Extended durability testing of an external fuel processor for SOFC

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June 8, 2010

DOE Project Officer: Jesse J. Adams **Project ID: FC072**

DE-FG36-08GO88113

Acknowledgement: **"This material is based upon work supported by the U.S. Department of Energy under Award Number DE-FG36-08GO88113."**

Overview

Timeline

- Project start: 01/01/2009
- Project end: 12/31/2011
- Percent complete: 31%

Budget

- Project funding total $1,968,000
  - DOE share = $984,000
  - RRFCS (US) Inc. = $984,000
- Funding received in FY08 - $984K
- Funding in FY09 - $0.0K
- Funding in FY10 - $0.0K

Barriers

Fuel Processor

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

Partners

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

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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 small, secure 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 coal synthesis gas, liquid hydrocarbon fuels and alternative fuels such as biogas.

Relevance

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.

Specific targets and milestones

This project addresses milestones 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." These targets will be addressed as they relate to durability, performance, and transient response.

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 June 2009 through May 2010 included:

- Obtain DOE approval for the project's hydrogen safety plan
- Complete synthesis-gas subsystem durability testing
- Install desulfurizer and start-gas subsystems in outdoor test facility
- Complete shakedown and commissioning of desulfurizer and start-gas subsystems

Approach

Operate fuel processor subsystems on pipeline natural gas for extended periods

Conduct subsystem tests in relevant environments

- Synthesis-gas subsystem - up to 1,200 hours in warm environment
- Start-gas subsystem - up to 200 hours in outdoor environment (hot / cold)
- Desulfurizer subsystem - for 8,000 hours in an 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 any deposits and signs of wear, damage, corrosion or erosion

Planned milestones

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

Synthesis-gas subsystem generates a hydrogen-rich gas for SOFC heat-up and low-load operation

- Synthesis gas (H_2 and CO) generated from pipeline natural gas and compressed air
- The synthesis-gas subsystem uses:
  - Catalytic, partial oxidation reactor
  - Automatic control system for unattended operation

Synthesis-gas subsystem test plan

- **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 any impact of operating time on gas composition (hydrogen, carbon monoxide and methane)**
    - **Target performance - less than 10% reduction in H_2 content over catalyst life**
- **Perform 10 start-up cycles**
  - **Determine any impact of operating time on start-up time and light-off**
- **Post-test examination**
  - **Disassemble Synthesis-gas reactor**
    - **Determine catalyst surface area, pore volume, carbon content, sulfur content and loss of precious metals**
    - **Examine reactor vessel, inlet and outlet piping, and internal components (use scanning electron microscope to examine samples when needed)**
    - **Inspect insulation and internal components**

Start-gas subsystem generates a nonflammable reducing gas that is used for SOFC start-up and shutdown

- Start-gas is to be generated from pipeline natural gas and an oxygen-depleted air stream
- The 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

Start-gas subsystem test plan

- **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 time and light-off temperature**
- **Post-test examination**
  - **Disassemble Start-gas reactor**
    - **Determine catalyst surface area, pore volume, carbon content, sulfur content and any change in precious metals loading**
    - **Examine reactor vessel, heat exchanger and piping**

      (use scanning electron microscope to examine samples when needed)
    - **Inspect insulation and internal components**

Approach

Desulfurizer subsystem generates high-pressure desulfurized natural gas

- The SOFC requires high pressure (10 Bara) desulfurized natural gas (< 100 ppb)
- The desulfurizer subsystem uses:
  - Pipeline natural gas (2 to 10 ppmv sulfur) and compressed air as reactant
  - Catalytic reactor for oxy-desulfurization with high-capacity sulfur sorbent
  - Automatic control system for unattended operation

Desulfurizer subsystem test plan

- **Operate desulfurizer subsystem for up to 8,000 hours**
  - **Determine sulfur content in product gas at part-load and full-load**
  - **Determine impact of operating time on product gas composition (sulfur, methane, ethane, propane, butane, pentane and carbon dioxide)**
  - **Target performance**
    - **Less than 100 ppb sulfur in product - desulfurized natural gas**
    - **Desulfurized natural gas retains >98% of its original calorific value**
- **Post-test examination**
  - **Disassemble reactor, sorbent vessel and start-up burner**
    - **Determine catalyst surface area, pore volume, carbon content, sulfur content and any change in precious metals loading**
    - **Determine sorbent carbon content and sulfur contents (SO_2/SO_3)**
    - **Examine reactor, vessels, start-up equipment, heat exchanger, and piping (use scanning electron microscope to examine samples when needed)**
    - **Inspect insulation and internal components**

Technical accomplishments and progress

- **Hydrogen safety plan issued and approved by DOE's safety review panel**
- **Synthesis-gas subsystem installed, commissioned, and tested**
- **Fabrication of outdoor test facility completed**
- **Start-gas subsystem installed in outdoor test facility**
  - Control software commissioning underway
  - Mechanical commissioning underway
- **Desulfurizer subsystem installed in outdoor test facility**
  - Control software written and being commissioned
  - Mechanical commissioning underway

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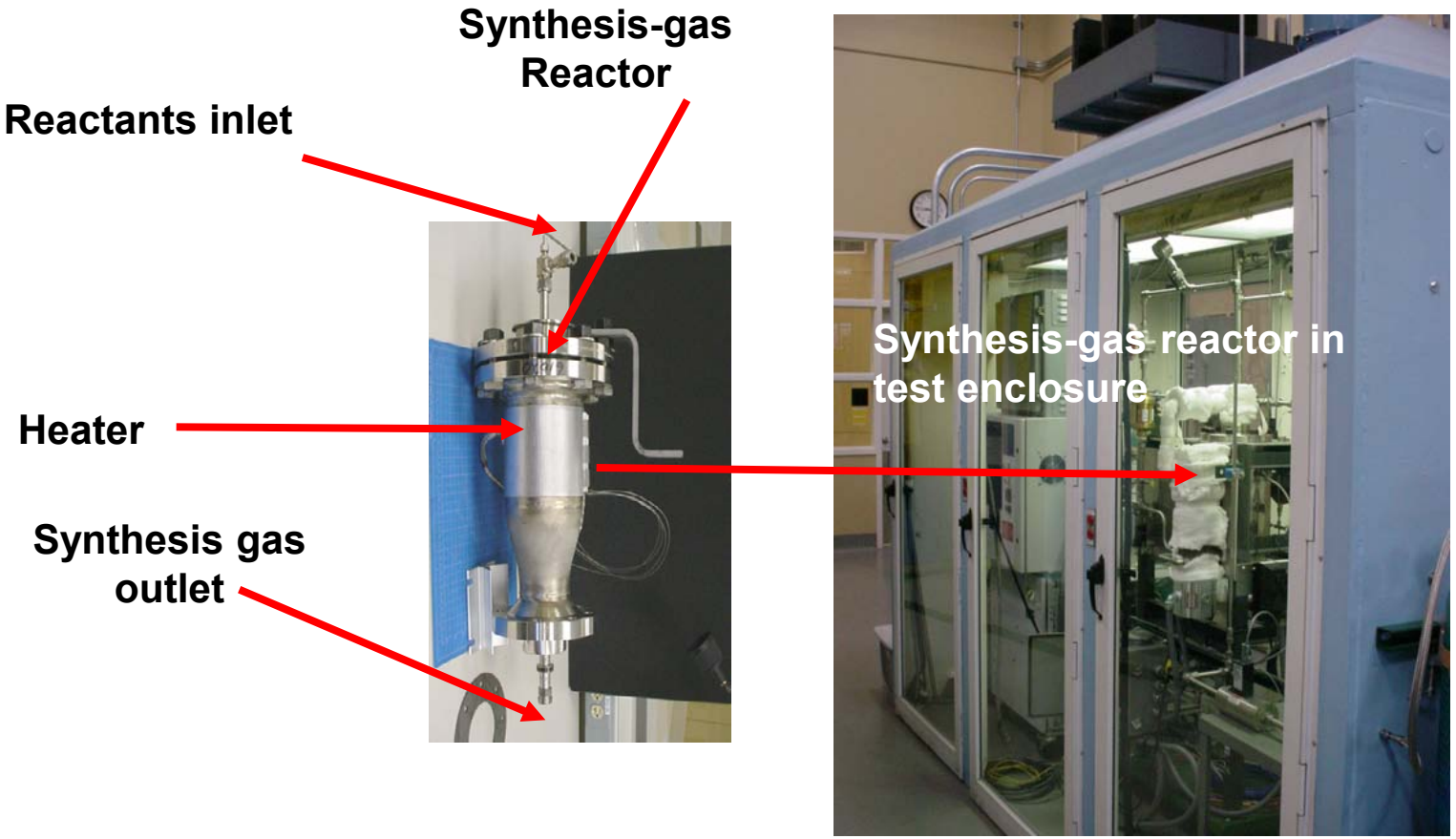
Synthesis-gas reactor installed in test enclosure



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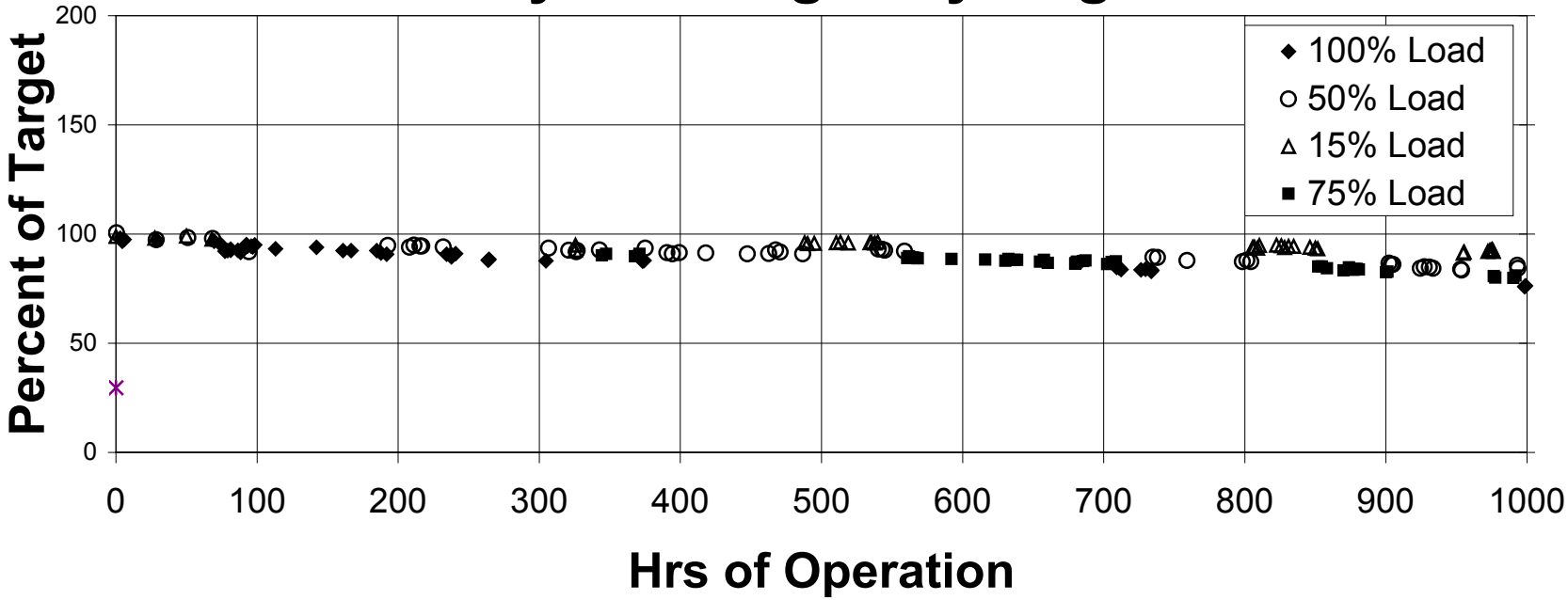
Synthesis-gas subsystem durability testing results

Synthesis gas hydrogen



- Hydrogen in product gas decreased with time-on-stream
  - 21% decrease in hydrogen concentration at 100% load after 1,000 hours of operation
  - 7% decrease in hydrogen concentration at 15% load after 1,000 hours of operation
- Observed decreases in hydrogen not expected to be an issue

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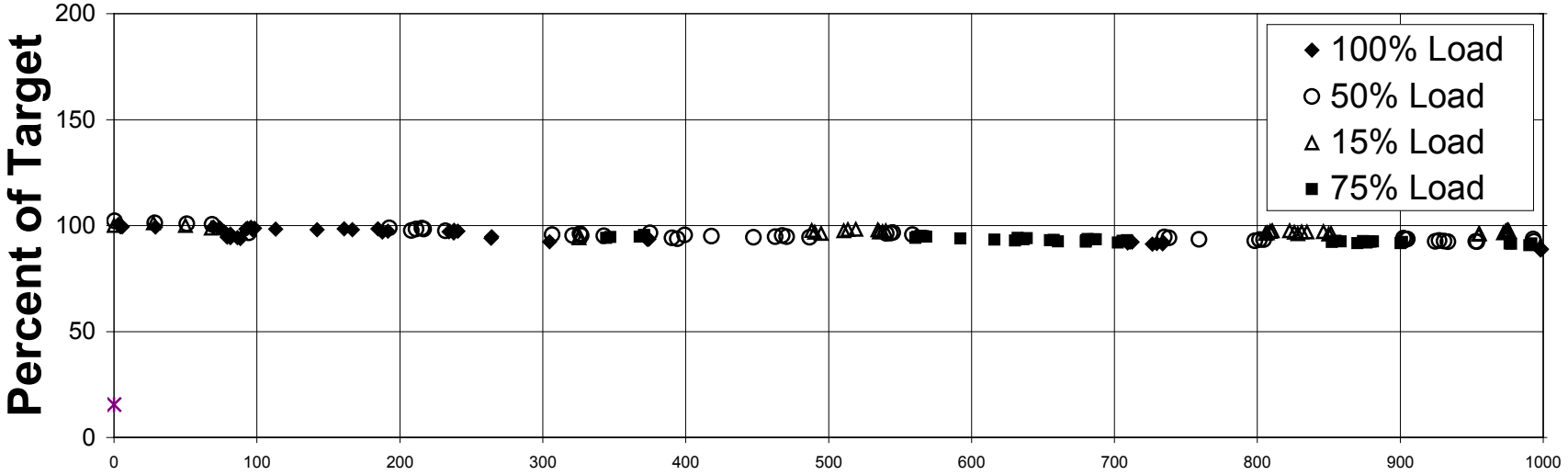
Synthesis-gas subsystem durability testing results

Synthesis gas carbon monoxide



- Carbon monoxide in product gas decreased with time-on-stream
  - 11% decrease in CO concentration at 100% load after 1,000 hours of operation
  - 3% decrease in CO concentration at 15% load after 1,000 hours of operation
- Observed decrease in carbon monoxide not expect to be an issue

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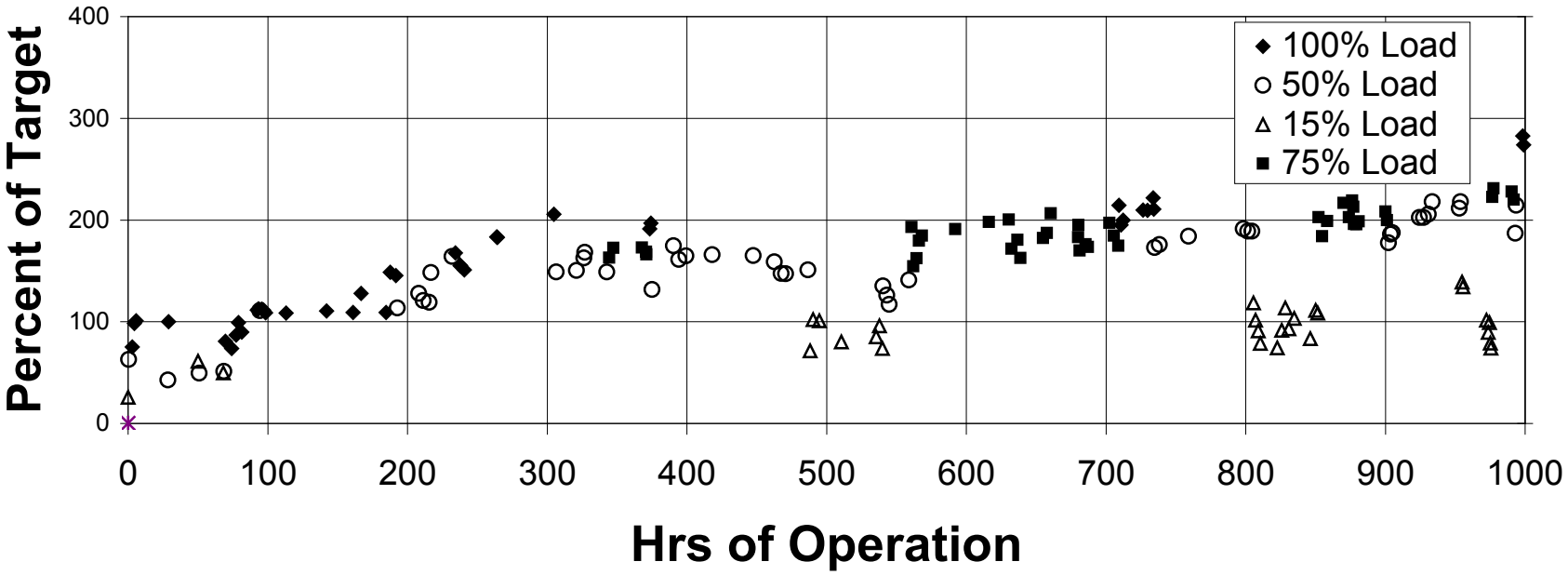
Synthesis-gas subsystem durability testing results

Synthesis gas methane



- Methane in product gas increased with time-on-stream
  - At 100% load, methane more than doubled (after 1,000 hours of operation)
  - At 15% load methane increased ~ 40% (after 1,000 hours of operation)
- Observed increase in methane not expected to be an issue

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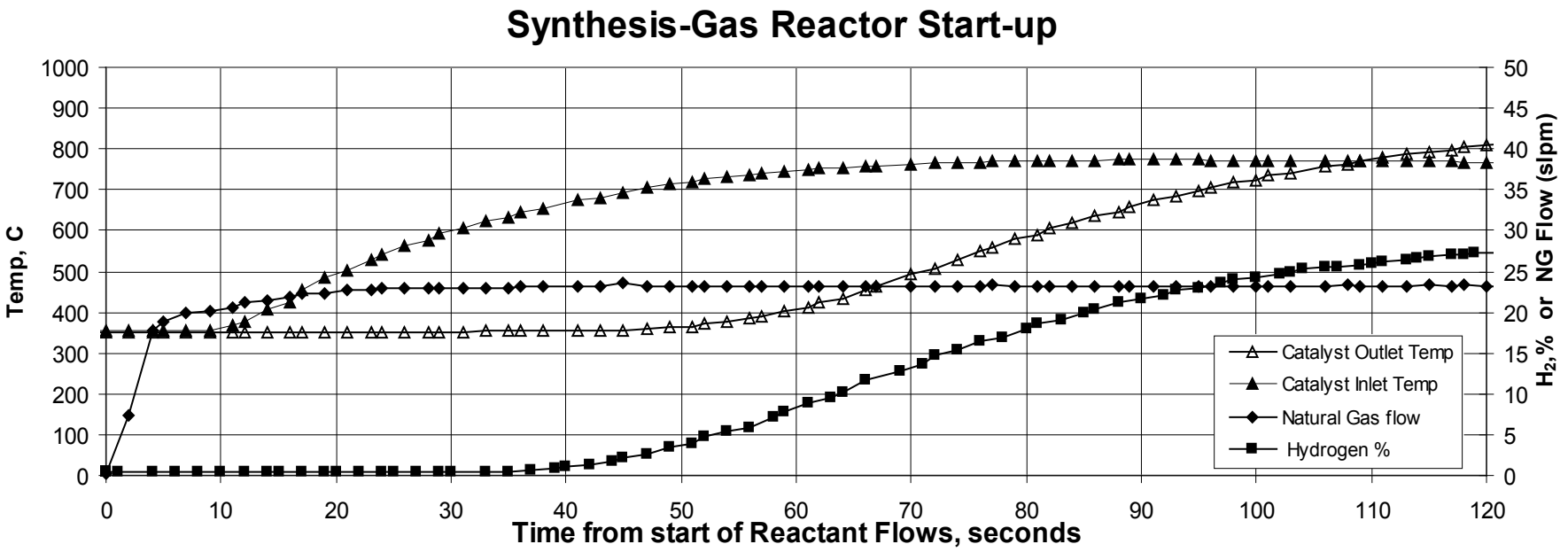
Synthesis-gas subsystem durability testing results



- Light-off temperature was 350C
- Approximate start-up time was two minutes to target hydrogen level
- Hydrogen generation followed catalyst outlet temperature

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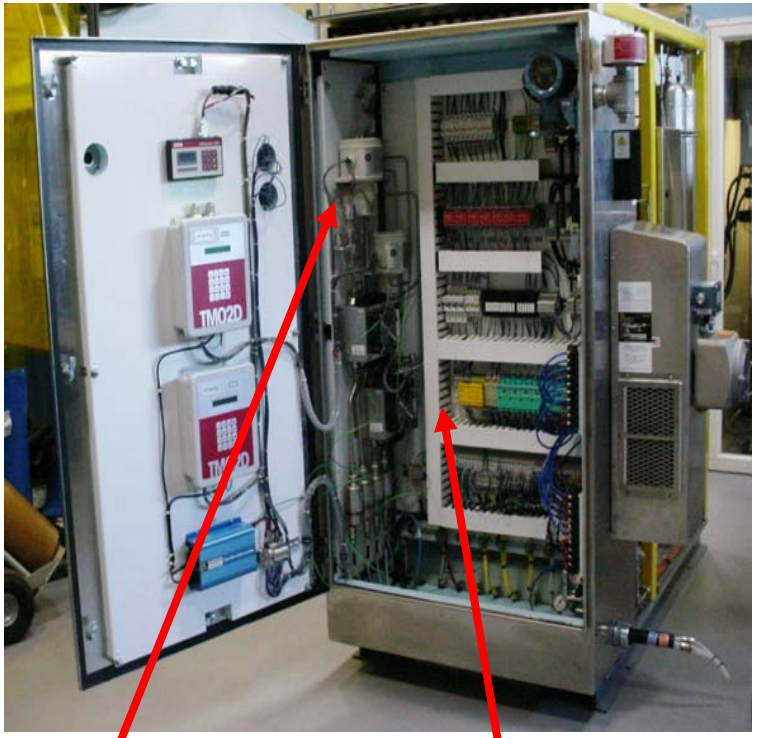
Start-gas subsystem hardware before installation in outdoor test facility



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1 MWe Desulfurizer subsystem hardware before installation in outdoor test facility

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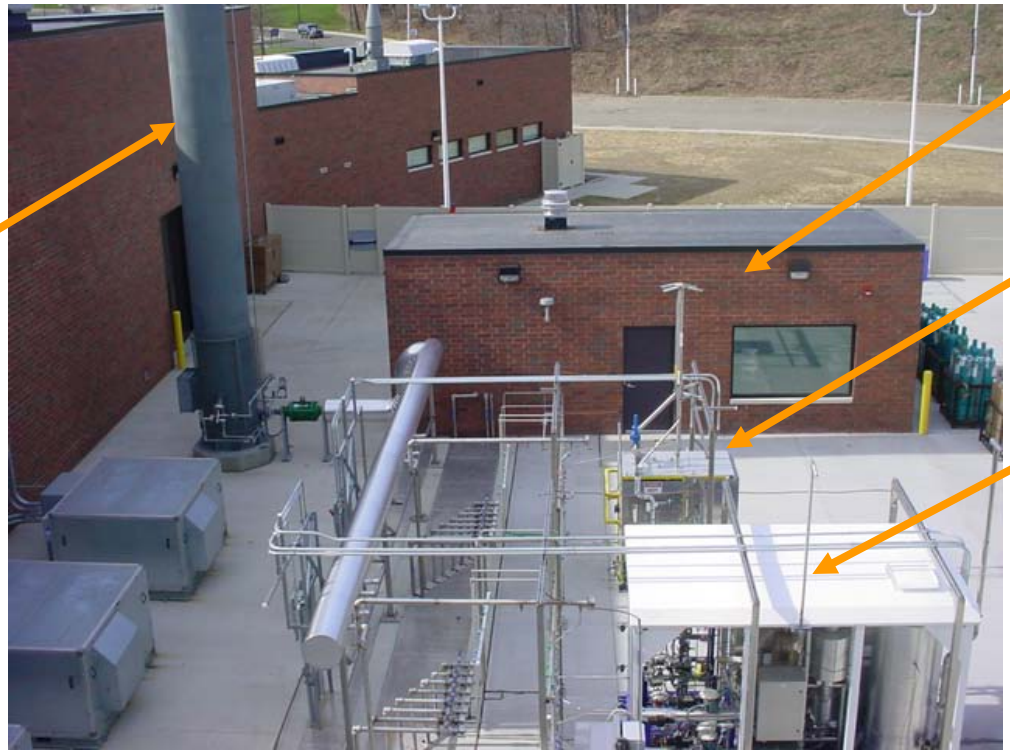
Installation of Desulfurizer and Start-gas subsystems in outdoor test facility



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Milestones

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		on schedule
6	Start Preparation of Start-gas Subsystem	July 2009	December 2009	completed
7	Begin Start-gas Subsystem Durability Testing	September 2010		**on schedule**
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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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 Stark State College of Technology (SSCT) campus. The expansion included construction of:**
  - **Outdoor and indoor test facilities for use by RRFCS**
  - **SSCT's Fuel Cell Center (laboratory space for fuel cell education)**
- **SSCT has associate degree programs in electrical engineering technology and mechanical engineering technology with a fuel cell option. RRFCS has five graduates of these programs as either interns or as permanent employees to support this and other fuel cell projects.**

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Proposed future work

2010

- Perform post-test inspection and analyses of synthesis-gas subsystem (FY10 Q3)
- Complete commissioning of Start-gas and Desulfurizer subsystems (FY10 Q2)
- Begin durability testing of Start-gas and Desulfurizer subsystems (FY10 Q3)

2011

- Complete durability testing of Start-gas and Desulfurizer subsystems (FY11 Q3)
- Perform post-test inspections of Start-gas and Desulfurizer subsystems (FY11 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
- Durability testing has been completed on the Synthesis-gas subsystem
- The Desulfurizer and Start-gas subsystems have been installed in the outdoor test facility. Commissioning is underway.