V.K.3 CIRRUS: Cell Ice Regulation and 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 this project is to advance the state-of-the-art in fuel cell operability under subfreezing conditions, consistent with automotive requirements and DOE targets, specifically to:

- Demonstrate repeatable achievement of 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

Prior to the start of this project, there was evidence that several developers had achieved rapid start from subfreezing conditions, namely 50% power output in less than one minute. However, the scale of these tests (cell vs. stack, active area), power rating points of the devices, and the practicality of the approaches (requirements imposed on the powerplant, and respect of the energy budget) were not firmly established. In the current project, Nuvera is seeking to demonstrate achievement of DOE's 2010 targets in a full format, subscale automotive stack assembly using system-compatible operating protocols.

In the initial phase of the project, Nuvera is using its proven Andromeda™ automotive stack hardware -- which was designed to address 2005 DOE targets, has an active area of 360 cm^2, runs on unhumidified inlet air, and has a design rating current density (RCD) of 1.0 A/cm^2 – as the "Reference Technology." In the past year, reductions of over 75% in auxiliary energy use associated with subfreezing start-up have been realized, approaching DOE's targets for 2010 and beyond, as reported in Table 1.

In the latter phase of the project, Nuvera will employ an improved stack with an RCD of 1.7-2.0 A/cm^2, and an areal power density of 1.0-1.2 W/cm^2 as the "2010 Technology." This stack will have a thermal mass of 30-40% less than the Reference Technology, thereby affording reductions in start-up time, and lowering the temperature from which self-start is feasible.

Accomplishments

- Installed and commissioned subfreezing stack test infrastructure.
- Developed a predictive model capturing fuel cell start-up dynamics.
- Achieved 50% power in 30 seconds from <-20°C start temperature.

TABLE 1. CIRRUS Project Progress in FY 2008 with respect to DOE Targets

Technical Targets: 80-kWe (net) Transportation Fuel Cell Stacks Operating on Direct Hydrogen					
Characteristic	Units	Status 2005 (DOE)	Status CIRRUS FY08	DOE Targets 2010	DOE Targets 2015
Cold start-up time to 50% of rated power	secs	20	**30**	30	30
Startup and shutdown energy (from -20°C ambient)	MJ	7.5	**5.6**	5.0	5.0
Unassisted start from low temperature	C	-20	**-25**	-40	-40

- Demonstrated self-startability from -25°C initial temperature.
- Established feasibility of 2.0 A/cm^2 RCD for 2010 stack technology.

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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 represents a significant technical challenge.

Water transport studies are imperative for achieving DOE targets for fuel cell start-up 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 (1) enable the fuel cell to start, i.e. generate power and heat-up sufficiently before ice extinguishes the galvanic reactions, and (2) afford evacuation of a sufficient amount of water, using a limited amount of auxiliary power, at shut-down.

Approach

To accomplish the objectives of the project, Nuvera is working on two parallel paths, one from a systems perspective and the other from the standpoint of enabling materials. The initial emphasis is on realization of stack embodiments and operating protocols that achieve DOE's 2010 goals. This effort consists of engineering analyses (thermal mass, heat generation), stack modeling (to predict local temperatures and potentials inside the stack), controls development (to posit system-compatible control parameter schedules to (1) enable start-up, and (2) facilitate water removal at shut-down), extensive laboratory testing (to validate and tune control methods), and post-test materials characterization (to identify and understand durability issues).

Materials development, selection, and detailed characterization, the scope of Nuvera's partners, are proceeding in parallel. The gas diffusion layer has an important influence on water transport, and SGL is studying the impact of design parameters such as porosity and thickness. W.L. Gore is supplying commercial membrane electrode assembly (MEA) materials, and conducting extensive a posteriori analyses to understand the effects of subfreezing start/stop on aging. The University of Delaware is conducting parametric studies (temperature and relative humidity) of mechanical stresses inside MEA membranes, and creating a model which will afford prediction of aging and/or failure modes associated with the start/stop protocols developed.

Results

Analysis of the Reference Technology (shown in Figure 1) thermal mass profile revealed that the DOE start time goal could be achieved at -20°C with or without coolant inside, and this was experimentally verified. From a start temperature of -25°C, start-up is predicted to be feasible only when coolant is evacuated from the stack, also consistent with Nuvera experience.

As evidence of the delicate balance that must be struck during start-up under such conditions, in the first ten attempts to start from subfreezing temperatures, six failed, i.e. ice formation caused shutdown of the cell. To date over 40 start-ups have been run, and all of the latest ten were successful, a testament to the progress achieved in the project. The plot of the run in which 50% power was achieved in 30 seconds, meeting the DOE 2010 start-up time goal, is shown in Figure 2.

The current project is seeking to reduce the minimum temperature from which self-start can be achieved. To accomplish this, the specific power of the stack test article must be increased, and the thermal mass reduced, and this is the ambition of developing and commissioning the 2010 stack technology.

Scoping experiments were conducted to establish the feasibility of rating a next generation stack at high current density. Using the Andromeda design and modified parts (in line with 2010 design concepts, largely addressing flow resistance issues at high flowrates), favorable results were obtained at low pressure using an 8-cell stack. These results, shown in Figure 3, confirm stable operation, with no evidence

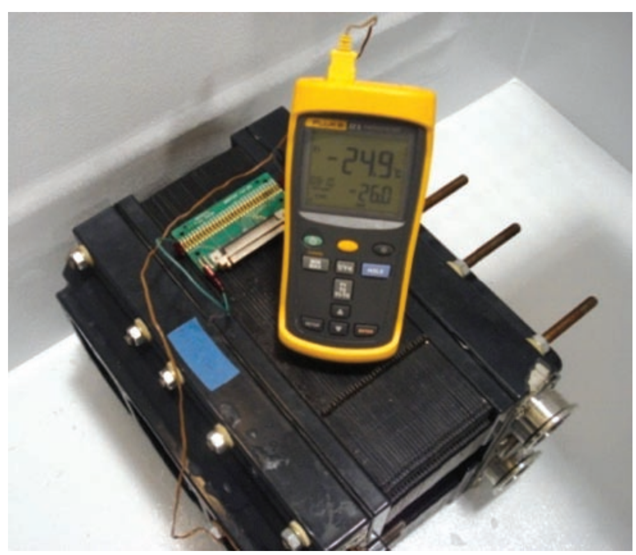

FIGURE 1. Reference Technology Stack (32 cells, -25°C)

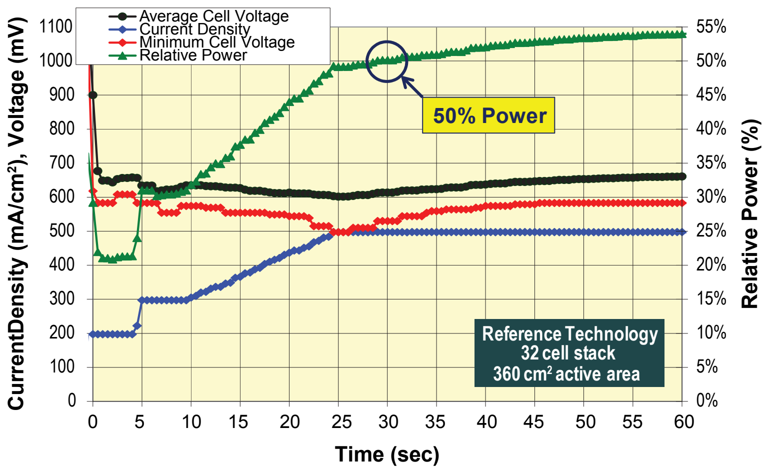

FIGURE 2. Achievement of 50% Power in 30 Seconds (DOE 2010 Target)

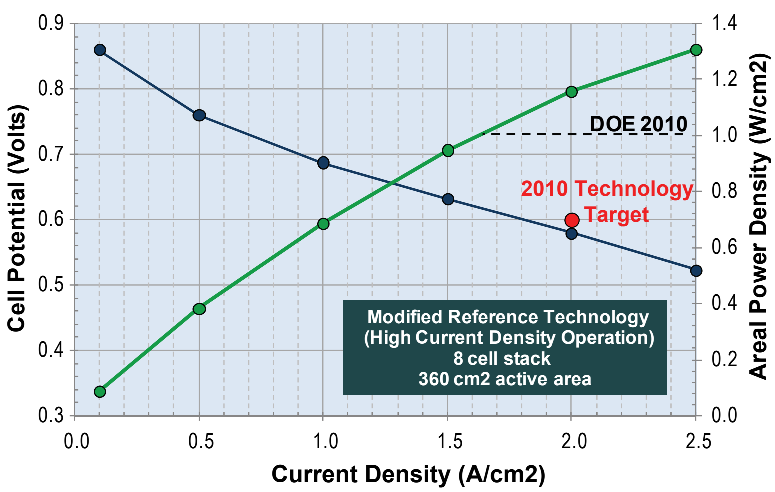

FIGURE 3. Polarization Curve for Modified Reference Technology Stack

of mass transport limitations, at current densities up to 2.5 A/cm^2.

Conclusions and Future Directions

Further refinements in start-up trajectory and optimization of auxiliary energy use, facilitated by both modeling and experimentation, as well as material improvements, are envisioned. These will enable the Reference Technology to meet DOE's 2010 targets for start-up time, while respecting the energy budget (an additional 10% improvement is needed).

The Reference Technology will not be able to self-start from -40°C (-25°C is close to the practical limit for the current generation). Nuvera is presently developing the 2010 Technology stack design, with plans for prototype evaluation in early 2009. Preliminary estimates suggest this stack will be able to self-start from in the range -40°C to -35°C. This estimate will be refined as the design evolves in the coming months.

FY 2008 Publications/ Presentations

1. The University of Delaware has submitted three papers to technical journals, and all of these are expected to be published within the next twelve months.