Extended durability testing of an external fuel processor for SOFC

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Project ID: FC072

Overview

Timeline

- Project start: 08/01/2008
- Project end: 06/30/2012
- Percent complete: 90%

Budget

- Project funding total $1,968,000
  - DOE share = $984,000
  - RRFCS = $984,000
- Funding received in FY11 = $0
- Planned funding in FY12 = $0

Barriers

Fuel Processor

- Durability
- Performance

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 and Fuel Cells 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 and Fuel Cells 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."

Relevance

Technical barriers and targets

This project addresses technical barriers:

A – Durability and C –Performance from the Fuel Cells section of the Fuel Cell Technologies Program (FCT) 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 for distributed generation.

This project addresses the following technical targets:

Technical Targets [a] : 100kW – 3 MW Distributed Generation Fuel Cell Systems Operating on Natural Gas [b]				
Characteristic	**DOE 2011 Status**	**DOE 2015 Targets**	**DOE 2020 Targets**	**RRFCS Targets mature product**
Electrical efficiency at rated power [c]	42-47%	45%	>50% [d]	~ 60%
System availability [e]	95%	98%	99%	95%
Sulfur content in product stream, ppbv [f]	<10			<100

a - Includes fuel processor, stack and ancillaries. b - Pipeline natural gas. c - Ratio of regulated AC net output energy to lower heating value (LHV) of input fuel. d - Higher electrical efficiencies (e.g. 60% using SOFC) are preferred for distributed generation applications. e - Percentage of time available for operation. Unavailable time includes scheduled maintenance. f - Parts-per-billion, dry volume basis.

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 2011 through May 2012 included:

- **Complete Desulfurizer subsystems testing in outdoor test facility**
  - **Operate Desulfurizer subsystem round-the-clock in an unattended mode for 8,000 hours by end of December 2011**
- **Evaluate materials of construction for:**
  - **Sorbent vessel used in the Desulfurizer subsystem**
  - **Reactor components in Synthesis-gas subsystem**
- **Perform Start-gas subsystem testing to:**
  - **Complete shakedown and commissioning**
  - **Confirm multiple system start-ups**
  - **Demonstrate operation of Start-gas subsystem**

Approach

Operate the three fuel processor subsystems on pipeline natural gas for extended periods. Conduct subsystem tests in <u>relevant environments:</u>

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
- Perform post-test inspections

Start-gas subsystem test plan

- Start gas is non-flammable or weakly flammable reducing gas 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 as a function of operating conditions
  - Determine impact of operating time on gas composition (hydrogen, carbon monoxide, and methane)
  - Target performance - less than 20% variability from target flammables content
- Perform 24 start-up cycles
  - Determine impact of operating time on start-up and light-off
- Perform post-test inspections

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
    - Total hydrocarbons (mostly methane) $\geq$ 90% in desulfurized natural gas
    - Desulfurized natural gas retains > 98% of its original calorific value
  - Evaluate materials for sorbent vessel
- Perform post-test inspections

Milestones - status

No.	Description	Planned	Actual	Status
1	Start Preparation of Synthesis-gas Subsystem	Jan. 2009	Jan. 2009	completed
2	Begin Synthesis-gas Subsystem Durability Test	April 2009	Sept. 2009	completed
3	Start Preparation of Desulfurizer Subsystem	July 2009	Dec. 2009	completed
4	Complete Synthesis-gas Subsystem Durability Test	Sept. 2009	April 2010	completed
5	Complete 1,000 hours Operation of Desulfurizer	Sept. 2010	Nov. 2010	completed
6	Start Preparation of Start-gas Subsystem	July 2009	Dec.2009	completed
7	Begin Start-gas Subsystem Durability Testing	Sept. 2011	Feb. 2012	completed
8	Complete Desulfurizer Subsystem Test	Dec. 2011	Dec. 2011	completed
9	Complete Start-gas Subsystem Test	June 2012		**on schedule**
10	Complete Final Report	Sept. 2012		**on schedule**

Technical accomplishments and progress

- **Synthesis-gas subsystem testing completed April 2010**
  - Results presented at DOE 2010 Annual Merit and Peer review Meeting
  - Results received from post-test inspections and impact on life being assessed
- **Start-gas subsystem**
  - Control software and mechanical hardware commissioned
  - System shakedown completed
  - Operation of subsystem confirmed March 30, 2012
  - Multiple start-ups of subsystem confirmed March 30, 2012
  - Plan prepared for durability testing
- **Desulfurizer subsystem installed in outdoor test facility**
  - Control software and mechanical hardware commissioned
  - Durability testing completed 8,000hrs of operation on November 15, 2011
  - Sulfur removal targets achieved
  - Results received from post-test inspections and impact on life being assessed

Technical accomplishments and progress

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

Flare Stack

Control room

Start-gas subsystem

Desulfurizer subsystem

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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
- Testing underway

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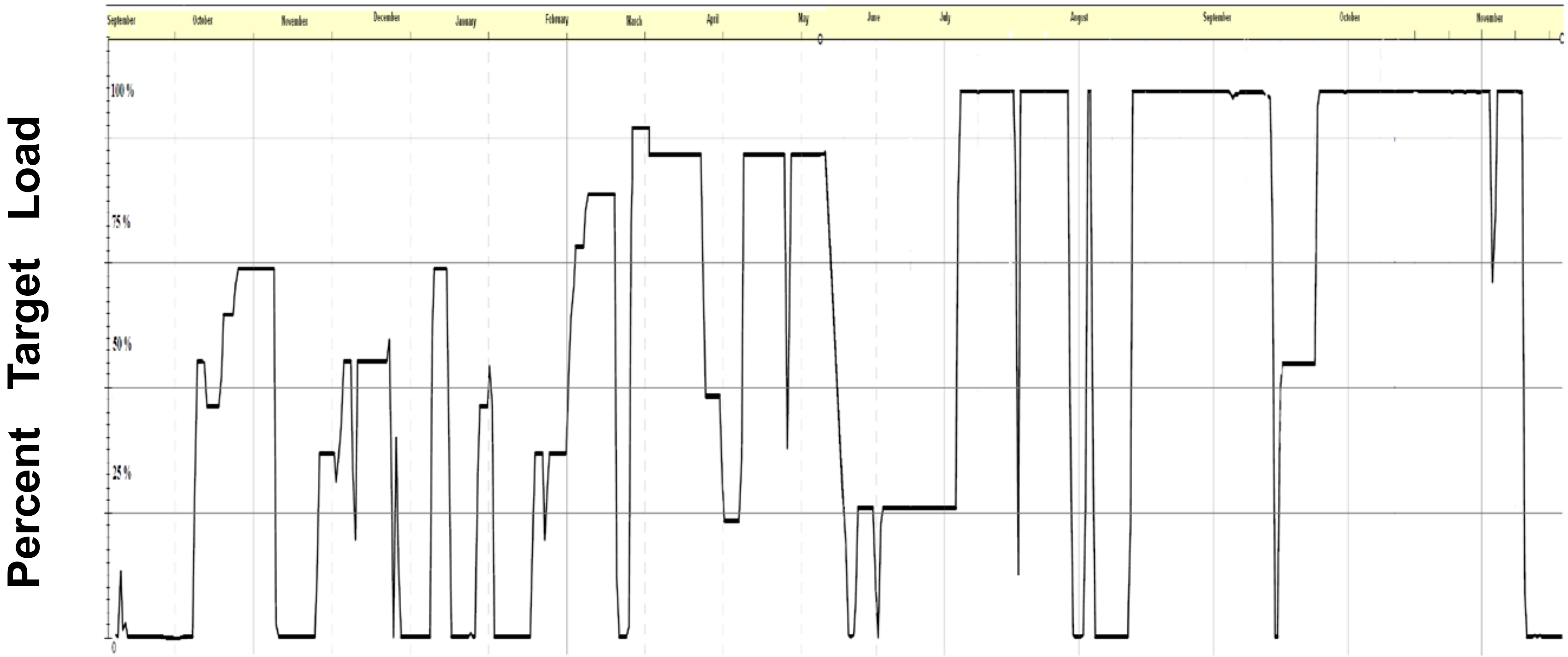
Technical accomplishments and progress

Desulfurizer subsystem installed in outdoor test facility

- Control system commissioned
- Safety system commissioned
- Instrumentation calibrated
- Control valves tuned
- Gas sensors calibrated
- Durability testing started 10/2010
- Durability testing completed 11/15/2011 after logging 8,000hrs time-on-stream
- Sulfur target (<100 ppb) achieved

Technical accomplishments and progress
Desulfurizer subsystem durability testing results



- •Durability testing started in September 2010
- •Completed 8,000 hrs time-on-stream on 15th – November 2011

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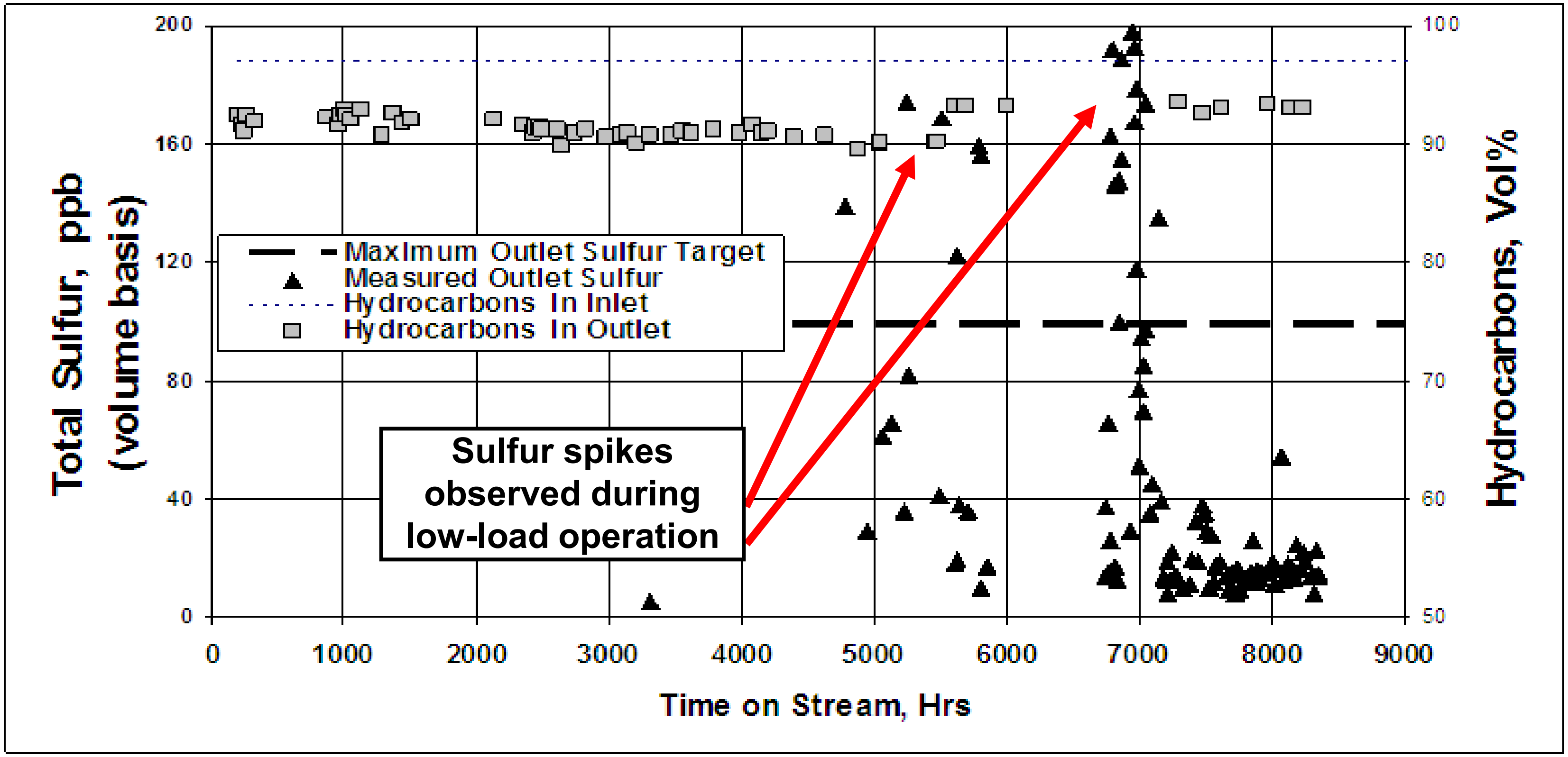
Desulfurizer subsystem durability testing results



- Total sulfur in DNG mostly < 100 parts per billion (detection limit=10 ppb)
  - Sulfur spikes observed in the outlet DNG at low load are being investigated
- Total hydrocarbons in DNG > 90% (volume basis)

Synthesis gas subsystem post-test inspections

Evaluations of materials of construction

Synthesis-gas reactor parts after 1000hrs operation

Catalyst Holder

Reactor Outlet

Sleeve

Thermowell

Support Piece

- **Samples submitted to metallurgy laboratory for analysis**

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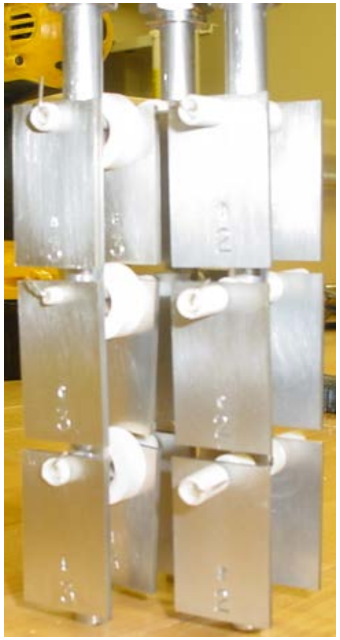
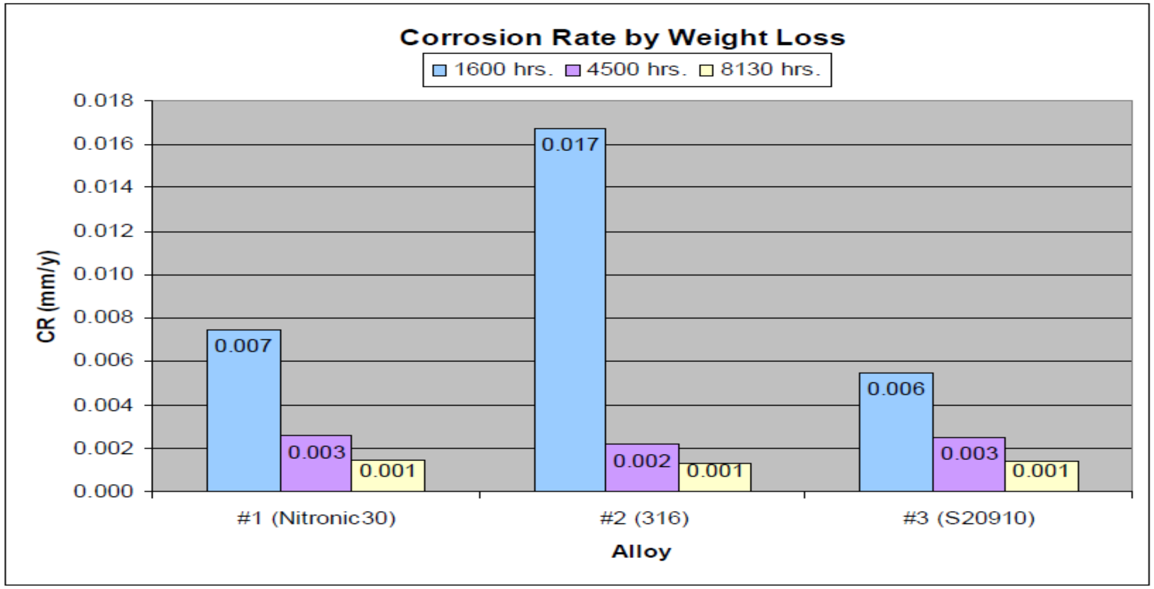
Desulfurizer subsystem durability testing results

Evaluations of materials



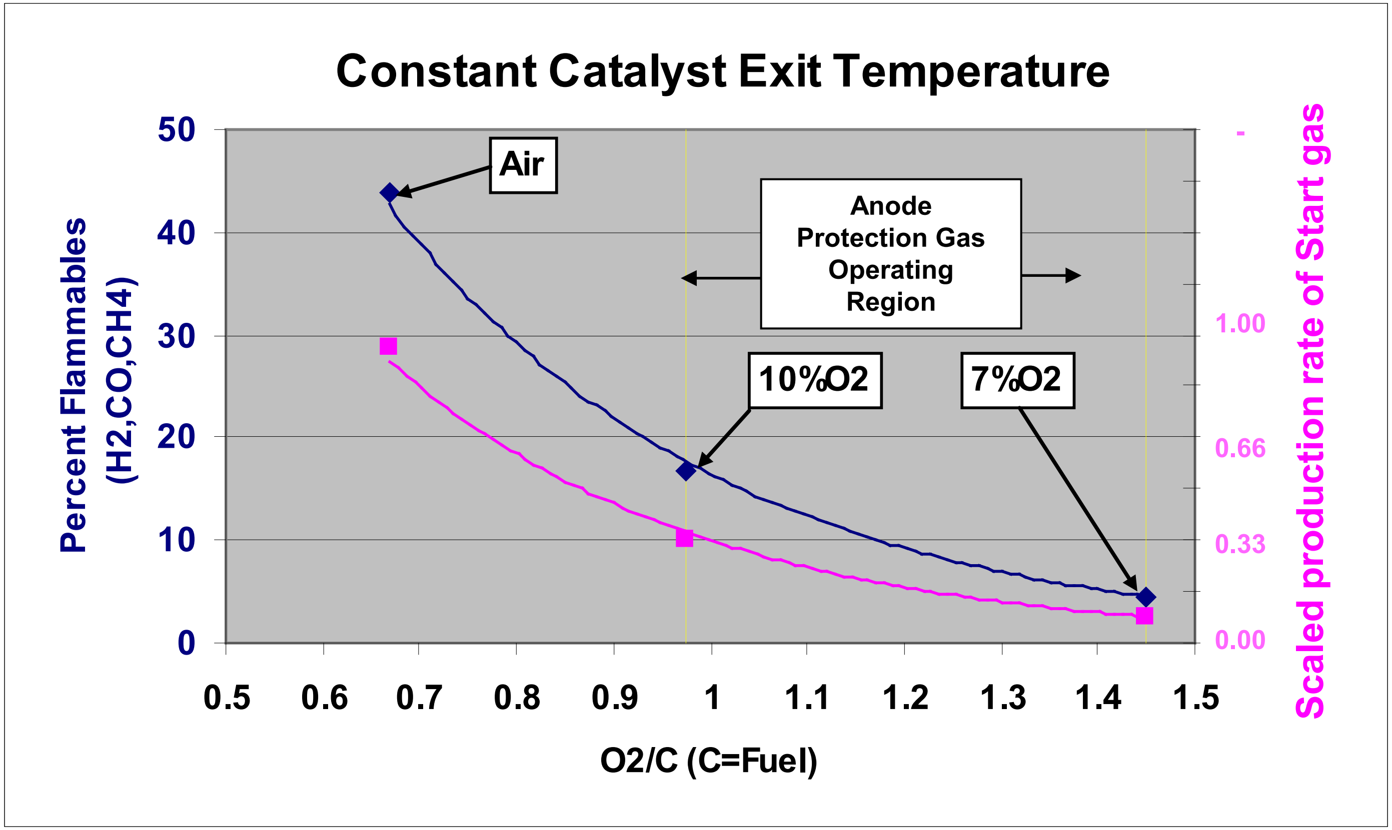
Metal Coupons from Desulfurizer



Alternative materials (Nitronic®30 and S20910) showed significantly lower initial corrosion rates compared to SS316. These are being considered in the design for the fuel processor commercial product.

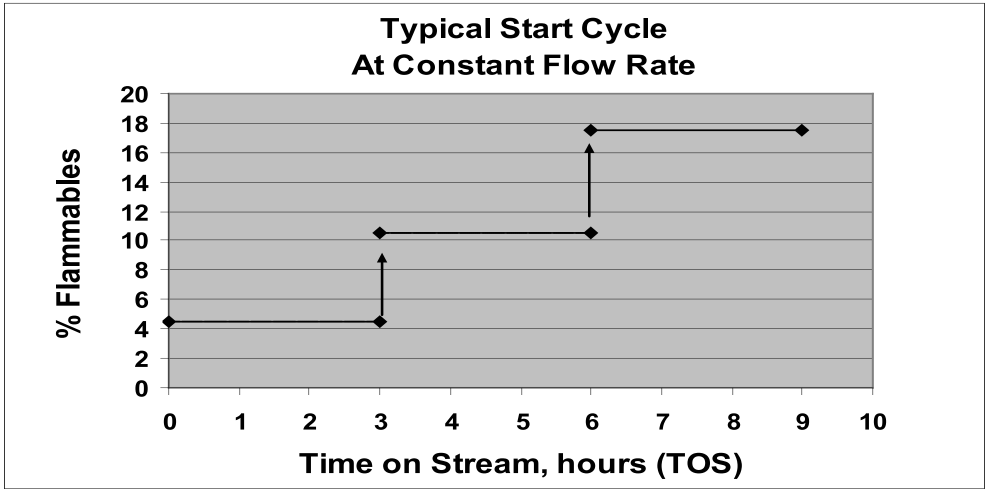
Start-gas subsystem testing results

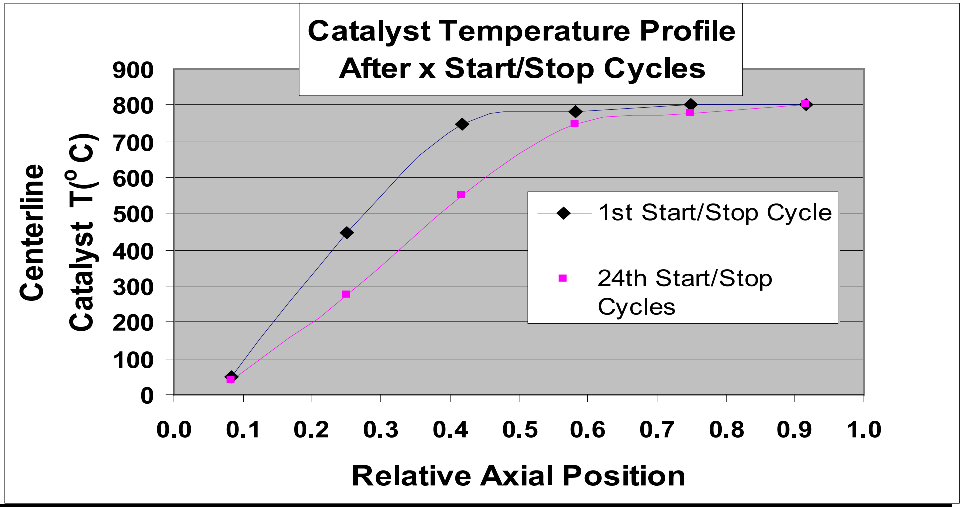
Required operating range



Start-gas subsystem durability testing results

- Typical SOFC start cycle with required flammables concentration from Start-gas subsystem
- Degradation Results after multiple start/stop cycles
  - Degradation indicated by progression of temp. profile downstream
  - Very little degradation observed





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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

2012

- Complete post-test analyses of Desulfurizer subsystem (Q2CY12)
- Complete durability testing of Start-gas subsystem (Q2CY12)
- Perform post-test inspections and analyses of Start-gas subsystem (Q2CY12)
- Issue final report for project (Q3CY12)

2013 – not part of this DOE project

- Operate the fuel processor subsystems with a large-scale SOFC

Summary

An approach was developed and completed for testing durability and performance of an external fuel processor for a SOFC

- 8000-hr Desulfurizer subsystem durability testing was completed
- 1000-hr Synthesis-gas subsystem durability testing was completed
- 200-hr Start-gas subsystem testing is nearly completed
- Operational issues experienced during the project have been successfully addressed
- Material issues experienced during the project are being assessed and addressed

End of Presentation

Thank you!