



# Non-Flow-Through Fuel Cell System Test Results and Demonstration on the SCARAB Rover

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## Abstract

This paper describes the results of the demonstration of a non-flow-through PEM fuel cell as part of a power system on the SCARAB rover. A 16-cell non-flow-through fuel cell stack from Infinity Fuel Cell and Hydrogen, Inc. was incorporated into a power system designed to act as a range extender by providing power to the rover's hotel loads. This work represents the first attempt at a ground demonstration of this new technology aboard a mobile test platform. Development and demonstration were supported by the Office of the Chief Technologist's Space Power Systems Project and the Advanced Exploration System Modular Power Systems Project.

## Introduction

Over the past several years, NASA has been developing non-flow-through proton-exchange-membrane (PEM) fuel cell power systems for aerospace applications (Ref. 1). Due to the unique requirements of NASA missions, including operation with pure oxygen and improved water management in reduced and zero-gravity space environments, NASA has focused on modifying commercial fuel cell technology for NASA applications. Recent focus has been on the development of non-flow-through (NFT) fuel cell systems. As compared to a traditional flow-through system in which reactants are re-circulated to remove product water from the stack, a non-flow-through system is simplified by eliminating reactant recirculation. Reactants are dead-ended in the stack and product water is removed passively. This eliminates the need for pumps and other mechanical components typically needed to re-circulate reactants and remove water, and therefore results in a system with lower mass and volume and improved reliability.

As part of NASA's Advanced Exploration Systems Modular Power Systems Project (AMPS), NFT fuel cell technology is being integrated onto ground system demonstration vehicles. This paper describes the testing performed on a 16-cell, 132 Watt (W) NFT fuel cell stack from Infinity Fuel Cell and Hydrogen, Inc., and its demonstration as part of a fuel cell power system on Carnegie Mellon University's SCARAB rover. The fuel cell power system was meant to be a "range

extender" by providing power to the rover's hotel loads, with the SCARAB providing a mobile platform for the first demonstration of a non-flow-through fuel cell system on a moving test vehicle. Demonstration of the NFT fuel cell power system on the SCARAB rover will help to identify integration issues requiring further development to facilitate advancing the technology readiness level.

## Technology Development Background

NASA Glenn Research Center's fuel cell development over recent years has focused on non-flow-through (NFT) PEM fuel cell technology. As opposed to traditional flow-through systems, NFT systems are simplified by eliminating pumps and mechanical components typically needed for reactant recirculation and product water removal. The result is a system with lower mass, volume and parasitic power, and increased reliability. For these reasons, non-flow-through technology was down-selected over flow-through technology in 2008 (Ref. 2).

Development of NFT stack technology began under the Small Business Innovation Research (SBIR) Program and is currently funded by the Office of the Chief Technologist's Space Power Systems (OCT SPS) Project. Infinity's NFT technology eliminates the reactant recirculation of flow-through systems by dead-ending reactants in the fuel cell stack. Reactant feeds are driven solely by tank pressures, therefore eliminating the need for pumps, and product water removal is achieved through internal cell wicking mechanisms, eliminating the need for external water separation.

## Experimental

### Demonstration Vehicle

The test vehicle used in this demonstration of the NFT fuel cell technology was the SCARAB rover. The SCARAB rover was built by Carnegie Mellon University's (CMU) Robotic Institute to serve as a platform for experiments and field demonstrations, including previous experiments at the NASA Glenn Research Center (GRC). The rover has the ability to travel in both forward and backward directions while level or



Figure 1.—CMU SCARAB Rover.

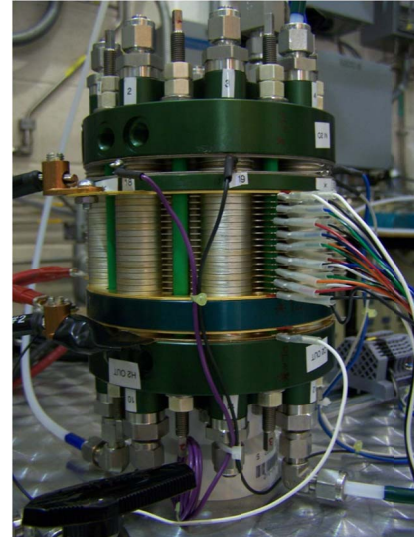


Figure 2.—Infinity 16-cell NFT FC stack.

TABLE 1.—SCARAB ROVER POWER REQUIREMENTS

Operating mode	Load, W	Total load including hotel loads, W
Hotel loads only	175	175
Stationary (elevation hold)	6	181
Driving, level	85	255
Driving, turn	200	375
Elevating body	225	400
Peak transient	590	765

on a sloped surface, turn, and elevate its body. Figure 1 depicts the SCARAB vehicle.

In the case of this demonstration, the SCARAB rover provided a mobile platform to test the ability of the NFT fuel cell power system to provide power to the rover under specific conditions, providing the first opportunity to demonstration NFT technology on a moving vehicle. The SCARAB had specific power requirements based on the different modes of operation. Table 1 lists the power requirements for each mode.

The SCARAB rover has an on-board battery bank to provide power during operation. The goal of this demonstration was to provide power to the hotel loads in order to conserve the rover’s batteries, therefore acting as a range extender to the rover.

## Fuel Cell Power System

The fuel cell power system as demonstrated and discussed in this paper was made up of several components. The main components of the power system included the NFT fuel cell stack, battery bank, reactant supply, electronics and power

control and distribution (PCAD) elements. As a system, the goal was to provide power to the rover’s hotel loads. Due to the size of the NFT FC stack, the fuel cell power system was limited in terms of the power level it could supply to the rover, and could not fully meet the power requirements in all modes of locomotion.

The fuel cell used in this demonstration was a 16-cell, 132 W NFT PEM fuel cell stack from Infinity. This stack has a 50 cm<sup>2</sup> active area with a nominal stack power of 132 W and nominal stack voltage of 12 Vdc. The stack is capable of providing a peak power of 237 W. Reactants are dead-ended and water is removed by internal wicking mechanisms in this non-flow-through system, therefore simplifying the balance-of-plant for the on-board demonstration.

The 16-cell stack, as shown in Figure 2, was developed by Infinity Fuel Cell and Hydrogen, Inc. The stack was tested at Infinity before being received at GRC for additional characterization in July 2011. Prior to demonstration on the SCARAB rover, all testing of the 16-cell NFT fuel cell stack was performed with a stationary test bed.

Since the fuel cell stack was not sufficiently sized to power both the balance-of-plant and the rover’s hotel loads, the fuel cell power system contained its own battery bank for load balancing. The battery bank consisted of eight, 95 Ah lithium-ion batteries from OceanServer. The battery bank was used to provide start-up power for the fuel cell system.

The electronics drawer was a modified version of the drawer from the 2010 Desert Research and Technology Studies (DRATS) NFT fuel cell system demonstration stand. A National Instruments CompactRIO embedded controller with LabVIEW programming from the DRATS drawer was used.

The entire fuel cell power system was mounted onto an aluminum frame which could be attached to the SCARAB rover. The system was secured to the frame and tested under this configuration prior to relocating the system onto the SCARAB vehicle.

## Demonstration Setup

The setup of the fuel cell power system on the rover and an overhead view of the system are shown in Figures 3 and 4, respectively.

As shown, the fuel cell power system was mounted on an aluminum plate frame and attached to the SCARAB rover using existing mounting points. The frame was designed to support the fuel cell power system including reactant storage with a system mass less than 200 kg while still allowing for access to system components once mounted to the rover. The fuel cell stack and its fluidics, thermal management, and reactant storage components were mounted on the top of the aluminum plate, and the electronics drawer containing the battery bank and PCAD was mounted below the plate.

## Demonstration and Results

The demonstration of the non-flow-through fuel cell power system on the SCARAB rover took place in the Simulated Lunar Operations (SLOPE) laboratory at GRC. The rover was operated on a flat surface of simulated lunar regolith.

Initially, the rover drew its power from its on-board battery bank. Then, the fuel cell power system was brought online and brought up to optimum operating temperature. Due to uncertainties involved with system dynamics, the transition from SCARAB battery power to the NFT FC power system was accomplished manually by engaging/disengaging the fuel cell power system.

Two tests were performed to demonstrate the fuel cell power system on the rover. First, a power integration test was performed to verify the hardware and ensure that bus voltages were similar. After the initial system checkout, the mobile demonstration was performed. During this test, power was switched from the rover's battery bank to the fuel cell power system. The fuel cell power system then successfully provided power to the rover's hotel loads during stationary operation. The system provided 39 Watt-hours (Wh) of energy to the SCARAB rover over a 26 min runtime, with a maximum system power output of 299 W. The fuel cell stack itself delivered 186 Wh to the balance-of-plant over a 139 min runtime, with a maximum power output of 127 W. Figure 5 displays the power profiles for one of the mobile demonstration test runs. During this period, the fuel cell power system delivered a maximum of 280 W to the rover.

A third test was performed to characterize the effect of slowly increasing the rover's speed while powered by the fuel cell power system. For this mobile characterization, the fuel cell stack was powered down since it was undersized to provide power to the rover during locomotion; the power system's internal battery bank provided power to the rover during this test. During this short duration test, the rover traversed across level ground while slowly increasing speed. It was during this mobile characterization that the fuel cell power system delivered its maximum power output of 299 W.

The power system successfully demonstrated its goal as a range extender by powering hotel loads on the SCARAB rover, making this demonstration the first to use the non-flow-through fuel cell technology on a mobile platform.

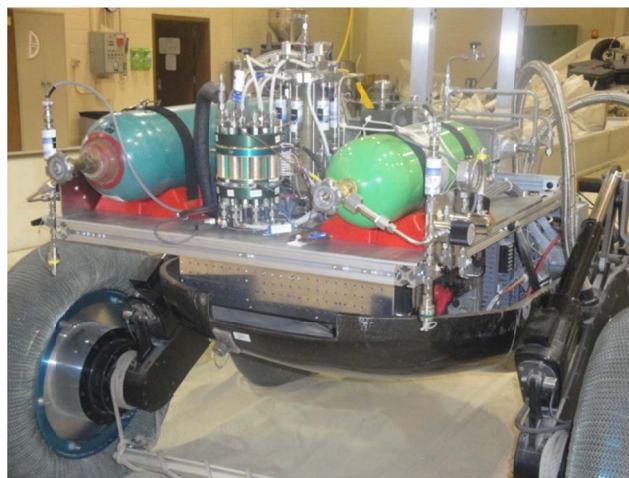


Figure 3.—CMU SCARAB Rover with NFT PEMFC Power System.



Figure 4.—Overhead view of NFT stack and reactant storage.

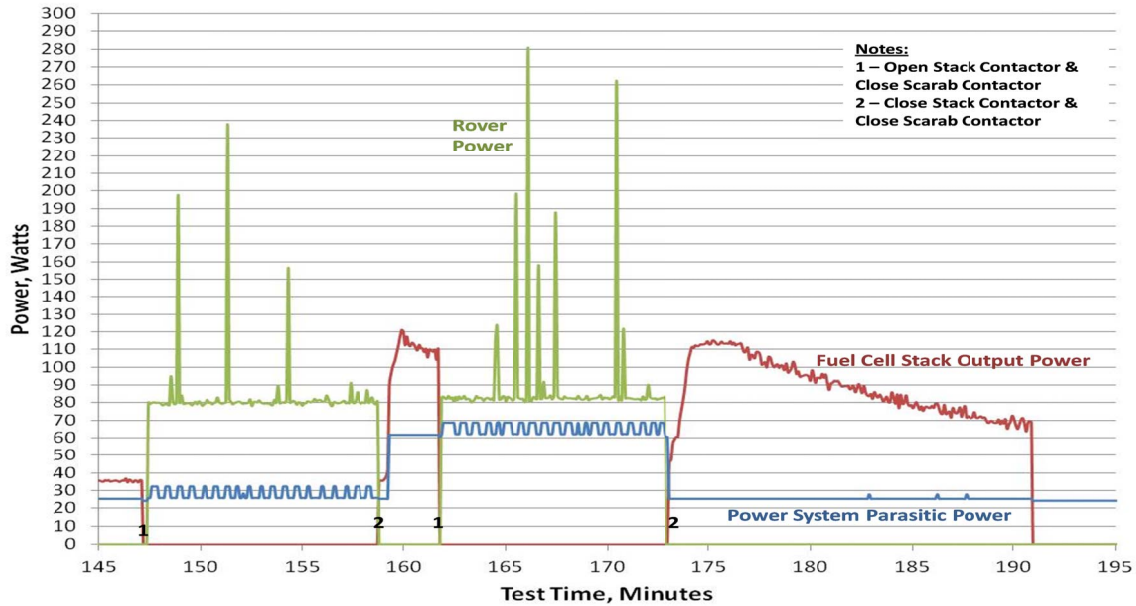


Figure 5.—SCARAB demonstration power profiles.

## Conclusions and Future Development Activities

The demonstration of the non-flow-through fuel cell power system on the SCARAB rover in the SLOPE laboratory at the NASA Glenn Research Center (GRC) was the first demonstration of NFT PEMFC technology for a mobile application. The successful integration of NFT fuel cell technology onto a ground demonstration vehicle will help to advance the Technology Readiness Level (TRL) of the technology as well as provide lessons learned for future mobile demonstrations.

This demonstration will lead to further development and demonstration to improve upon the NFT fuel cell power system. Development of a new, miniaturized electronics system is currently underway. The new electronics would significantly reduce the mass and volume of the power system.

Future demonstrations with the NFT technology also plan to incorporate advanced, custom interface plates that contain balance-of-plant fluidics developed at GRC. These interface plates would eliminate external plumbing to the fuel cell stack while also reducing system mass and volume.

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