from 420 kg of sand. See Figure 8.

General Electric is currently advancing combustion technologies for hydrogen fuels to achieve the same type of emissions improvement that have been accomplished for natural gas-fueled turbines. The new Hydrogen turbines will achieves an efficiency increase of 3-5 percentage points over current coal-powered turbine technologies.

Siemens Westinghouse Power Corporation now designs an advanced hydrogen-powered turbine system that employs newly designed system components for improved performance. Newly designed components will include an enhanced cooling subsystem for controlling operating temperatures, increased front-end temperatures for more efficient fuel consumption, and advanced materials and coatings for component durability and reduced operating costs.

Toshiba is currently in the process of developing a hydrogen combustion turbine called "advanced Rankine cycle" because it is a high-temperature, double-reheat Rankine cycle. It uses two hydrogen-oxygen combustors for heating and reheating. They generate high-temperature steam by combusting hydrogen and oxygen, whereas the conventional Rankine cycle uses a superheater and a reheater as part of a boiler in which steam temperature must be kept under 600°C because of the boiler material's temperature limit. Use of a combustor instead of a boiler enables significantly higher steam temperatures, which boosts thermal efficiency. Toshiba expects that a hydrogen turbine's efficiency could reach 71% (LHV, gross) if its firing temperature can be raised to 1,973K (1,700°C). In addition to its higher efficiency, a hydrogen-fuel turbine would also provide superior environmental performance as its only byproduct is clean water.

Production of 1 MW of Electricity*		
Reactants	**Consumption rate kg/h**	**Consumption rate metric tons/yr**
Sand	900	8000
Silicon	400	3700
H2	60	535
Water	556 (liters/h)	5,000,000 liters per year

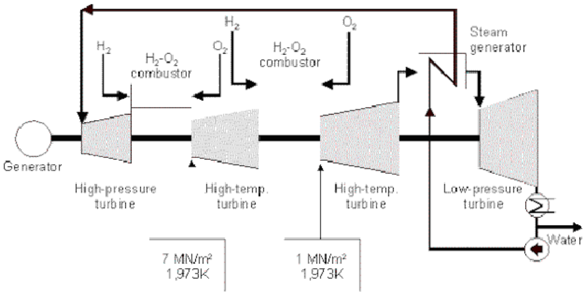


Figure 8: A typical hydrogen burning plant. The input hydrogen may be produced from sand/silicon. The amount of sand/silicon used per MW is shown in the table.

The success of developing hydrogen-fueled turbines requires developing new cooling technologies. Rather than choose between closed- or open-cycle cooling concepts, Toshiba proposes a hybrid cooling concept for cooling 1,973K-class (1,700°C) turbines. In an open-cycle system, after being used to cool internal blades the cooling medium is discharged into the turbine's hot gas path for film cooling, trailing-edge cooling, etc. A closed-cycle system does not discharge the turbine's cooling medium into its hot gas path, but instead recovers it for use in other parts of the system.

4. Conclusions

As carbon-based primary energy carriers become increasingly exhausted, it is obvious that the existing reserves should be better used for the production of valuable products as opposed to carbon dioxide. The concept outlined here describes a practical solution to secure the future supply of hydrogen via a "non-carbon" route for a range of applications. As shown in the figure below, the amount of CO2 that is prevented from being generated by burning hydrogen as opposed to fossil fuels is approximately 2.5 million tons per year for a 800 MW hydrogen hub power station. This size of power plant will serve approximately 2500 buses and 25,000 cars.

This concept of future energy supply based on hydrogen in effect represents the realization of the vision that fuel cells of various type will replace carbon-based power generation and that many of the technical challenges will be resolved in the near future.