V.H.1 CIRRUS: Cell Ice Regulation & Removal Upon Start-up

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Subcontractors:
- W.L. Gore & Associates, Elkton, MD
- SGL Carbon, Meitingen, Germany
- University of Delaware, Newark, DE

Project Start Date: July 1, 2007
Project End Date: June 30, 2010

Objectives

The objective of the CIRRUS project is to advance the state of the art in fuel cell operability under subfreezing conditions, consistent with requirements for applications involving such conditions (e.g. automotive, forklifts, backup power systems, and auxiliary power units) and DOE targets, specifically to:

- Demonstrate repeatably, ability to achieve 50% rated power in less than 30 seconds from a -20°C start condition, using less than 5 MJ auxiliary energy.
- Demonstrate unassisted start capability from an initial temperature of -40°C.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(D) Water Transport within the Stack
(G) Start-up and Shut-down Time and Energy/Transient Operation

Technical Targets

Nuvera is seeking to demonstrate the ability to achieve DOE's 2010 targets in a full format, subscale stack assembly operating in a simulated but fully realistic ambient environment, using system-compatible operating protocols.

In the first half of the project Nuvera has been striving to achieve the difficult target of a quick start (50% of rated power in 30 seconds or less) from a -20°C start condition, respecting the budget of 5 MJ of energy for the complete start-up and shutdown cycle. The hardware platform used in this work is Nuvera's Andromeda™ fuel cell – this particular fuel cell design was realized first in 2005 and has been substantially validated over the past four years. Andromeda™ has an active area of 360 cm^2 and a rating current density of 1.0 A/cm^2.

Over the last year Nuvera succeeded in demonstrating the capability of the current technology to meet, and exceed, the target in realistic conditions, as illustrated in Figure 1, and as will be described below.

Thermal analyses and operating experience indicate that the thermal mass of Andromeda™ will likely prevent the technology from meeting the -40°C startability target. In order to accomplish the extreme low temperature start goal, Nuvera has conceived, designed, and prototyped a new stack technology named Orion™. The Orion™ platform has a rating current density of 2 A/cm^2, and

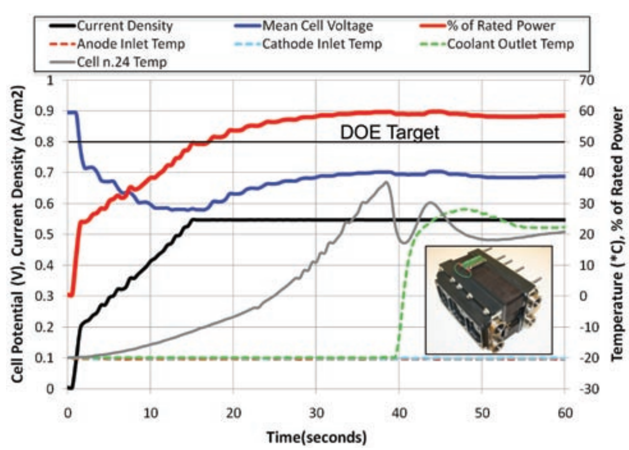

FIGURE 1. Freeze Start of Andromeda™ Stack from -20°C Meeting DOE Target

will exploit higher current density operation to achieve increased power density and reduced thermal mass, with the objective of enabling operation from -40°C.

Accomplishments

- Installed and commissioned a climatic chamber that maintains stack ambient environment and reactant gases to -20°C during testing, to ensure test conditions simulate real-world operating conditions.
- Reduced stack freezing time from 8 hours to 60 minutes to enable significantly increased testing throughput
- Optimized shutdown protocol to achieve a 75% reduction in shutdown time (in preparation for freeze start), from 8 minutes to 2 minutes.
- Achieved 50% of rated stack power in 18 seconds from a -20°C starting temperature, using 3.3 MJ of energy (34% less than target).
- Fabricated and conducted preliminary testing of the proof-of-concept Orion™ stack.

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Introduction

For fuel cells to be commercially viable as powerplants in automotive applications, the ability to survive and start reliably in cold climates (as low as -40°C) is a must. Since fuel cells are water-based energy systems, this requirement is a significant technical challenge.

Water transport studies are imperative for achieving DOE targets for fuel cell startup time from subfreezing conditions. Stack components must be selected that endure thermal and humidity cycling over the operating range, and operating strategies must be devised that enable the fuel cell to start, i.e. generate power and heat up sufficiently before ice extinguishes the galvanic reactions, and afford evacuation of a sufficient amount of water, using a limited amount of auxiliary power, at shutdown.

Approach

Nuvera has structured the project into four different phases: investigation, selection, qualification and validation. In the investigation phase (Q3 and Q4 2007, completed) Nuvera surveyed the state-of-the-art on the topic and developed the “enabling tools” to execute the project (test infrastructure and modeling capabilities). In the following selection phase (2008, completed) Nuvera used such tools to select a proper freeze start strategy to meet the DOE requirements and a set of material to enable the successful execution of the test. Nuvera is currently in the qualification phase (2009) in which the performance stability of the material set and operating methods is being assessed in a durability test campaign. The results of this campaign, supported by the interaction with the partners of the project (W.L Gore, SGL and University of Delaware) will identify improvements to be pursued through one or more iterations of materials, strategy and stack architecture. The effectiveness of these actions will be verified in the validation phase (Q1 and Q2 2010) in which the most advanced configuration will be tested and the improvements will be quantified.

Results

Since the last reporting period, Nuvera has worked to increase the level of realism in its testing procedure and dramatically decrease the energy budget consumed to achieve the startup.

Facilitated by a new climatic chamber, freeze start testing is performed with the stack frozen in a controlled environment at -20°C. Moreover the reactant gases pass through dedicated heat exchangers that cool them down before they reach the stack. The previous setup controlled only the temperature of stack (-20°C), and the test was performed at room temperature.

Nuvera recognized in the early phases of the project the importance of applying an effective purging procedure prior to shut down in a cold condition to minimize the amount of water that could potentially freeze. Formerly the anode and cathode compartments were purged with constant flows of, respectively, hydrogen and air. On a real system a constant flow of H_2 on anode side can only be achieved with a recirculation pump that adds cost to the system and the increases the energy used to perform the procedure on account of its inefficiency. In light of this, the purging strategy has been changed and currently is based on a high pressure (4 bar absolute max), instantaneous purge of H_2 that can be achieved through a proper set of valves. This new approach enabled a significant reduction of the energy consumed for this purpose (from 3.9 MJ to 0.45 MJ, as reported in Table 1).

The startup procedure has also been optimized, adopting a steeper ramp of current. This approach accelerates heat production, preventing the water produced in the reaction from freezing and blocking the active sites.

The combination of these two improvements has enabled a successful startup from -20°C exceeding the 2010 targets both in terms of time to 50% power (18 seconds vs. 30 seconds) and energy consumption (3.3 MJ vs 5.0 MJ).

The process of optimizing the startup strategy has itself represented an endurance test: Figure 2 shows the cell voltage over 100 successive freeze starts performed

TABLE 1. Contributions to Energy Consumption Calculation

Energy consumed during Shutdown…	
Air compressor parasitic (LHV of H_2 consumed to power compressor during purging phase)	0.564 MJ
H2 wasted in purges (LHV of H_2 vented or burned)	0.450 MJ
Energy consumed during Startup…	
H2 used during startup (LHV of H_2 consumed to produce electric power in first 30 sec)	2.292 MJ
TOTAL	**3.306 MJ***

**It was 5.6 MJ in Fiscal Year 2008, 26 MJ in FY 2007, H_2 at startup was not considered.*

LHV - lower heating value

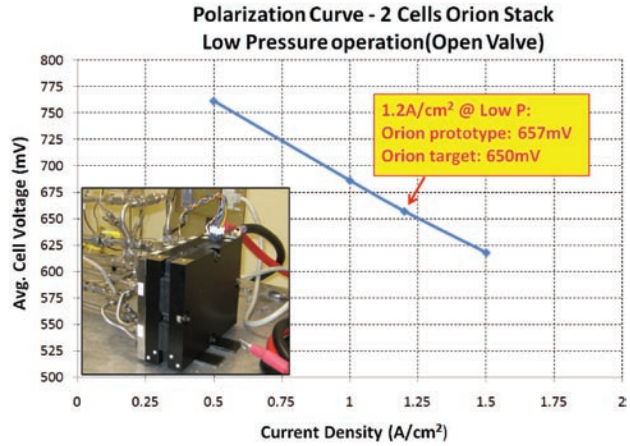

FIGURE 3. Polarization Curve of Orion™ Stack (2 cells) in Low Pressure Conditions (open valve)

to tune the strategy. These results confirm that the stack can survive in the short run. More diligence is needed to assess and understand decay modes associated with the start/stop strategy, and accordingly drive the development of more suitable materials. In this endeavor, Nuvera engaged the proton exchange membrane fuel cell community in an intensive workshop (February 20, 2009) dedicated to the freeze topic in which 38 participants from 22 different organizations came together to examine existing data and understand the main causes of degradation and the open issues that remain to be addressed.

Nuvera has actively advanced the design of the new Orion stack architecture that will enable a significant reduction of the thermal mass and corresponding startability at temperatures below -20°C. Nuvera has successfully assembled the first prototypes (example shown in Figure 3), that are meant to offer a proof of concept of the proposed architecture without requiring sophisticated and costly production tools. Early tests performed in standard operating conditions (T>0°C, open valve operation on air compartment) have shown performances in line with the design point (see Figure 3), and offer an exciting preview of the results yet to come.

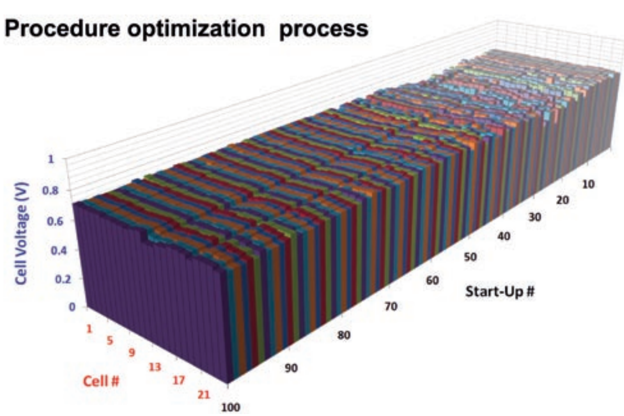

FIGURE 2. Cell Voltage Profile over 100 Freeze Starts Performed to Optimize Startup Procedure

Conclusions and Future Directions

Nuvera recognizes the need to reduce stack thermal mass as a key strategy to accomplish the DOE target of startability from -40°C. Nuvera will continue developing Orion™, improving the quality of the prototypes and fine tuning the design features, to enable operation at temperatures below 0°C. Nuvera is confident of being able to perform a successful startup from extreme temperatures on the Orion™ technology in the validation phase.

In parallel, Nuvera is working on understanding the stability of the current freeze start method through a durability campaign based on two separate tests: (1) subjecting a non-operational stack to thermal cycling to evaluate the pure effect of temperature oscillation, and (2) repeated freeze start/shutdown cycle testing of a separate stack to capture the full phenomena. Subsequent to testing, the materials used will be subjected to diagnostic analysis in collaboration with partners to measure the extent of the degradation, and assess the causative factors. Such investigation will lead to a new generation of materials with an extended life.

FY 2009 Publications/Presentations

1. July 2008 - Detroit, MI - FreedomCar Review.
2. December 2008 - Las Vegas, NV - FC Performance and Durability Conference.
3. February 2009 - Billerica, MA - Presentation at PEMFC Workshop organized by Nuvera.
4. May 2009 - Crystal City, VA - 2009 DOE Hydrogen Program Merit Review (FC38).

5. Kusoglu, A., Tang, Y., Santare, M.H., Karlsson, A.M., Cleghorn, S., Johnson, W.B., *"Stress-Strain Behavior of Perfluorosulfonic Acid (PFSA) Membranes at Various Temperatures and Humidities: Experiments and Phenomenological Modeling,"* Journal of Fuel Cell Science and Technology, v. 6, #1, p. 011012, 2009.

6. Kusoglu, A., Santare, M.H., Karlsson, A.M., Cleghorn, S., Johnson, W.B., *"Micro-Mechanics Model Based on the Nanostructure of PFSA Membranes,"* Journal of Polymer Science: Part B: Polymer Physics, v. 46, #22, p. 2404-17, 2008.

7. Kusoglu, A., Karlsson, A.M., Santare, M.H., Cleghorn, S., Johnson, W.B., *"Investigation of Stress and Water Distribution in Membrane Electrode Assembly (MEA) During Fuel Cell Operation,"* Electrochemical Society Transactions, 16 (2) p. 551-61, 2008.