Extended durability testing of an external fuel processor for SOFC

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Project ID: FC072

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DOE Hydrogen Program

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Overview

Timeline

- Project start: 08/01/2008
- Project end: 12/31/2011
- Percent complete: 58%

Budget

- Project funding total $1,968,000
  - DOE share = $984,000
  - RRFCS = $984,000
- Funding received in FY08 = $984K
- Funding in FY09 to FY11 = $0K

Barriers

Fuel Processor

- Durability
- Performance
- Start-up and Shutdown time
- Transient operation

Partners

- RRFCS – project lead
- Ohio Department of Development
  - Funding for Outdoor Test Facility
- Stark State College
  - Student Interns

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Relevance
Stationary power generation with fuel cells

Rolls-Royce Fuel Cell Systems (US) Inc. (RRFCS) believes its 1 MWe Solid-Oxide Fuel Cell (SOFC) power plant concept is best suited for stationary power generation applications. With its high electrical efficiency (~60%), negligible air emissions, and minimal noise profile, the concept is highly suitable for connection to local distribution networks in urban areas. The applications of interest include hospitals, universities, shopping malls, factory units, etc.

The 1 MWe SOFC power plant will be configured initially to use pipeline natural gas. Future development may target alternative fuels such as biogas.

RRFCS' SOFC power plant concept through its high efficiency, negligible air emissions and potential fuel flexibility directly supports the DOE Hydrogen Program's mission statement "to reduce petroleum use, greenhouse gas emissions, and air pollution and to contribute to a more diverse and efficient energy infrastructure by enabling the widespread commercialization of hydrogen and fuel cell technologies."

RRFCS' SOFC power plant concept for stationary power supports the DOE Hydrogen Program's goal to advance fuel cell technologies "…through research, development, and validation efforts – to be competitive with current technologies in cost and performance, and to reduce the institutional and market barriers to their commercialization."

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Technical barriers

This project addresses technical barriers A - durability, C - performance, and G - start-up and shut-down time and energy / transient operation from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program (HFCIT) Multi-Year Research, Development and Demonstration (RD&D) Plan.

These barriers will be addressed as they relate to the external fuel processor in RRFCS' 1 MWe SOFC power plant concept.

Technical Targets

This project addresses milestone # 59 in the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program (HFCIT) Multi-Year Research, Development and Demonstration (RD&D) Plan. Milestone # 59 is to "evaluate fuel processing subsystem performance for distributed generation against system targets for 2011." The targets listed below will be addressed as they relate to the External Fuel Processor Subsystem for a 1 MWe SOFC.

Characteristic	Units	2005 Status	DOE 2011 Targets	RRFCS 2011 Targets
Cold start-up time to full load @ -20°C ambient	minutes	< 90	< 30	60
Transient response (10 to 90% load) Load rate of change	Minutes (% per min)	< 5 (16)	1 (80)	2 (40)
Durability	hours	20,000	40,000	8,000
Survivability (min and max ambient temperature)	°C °C	-25 +40	-35 +40	-40 +40
Sulfur content in product stream	ppbv (dry)	< 10	< 4	< 100

External fuel processor for SOFC

The external fuel processor for the RRFCS 1-MWe SOFC power plant concept uses only air and pipeline natural gas to provide all required gas streams for:

- **Start-up & shutdown – nonflammable reducing gas**
- **System heat-up and part-load operation – synthesis gas**
- **Normal operation - desulfurized natural gas**

The external fuel processor eliminates the need for on-site storage of high-pressure gas cylinders to supply hydrogen and nitrogen.

Overall Objectives

- **Conduct long-term tests in relevant environments for the three fuel processor subsystems that support operation of the 1-MWe SOFC power plant. The subsystems include:**
  - **Synthesis-gas subsystem**
  - **Start-gas subsystem**
  - **Desulfurizer subsystem**
- **Determine long-term performance of key components such as catalysts, sorbents, heat exchangers, control valves, reactors, piping, and insulation**
- **Evaluate the impact of ambient temperatures (hot and cold environment) on performance and component reliability**
- **Determine system response for transient operation**

Objectives

The project objectives from May 2010 through May 2011 included:

- Install Desulfurizer and Start-gas subsystems in outdoor test facility
- Complete shakedown and commissioning of Desulfurizer and Start-gas subsystems
- Operate Desulfurizer subsystem around-the-clock in an unattended mode for 4,000 hours by May 2011 (8,000 hours by end of project December 2011)
- Evaluate alternative materials of construction for vessels used in the Desulfurizer subsystem
- Operate start-gas subsystem with multiple start-ups
- Perform post-test inspections and analyses

Approach

Operate the three fuel processor subsystems on pipeline natural gas for extended periods

Conduct subsystem tests in relevant environments

1. Synthesis-gas subsystem - up to 1,200 hours in warm environment
2. Start-gas subsystem - up to 200 hours in outdoor environment (hot / cold)
3. Desulfurizer subsystem - for 8,000 hours in outdoor environment (hot / cold)

Perform post- test inspections and analyses

- Physical and chemical analyses of catalysts, sorbents, piping, reactors, and insulation
- Functional checks of control valves, heaters, heat exchangers, control system sensors and safety system sensors
- Identify deposits and signs of wear, damage, corrosion or erosion

Synthesis-gas subsystem test plan

- Synthesis gas (H_2 and CO) is generated from pipeline natural gas and compressed air using a catalytic, partial oxidation reactor with automatic control system

- Operate Synthesis-gas subsystem for up to 1,200 hours
  - Determine synthesis gas composition as a function of load (10%, 50% and 100% of design flow)
  - Determine impact of operating time on gas composition (hydrogen, carbon monoxide and methane)
  - Target performance - less than 10% reduction in H_2 over catalyst life
- Perform 10 start-up cycles
  - Determine impact of operating time on start-up and light-off

Start-gas subsystem test plan

- Start gas (non-flammable reducing gas) is generated from pipeline natural gas and an oxygen-depleted air stream
- Start-gas subsystem uses:
  - Low-oxygen content oxidant stream generator
  - Catalytic reactor to generate hydrogen and carbon monoxide
  - Air-cooled heat exchanger to cool product gas
  - Automatic control system for unattended operation
- Operate Start-gas subsystem for up to 200 hours
  - Determine gas composition at full-load conditions
  - Determine impact of operating time on gas composition (hydrogen, carbon monoxide, and methane)
  - Target performance - less than 20% variability in flammables content
- Perform 24 start-up cycles
  - Determine impact of operating time on start-up and light-off

Desulfurizer subsystem test plan

- SOFC requires high pressure (10 Bara) desulfurized natural gas with < 100 ppb total sulfur
- Desulfurizer subsystem uses:
  - Pipeline natural gas (1 to 10 ppmv sulfur) and compressed air as reactants
  - Catalytic reactor for oxy-desulfurization with high-capacity sulfur sorbent
  - Automatic control system for unattended operation
- Operate for up to 8,000 hours
  - Determine sulfur content in product gas as a function of load
  - Determine impact of operating time on product gas composition
  - Target performance
    - Less than 100 ppb sulfur in outlet gas - desulfurized natural gas
    - Desulfurized natural gas retains > 98% of its original calorific value
    - Total hydrocarbons (mostly methane) $\geq$ 90% in desulfurized natural gas

Milestones - status

No.	Description	Planned	Actual	Status
1	Start Preparation of Synthesis-gas Subsystem	January 2009	January 2009	completed
2	Begin Synthesis-gas Subsystem Durability Testing	April 2009	September 2009	completed
3	Start Preparation of Desulfurizer Subsystem	July 2009	December 2009	completed
4	Complete Synthesis-gas Subsystem Durability Test	September 2009	April 2010	completed
5	Complete 1,000 hours Operation of Desulfurizer	September 2010	November 2010	completed
6	Start Preparation of Start-gas Subsystem	July 2009	December 2009	completed
7	Begin Start-gas Subsystem Durability Testing	September 2010	April 2011	**on going**
8	Complete Desulfurizer Subsystem Test	October 2011		**on schedule**
9	Complete Start-gas Subsystem Test	October 2011		**on schedule**
10	Complete Final Report	December 2011		**on schedule**

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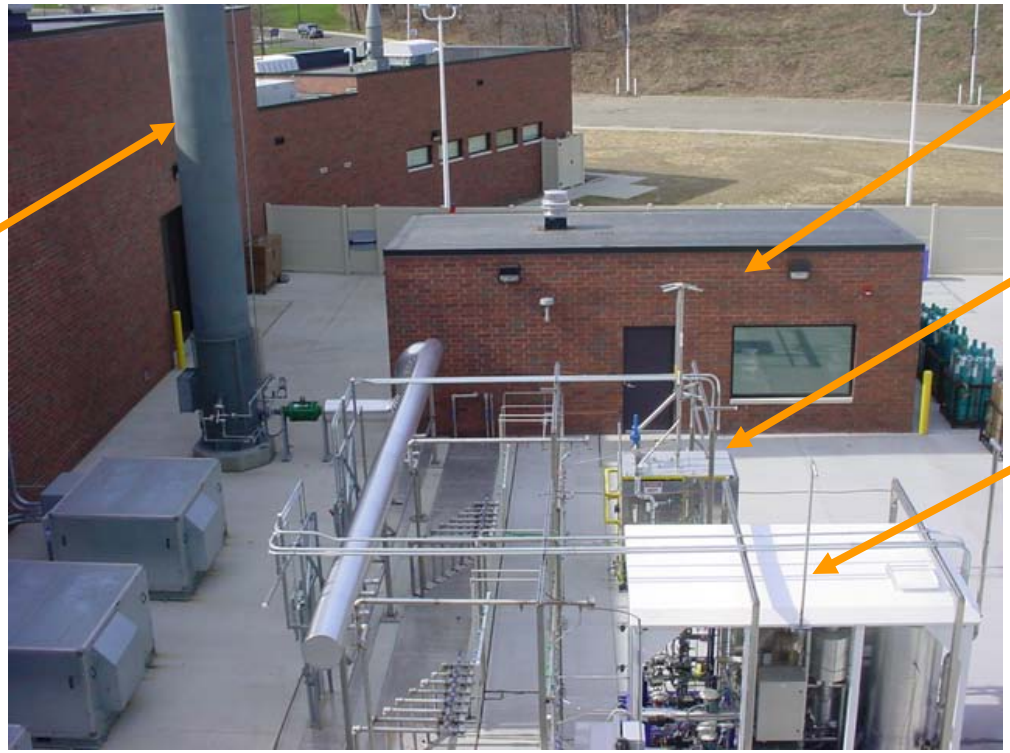
Technical accomplishments and progress

- **Synthesis-gas subsystem testing completed April 2010**
  - Results presented at DOE 2010 Annual Merit and Peer review Meeting
- **Start-gas subsystem installed in outdoor test facility**
  - Control software commissioned
  - Mechanical hardware commissioned
  - Durability testing on target for April start
- **Desulfurizer subsystem installed in outdoor test facility**
  - Control software commissioned
  - Mechanical hardware commissioned
  - Durability testing underway (3,600hrs out of 8,000hrs competed 4/15/2011)

Technical accomplishments and progress

Installation of Desulfurizer and Start-gas subsystems in outdoor test facility



Technical accomplishments and progress

Start-gas subsystem installed in outdoor test facility

- Control system commissioned
- Safety system commissioned
- Instrumentation calibrated
- Control valves tuned
- Gas sensors calibrated
- Start-up procedure confirmed
- Ready for durability testing

Technical accomplishments and progress

Desulfurizer subsystem installed in outdoor test facility

- Control system commissioned
- Safety system commissioned
- Instrumentation calibrated
- Control valves tuned
- Gas sensors calibrated
- Final hardware checks completed
- Durability testing started 10/2010
- 3,600hrs time-on-stream logged
  (as of the mid-April 2011)

Desulfurizer subsystem durability testing underway

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Desulfurizer subsystem durability testing underway

Sorbent Vessel

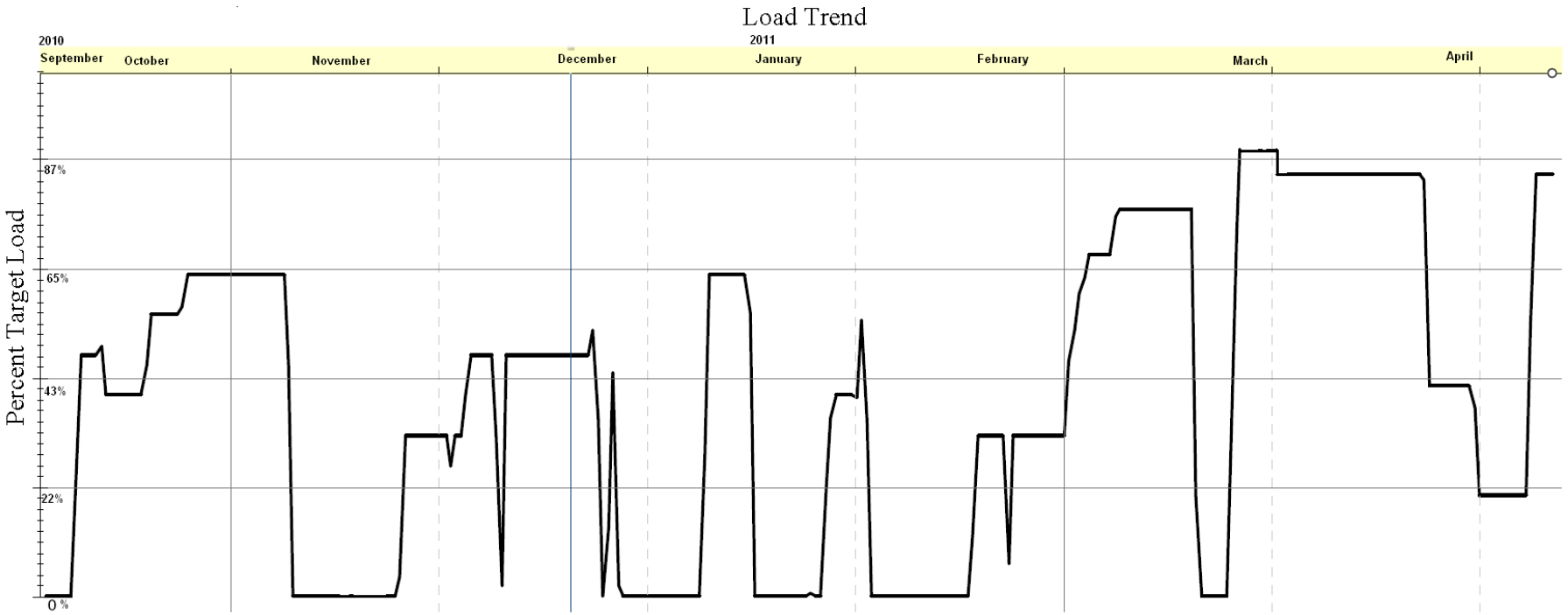
Control Valves

Control Cabinet

Snow ~ 1 ft

Ambient Temp = -10F (-23C)

Desulfurizer subsystem durability testing results



Durability testing started in September 2010

- Completed 3,600hrs time-on-stream (as of mid-April 2011)
- On schedule to meet target 8,000hrs by end of project

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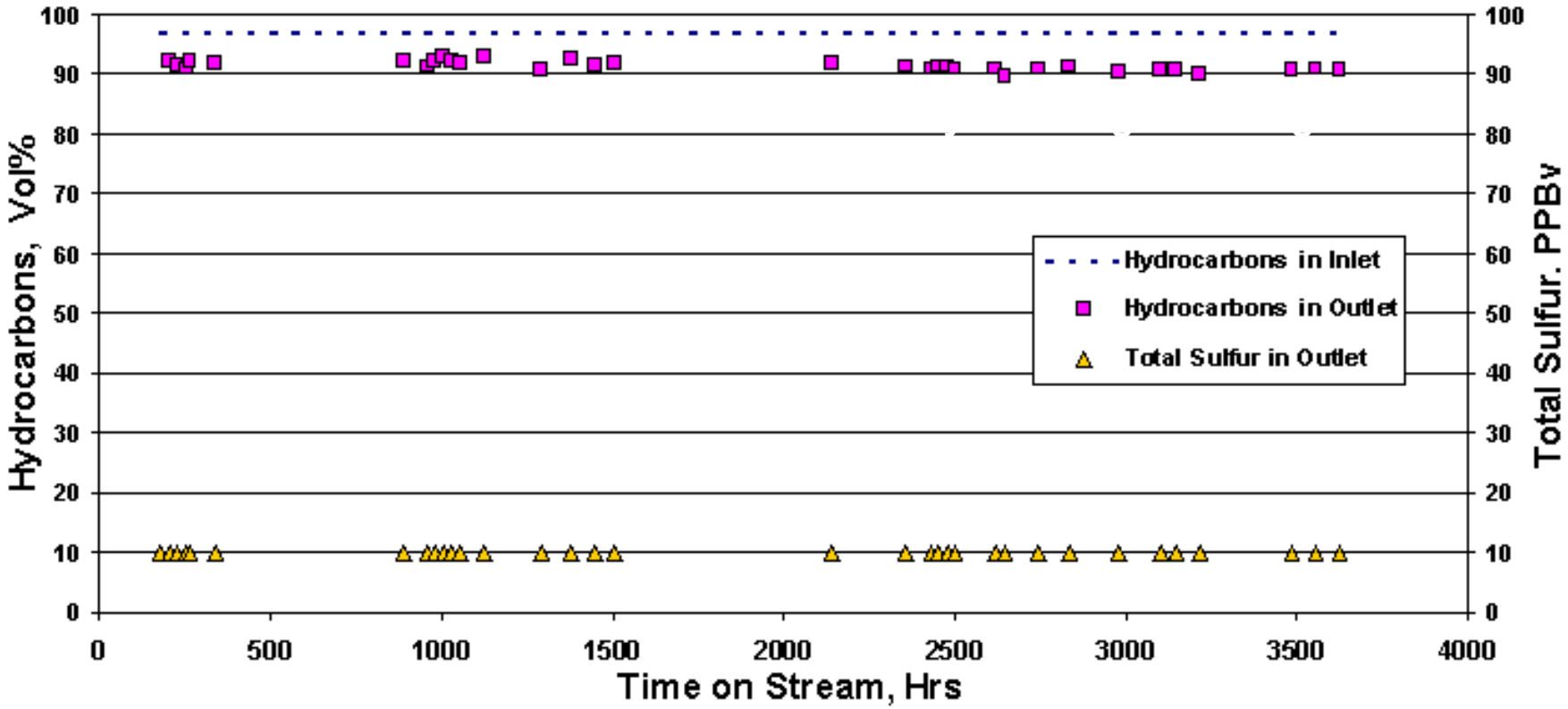
Desulfurizer subsystem durability testing results



Desulfurized natural gas composition

- Total hydrocarbons > 90% (volume basis)
- Total sulfur < 10 parts per billion (lower detection limit)

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Collaborations

- **RRFCS is the project lead. Significant collaboration between RRFCS and the Ohio Department of Development (ODOD) was required to enable this project to go forward.**
- **The Ohio Department of Development provided funding ($3 million) through Ohio's Third Frontier to expand the Fuel Cell Prototyping Center located on the campus of Stark State College. The expansion included:**
  - **Outdoor and indoor test facilities for use by RRFCS**
  - **Stark State College Fuel Cell Center (laboratory space for fuel cell education)**
- **Stark State College has associate degree programs in electrical engineering technology and mechanical engineering technology (with fuel cell option). RRFCS has eight current students or graduates of these programs as either interns or permanent employees to support this project and other fuel cell projects.**

Proposed future work

2011

- Perform post-test analyses of Synthesis-gas subsystem (CY11 Q2)
- Begin durability testing of Start-gas subsystems (CY11Q2)
- Complete durability testing of Start-gas and Desulfurizer subsystems (CY11 Q3)
- Perform post-test inspections and analyses of Start-gas and Desulfurizer subsystems (FY11 Q3 & Q4)
- Issue final report for project (FY11 Q4)

Summary

- An approach was developed for testing durability and performance of an external fuel processor for a SOFC
- The Desulfurizer subsystem commissioning has been completed and durability test is underway
- Start-gas subsystem has been installed and is ready for durability testing