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NASA's Planned Fuel Cell Development Activities for 2009 and Beyond in Support of the Exploration Vision

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Background

NASA's Energy Storage Project is one of many technology development efforts being implemented as part of the Exploration Technology Development Program (ETDP), under the auspices of the Exploration Systems Mission Directorate (ESMD). The Energy Storage Project is a focused technology development effort to advance lithium-ion battery and proton-exchange-membrane fuel cell (PEMFC) technologies to meet the specific power and energy storage needs of NASA Exploration missions. The fuel cell portion of the project has as its focus the development of both primary fuel cell power systems and regenerative fuel cell (RFC) energy storage systems, and is led by the NASA Glenn Research Center (GRC) in partnership with the Johnson Space Center (JSC), the Jet Propulsion Laboratory (JPL), the Kennedy Space Center (KSC), academia, and industrial partners. The development goals are to improve stack electrical performance, reduce system mass and parasitic power requirements, and increase system life and reliability.

Introduction

Fuel cells were used to generate power during the Gemini and Apollo programs, and are presently in use on the Shuttle (Ref. 1). Conventional alkaline fuel cell (AFC) technology used on the Shuttle is the only existing space-qualified fuel cell technology, but has a number of drawbacks. These include extensive operations requirements, limited life, high costs, and increasing obsolescence. PEMFC technology promises many advantages over existing AFC technology, including enhanced safety, increased robustness, higher peak power levels, longer life, lower weight, improved reliability and maintainability, reduced ground and missions operations support requirements, ability to share common reactants/tankage with hydrogen-oxygen propulsion systems, and lower costs. These advantages are the reason NASA is pursuing development of PEMFC technology for future Exploration missions.

NASA's development approach leverages the extensive commercial development of PEMFC technology, while also addressing the unique NASA requirements for space fuel cell applications. These more stringent space requirements include operation with pure oxygen (instead of air), and water management in reduced and zero-gravity environments. Over the past several years, NASA's initial PEMFC development efforts were focused on advancement of stack technology (Ref. 2). NASA's current development approach is still aimed at optimizing stack technology, but now has the additional focus of advancing the balance-of-plant technology for PEMFC systems, specifically the electrical components that monitor and control the system and the mechanical components that perform reactant and thermal management functions.

Development Areas

The NASA fuel cell development effort is focused on both primary fuel cell power systems and RFC energy storage systems. A RFC system is a combination of a primary fuel cell system and an electrolysis system, along with associated integration hardware (Ref. 3). The fuel cell and RFC work are categorized into three major areas: non-flow-through primary PEMFC development, high-pressure electrolysis development, and advanced membrane-electrode-assembly (MEA) development. A description of the work planned for 2009 and beyond in each of these three areas is presented below.

Non-Flow-Through Primary PEMFC Development

Compared to more traditional flow-through PEMFC technology in which ancillary components are required for reactant feed and product water separation, non-flow-through technology minimizes the ancillary system components required, resulting in a system with lower mass and volume, increased reliability, and longer life. In non-flow-through PEMFC technology, reactants are fed into the stack through diffusion; the product water that is generated at the electrode surface wicks across the adjacent gas cavity, through a hydrophilic membrane and into a water cavity (internal to each cell of the stack), as shown in Figure 1.

ETDP work to date in the area of non-flow-through PEMFC technology has been focused on both stack and balance-of-plant development. Stack development is taking place under small business innovative research (SBIR) contracts with several vendors, including Infinity Fuel Cells and Hydrogen, ElectroChem, Giner Electrochemical Systems, and Proton Energy Systems. Infinity is conducting a Phase III SBIR contract based on success during the Phase II program. Presently, their technology is considered the baseline non-flow-through stack technology. The stack technologies being developed by the other vendors under Phase II SBIR contracts are all considered to be alternative non-flow-through stack technologies because of their lower level of maturity. Balance-of-plant development is being

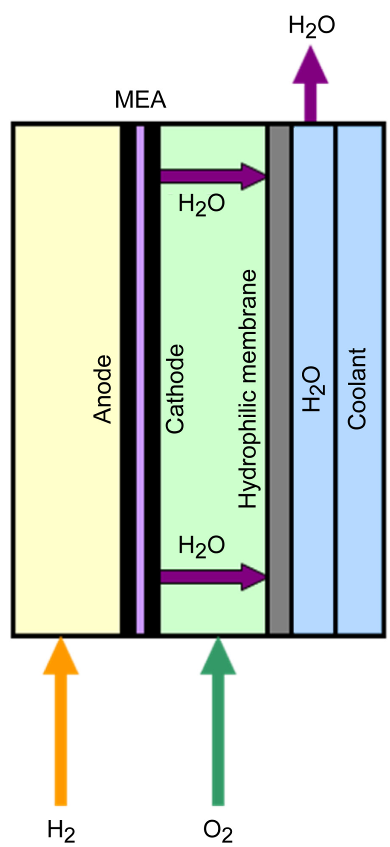

Figure 1.—Non-Flow-Through PEMFC Schematic.

conducted in-house at NASA GRC. The focus of this work is the development of ancillary components required to perform the fluid and thermal management of the stacks as well as all electrical monitoring and control. Significant reductions in weight, volume, and parasitic power of these components are the goal. This balance-of-plant development is generic, in concept, to all non-flow-through stack technologies under development, however required modifications specific to each vendor's technology are being factored in where necessary.

NASA's plans for 2009 call for further advancing the baseline and alternative stack technologies at the various vendors, as well as advancing the balance-of-plant technology being conducted in-house. The baseline stack technology will proceed with development of small-area short stacks (50 cm^2, 4-12 cells) integrated with a balance-of-plant for system testing at the TRL-4 level, followed by initial efforts to scale up both the stack cell area and number of cells (150 cm^2, ~40 cells) at the TRL-5 level. This scale-up will result in hardware sizes more applicable to those required for actual flight hardware. Balance-of-plant development at the TRL-5 level will also begin in late 2009. This advancement in the fidelity of component hardware will also result in hardware sizes more applicable for flight hardware. The TRL-5 effort for both the stack and balance-of-plant will continue through 2010 and conclude in 2011. Should the baseline stack technology falter, one of the alternative stack technologies will serve as a substitute.

Fuel cell technology is baselined for the Altair Lunar Lander descent module. In order to meet schedules which call for the Altair Preliminary Design Review (PDR) in late 2013, NASA will need to initiate the TRL-6 fuel cell development effort in 2011. At that time, NASA will enter a three-year development program for a fully autonomous 2 to 3 kW non-flow-through PEMFC engineering model system, culminating in the demonstration of TRL 6 by the end of 2013 through a series of performance and environmental tests.

High-Pressure Electrolysis Development

Development of high-pressure electrolysis technology will continue in 2009 through existing SBIR contracts and an Innovative Patnership Program (IPP). Electrolyzers are a key component of a RFC energy storage system. In this system, fuel cells consume reactant hydrogen and oxygen gases to produce electrical power, with liquid water as a by-product. An electrolyzer reverses this reaction, consuming electrical power to break down liquid water into gaseous hydrogen and oxygen. All work on RFC electrolysis development is being performed cognizant of the various requirements for different Exploration Mission electrolyzers, including those for extravehicular activity (EVA), in-situ resource utilization (ISRU), and environmental control and life-support (ECLS).

Initial work has been directed at balanced high-pressure electrolysis development, in which product hydrogen and oxygen are both delivered at minimum pressures of at least 2,000 psi. These high pressures result in smaller and less massive reactant storage tanks. Candidate options include both liquid and vapor water-feed electrolysis, on either the hydrogen or oxygen sides of the cell. Operational considerations of every option are also being taken into account, as electrolysis development shares the same goal as fuel cell development in terms of minimizing the number of ancillary system components required. This reduction in electrolysis ancillary components will have the same benefits as with non-flow-through primary fuel cell systems—lower mass and volume, increased reliability, and longer life.

NASA plans to continue SBIR and IPP development through 2011 at the TRL-4 level, and then initiate a two-year TRL-5 breadboard electrolysis development effort beginning in 2012. A fully integrated RFC development effort at the TRL-6 level would then be initiated in 2014. This effort would likely be completed in 2 to 3 years, depending on funding availability.

Advanced MEA Development

MEAs are a key electrochemical component within all PEMFC and electrolysis stacks. The physical characteristics of the MEA, its chemical composition and catalyst formulations, all play a role in determining its electrical performance and durability. The better the electrical performance of any given

MEA, the less reactants required to produce that electrical performance, and the lower the mass and volume requirements for the reactants and their respective storage tanks. ETDP work to date has been conducted by NASA JPL and is directed at making steady improvements in MEA electrical performance. Present electrical performance is less than 2 percent lower than that of AFC technology, the performance standard for space fuel cells, and is better than the electrical performance of any existing PEMFC vendor's MEA.

NASA's plans for 2009 and beyond call for a continuation of MEA development at NASA JPL. It is anticipated that the steady performance increases seen to date will continue, and the best available MEAs at the time will be inserted into fuel cell and electrolysis stacks, as appropriate, for evaluation. This process has been successful to date through 2008. Following continued performance increases which are expected to match and then exceed AFC electrical performance, the best MEA technology available at the time will be integrated into the fuel cell, electrolysis, and RFC development path from TRL 4 through TRL 6. Existing performance goals for eventual flight hardware are 0.92 V/cell for the fuel cell and 1.44 V/cell for the electrolyzer at 200 mA/cm^2.

Summary

The ETDP fuel cell development effort has as its focus the development of both primary fuel cell power systems and RFC energy storage systems. The development goals are to improve fuel cell and electrolyzer stack electrical performance, reduce system mass and parasitic power requirements, and increase system life and reliability. In order to achieve these goals, NASA has segmented the required work into three major development areas: non-flow-through primary PEMFC development, high-pressure electrolysis development, and advanced MEA development. In all cases, funding availability will dictate the degree of technology advancement in any given timeframe.

In primary PEMFC technology, NASA plans to continue advancing both stack and balance-of-plant technologies and to demonstrate these advancements through integrated systems testing. TRL-5 development and testing will conclude in 2011, with a three-year TRL-6 engineering model development effort concluding in 2013 to match the Altair PDR. In high-pressure electrolysis technology, NASA plans to develop a common, balanced high-pressure electrolyzer, if appropriate, for EVA, ISRU, ECLS, and RFC Exploration Mission applications. Common technology advancement will continue through 2011 at the TRL-4 level, followed by a two-year TRL-5 breadboard development effort concluding in 2013. In 2014, NASA will initiate a three-year engineering model RFC development effort, culminating in the achievement of TRL 6 by the end of 2016.

In MEA technology, NASA anticipates making continued steady improvement until electrical performance matches and then exceeds the performance standard for space fuel cells achieved by AFC technology. NASA also plans to insert the best MEA technology available at the time into all breadboard and engineering model fuel cell and electrolysis stacks as the effort proceeds. A technology progression in the three major technology areas is shown in Table 1.

Through prior technology development efforts as of 2008, NASA has identified that optimizing stack and balance-of-plant technologies are the most critical needs for both primary fuel cells and RFC energy storage systems. By leveraging past commercial developments and addressing the unique requirements for operation in space, NASA has formulated a sound approach as it moves forward in 2009 and beyond to improve stack electrical performance, reduce system mass and parasitic power requirements, and increase system life and reliability. If sufficient funding is available, NASA should be successful in meeting Exploration Mission requirements and achieving TRL 6 by the end of 2013 for primary PEMFC systems, and TRL 6 by the end of 2016 for RFC energy storage systems.

TABLE 1.—FUEL CELL AND REGENERATIVE FUEL CELL TECHNOLOGY PROGRESSION

Development area	2009	2010	2011	2012	2013	2014	2015	2016
Non-Flow-Through								
Primary PEMFC								
Achieve TRL 4 (small-area short stacks + balance-of-plant)	✓							
Achieve TRL 5 (large-area stack + balance-of-plant)			✓					
Achieve TRL 6					✓			
High-pressure electrolysis								
Achieve TRL 4			✓					
Achieve TRL 5					✓			
RFC								
Achieve TRL 6								✓
Advanced MEAs								
Fuel cell insertion	✓		✓		✓			
Electrolysis insertion			✓		✓			
RFC insertion								✓

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
NASA's Energy Storage Project is one of many technology development efforts being implemented as part of the Exploration Technology Development Program (ETDP), under the auspices of the Exploration Systems Mission Directorate (ESMD). The Energy Storage Project is a focused technology development effort to advance lithium-ion battery and proton-exchange-membrane fuel cell (PEMFC) technologies to meet the specific power and energy storage needs of NASA Exploration missions. The fuel cell portion of the project has as its focus the development of both primary fuel cell power systems and regenerative fuel cell (RFC) energy storage systems, and is led by the NASA Glenn Research Center (GRC) in partnership with the Johnson Space Center (JSC), the Jet Propulsion Laboratory (JPL), the Kennedy Space Center (KSC), academia, and industrial partners. The development goals are to improve stack electrical performance, reduce system mass and parasitic power requirements, and increase system life and reliability.

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