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NASA's PEM Fuel Cell Power Plant Development Program for Space Applications

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Introduction

Proton-exchange-membrane (PEM) fuel cells were the primary electrical power source on both the Gemini and Apollo missions, and more recently, alkaline fuel cells have powered the Shuttle Orbiter. During the first twenty years of Shuttle operation, PEM fuel cell technology underwent only minor development for space applications, while development for commercial terrestrial applications was initiated and has grown exponentially. However, NASA recognized the advantages that PEM technology promises over existing alkaline fuel cell technology for space applications, and beginning in 2001, embarked on a five-year PEM fuel cell power plant development program. These advantages include enhanced safety, increased robustness, improved modularity, higher power levels, longer life, lower weight, improved reliability and maintainability, higher peak-to-nominal power capability, the ability to operate on lower purity propulsion-grade reactants, reduced ground and mission operations support, and lower recurring costs. NASA's five-year program has been conducted by a three-center NASA team of Glenn Research Center (GRC, lead), Johnson Space Center (JSC), and Kennedy Space Center (KSC). The program was initially aimed at developing PEM fuel cell hardware for a reusable launch vehicle (RLV) application, but more recently has shifted to applications supporting the NASA Exploration Program.

In contrast to the early days of PEM fuel cell technology development when NASA pioneered fuel cell development during the Gemini and Apollo eras, NASA is now able to leverage technology advances from the commercial sector in developing PEM fuel cell technology for space applications. The major differences between commercial terrestrial technology and space technology are that space fuel cells must be able to operate with pure oxygen as the oxidant (as opposed to air) and water removal must take place in a multi-gravity environment (from zero-gravity to several times that of Earth's gravity). These challenges have been the primary focus of NASA's development effort. The first phase of the effort, to develop breadboard hardware in the 1 to 5 kW power range, was conducted by two competing vendors under NASA contract. The second phase of the effort, to develop Engineering Model hardware at the 10 kW power level, was conducted by the winning vendor from the first phase of the effort. Both breadboard power plants and the single engineering model power plant were delivered to NASA for independent testing.

Breadboard Development Effort

Phase I of NASA's five-year program was the development of breadboard power plants by two competing vendors, ElectroChem, Inc. and Teledyne Energy Systems, Inc. This effort, which occurred during the first two years of the program, was concentrated on building power plants of sufficient size to demonstrate the capabilities of the two vendor's technologies. The goal was to deliver power plants at minimum cost in a short period of time, hence off-the-shelf hardware was utilized as much as possible. Table 1 shows a comparison of the design parameters for the two breadboard units.

TABLE 1.—BREADBOARD POWER PLANT COMPARISON

Vendor	ElectroChem	Teledyne
Nominal power, kW	1.0	5.0
Number of cells	45	82
Cell active area, cm^2	232	302
Nominal current density, mA/cm^2	110	270
Peak power capability, peak: nominal	6:1	>6:1
Reactant rcirculation approach	Passive (ejectors)	Active (pumps)

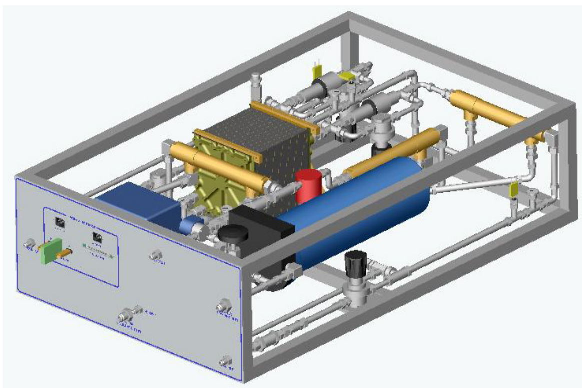

Figure 1.—ElectroChem breadboard schematic.

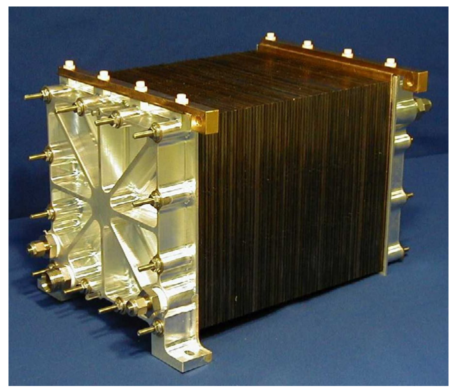

Figure 2.—ElectroChem fuel cell stack.

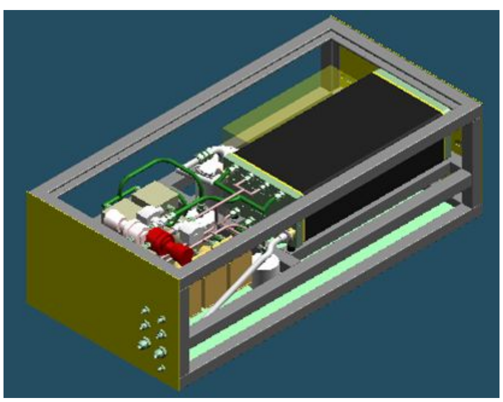

Figure 3.—Teledyne breadboard schematic.

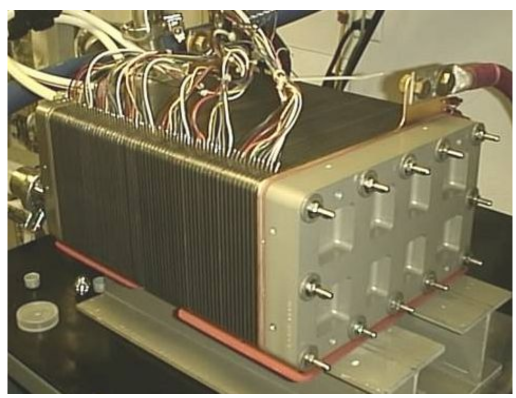

Figure 4.—Teledyne fuel cell stack.

Figures 1 to 4 show schematic representations of the breadboard power plant units as well as photos of the individual fuel cell stacks within each breadboard unit.

After design and fabrication, the breadboard power plant unit from each vendor was delivered to NASA for independent testing. Following several months of extensive performance testing under several load profiles, Teledyne was selected to participate in the engineering model portion of the program.

Engineering Model Development Effort

Phase II of NASA's five-year program was the development of a single engineering model power plant by Teledyne Energy Systems, Inc. The goal of this effort, which took place during the final three years of the program, was to further advance PEM fuel cell technology at the system level. The fidelity of the engineering model power plant was to more closely resemble space flight hardware than the off-the-shelf commercial hardware utilized in the breadboard power plants. Table 2 summarizes the key engineering model system requirements.

The engineering model power plant as delivered to NASA fully met all of the above program goals, except for a 25 percent excess in power plant weight. Schedule and cost constraints prevented further reductions in balance-of-plant weight surrounding the fuel cell stack, which was the major contributor to the excess. Just as with the breadboard units, at the conclusion of design and fabrication the engineering model unit underwent independent testing by NASA. However, the engineering model testing was more extensive than that of the breadboards. The test regime included routine tests such as polarization curves, a variety of performance tests under multiple load profiles, specialty tests such as rapid start-up and loss-of-coolant tests, and environmental tests such as thermal vacuum and vibration tests. A photograph of the engineering model in NASA GRC's fuel cell test facility is shown in figure 5.

TABLE 2.—ENGINEERING MODEL POWER PLANT KEY REQUIREMENTS

Requirement	Goal
Nominal power, kW	7 to 10
Voltage regulation, V	30±10 percent
Voltage response time, s	<0.2
Operating life, hr	10,000
Operating temperature, °C	60 to 80
Operating pressure, kPa	<690
Power plant weight, kg	<140
Power plant volume, m^3	<0.2

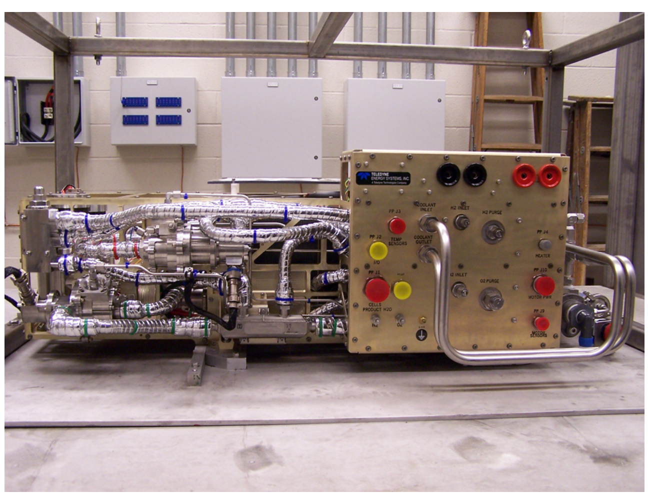

Figure 5.—Teledyne engineering model fuel cell power plant.

Summary

Recognizing the advantages that PEM fuel cell technology promises over existing alkaline fuel cell technology used on the Shuttle Orbiter, NASA is completing a five-year PEM fuel cell power plant development program for future space applications. This effort has been conducted by a three-center NASA team led by Glenn Research Center in Cleveland, Ohio. By leveraging significant advances in commercial PEM fuel cell technology, NASA has successfully adapted terrestrial technology for space applications by addressing the key mission requirements of using pure oxygen as an oxidant and operating in a multi-gravity environment.

Competing vendors developed breadboard units in the 1 to 5 kW power range during the first phase of the program, and a single vendor developed a nominal 10 kW engineering model power pant during the second phase of the program. This engineering model unit underwent a series of performance and environmental tests conducted by NASA to assess its applicability for future space missions. Although not yet of flight hardware fidelity, the PEM fuel cell engineering model power plant was very similar in terms of form, fit, and function to the alkaline fuel cell power plant used on the Shuttle Orbiter. With continued advances in fuel cell stack and balance-of-plant ancillary hardware, PEM fuel cell technology will be ready to meet the electrical power needs of future space missions.

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14. ABSTRACT
A three-center NASA team led by the Glenn Research Center in Cleveland, Ohio is completing a five-year PEM fuel cell power plant development program for future space applications. The focus of the program has been to adapt commercial PEM fuel cell technology for space applications by addressing the key mission requirements of using pure oxygen as an oxidant and operating in a multi-gravity environment. Competing vendors developed breadboard units in the 1 to 5 kW power range during the first phase of the program, and a single vendor developed a nominal 10-kW engineering model power pant during the second phase of the program. Successful performance and environmental tests conducted by NASA established confidence that PEM fuel cell technology will be ready to meet the electrical power needs of future space missions.

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