Plate Based Fuel Processing System

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May 23 – 26, 2005

This presentation does not contain any proprietary or confidential information

Project ID# FCP15

Overview

Timeline

- Project start: October 2001
- Project end: September 2005
- Percent complete: 85%

Barriers

- Barriers addressed
  - A. Durability
  - B. Cost
  - I. Hydrogen Purification/Carbon Monoxide Clean-up
  - J. Start-up Time/Transient Operation

Budget

- Total project funding
  - DOE share: $7M
  - Contractor share: $3M
- Funding received in FY04: $1.9M
- Funding for FY05: $1.1M

Partners

- Argonne National Laboratory
- Pacific Northwest National Laboratory

Objectives

- Design and fabricate steam reforming prototype plate reactors at the 2 to 10kW(e) scale
  - Demonstrate steady state and transient performance
  - Evaluate rapid start up performance
- Develop highly active and durable low cost steam reforming, water-gas-shift and preferential oxidation catalyst materials compatible with the plate reactor system targeted at the DOE's $10 per kW(e) target
- Identify alternative applications and potential commercial outlets for the technology developed under this contract

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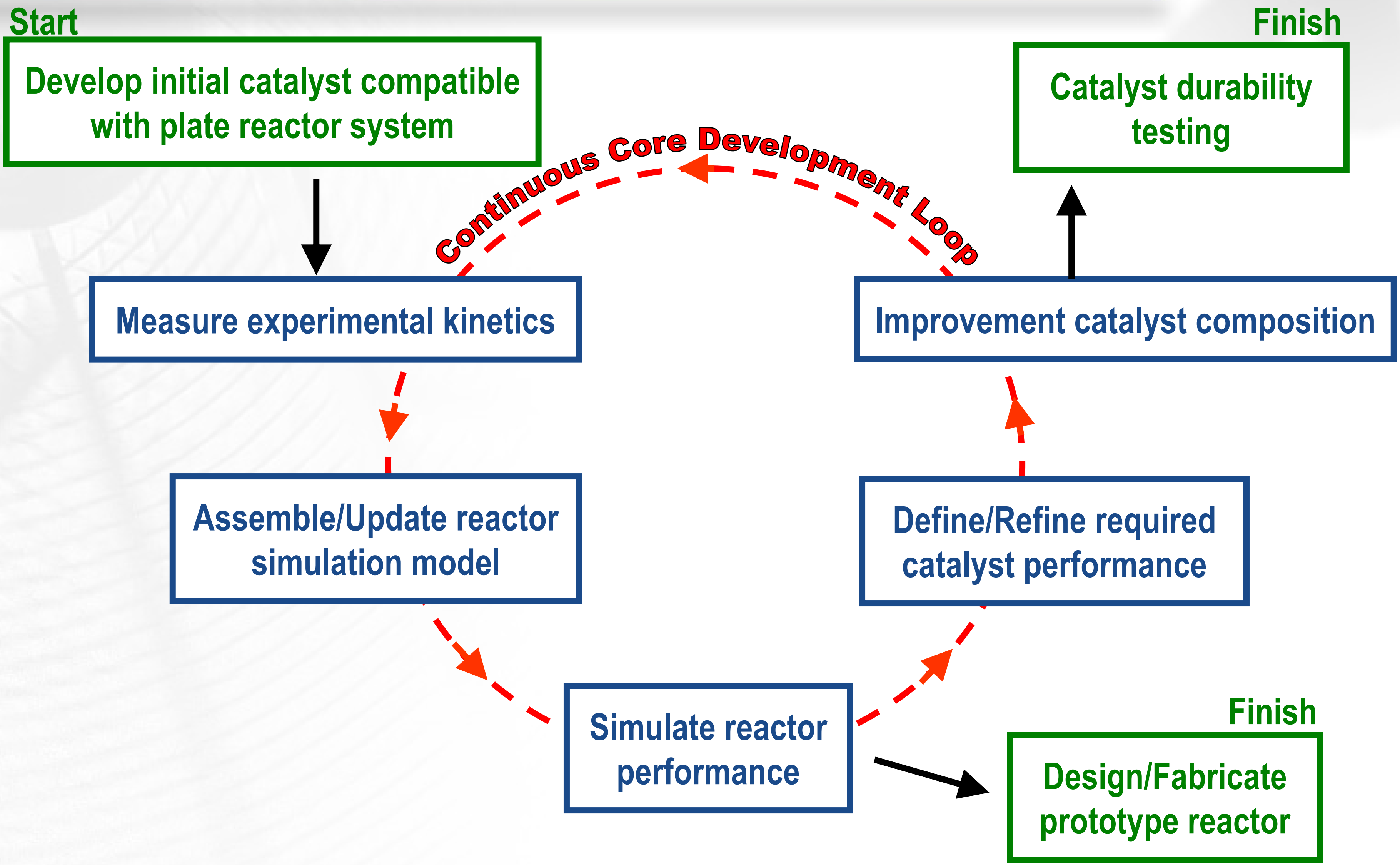
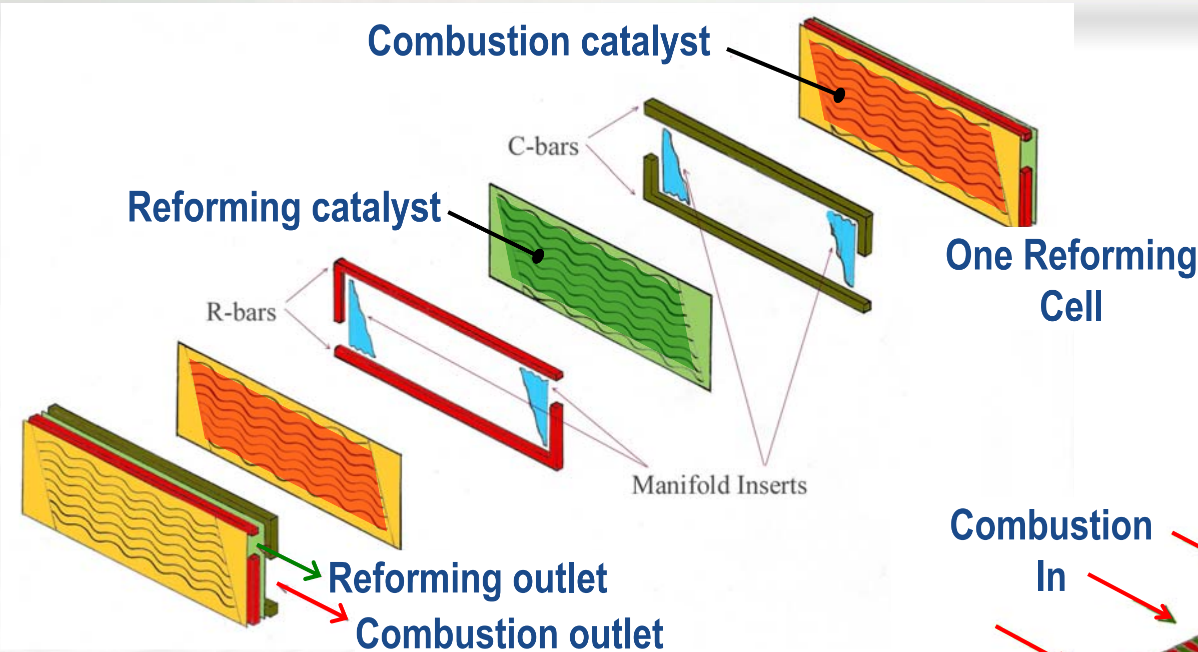
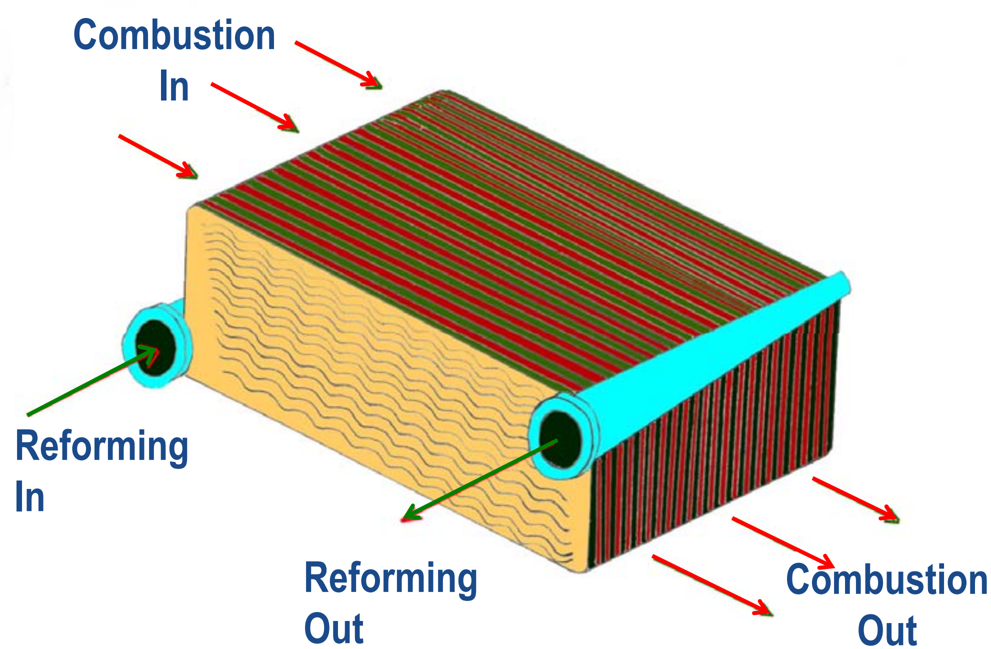
Approach


Start
Develop initial catalyst compatible with plate reactor system
Measure experimental kinetics
Continuous Core Development Loop
Assemble/Update reactor simulation model
Simulate reactor performance
Define/Refine required catalyst performance
Improvement catalyst composition
Finish
Catalyst durability testing
Finish
Design/Fabricate prototype reactor

CESI Steam Reforming Plate Reactor Approach





- Design based on plate-type heat exchanger
- Plates are coated with catalysts and paired together to form single cells
- Multiple cells are welded together to form the plate stack

First Steam Reformer Prototype Fabrication

- To reduce fabrication time, CESI utilized 0.0075" (0.2 mm) thick plates from an existing heat exchanger of a gas turbine recuperator
- Cut one-tenth sector (shaded region) to fabricate a simple prototype
- Utilized CESI coating knowledge to successfully develop a coating process
- Developed a welding process for the plate stack assembly

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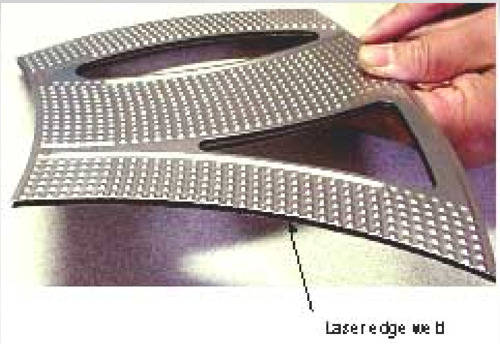
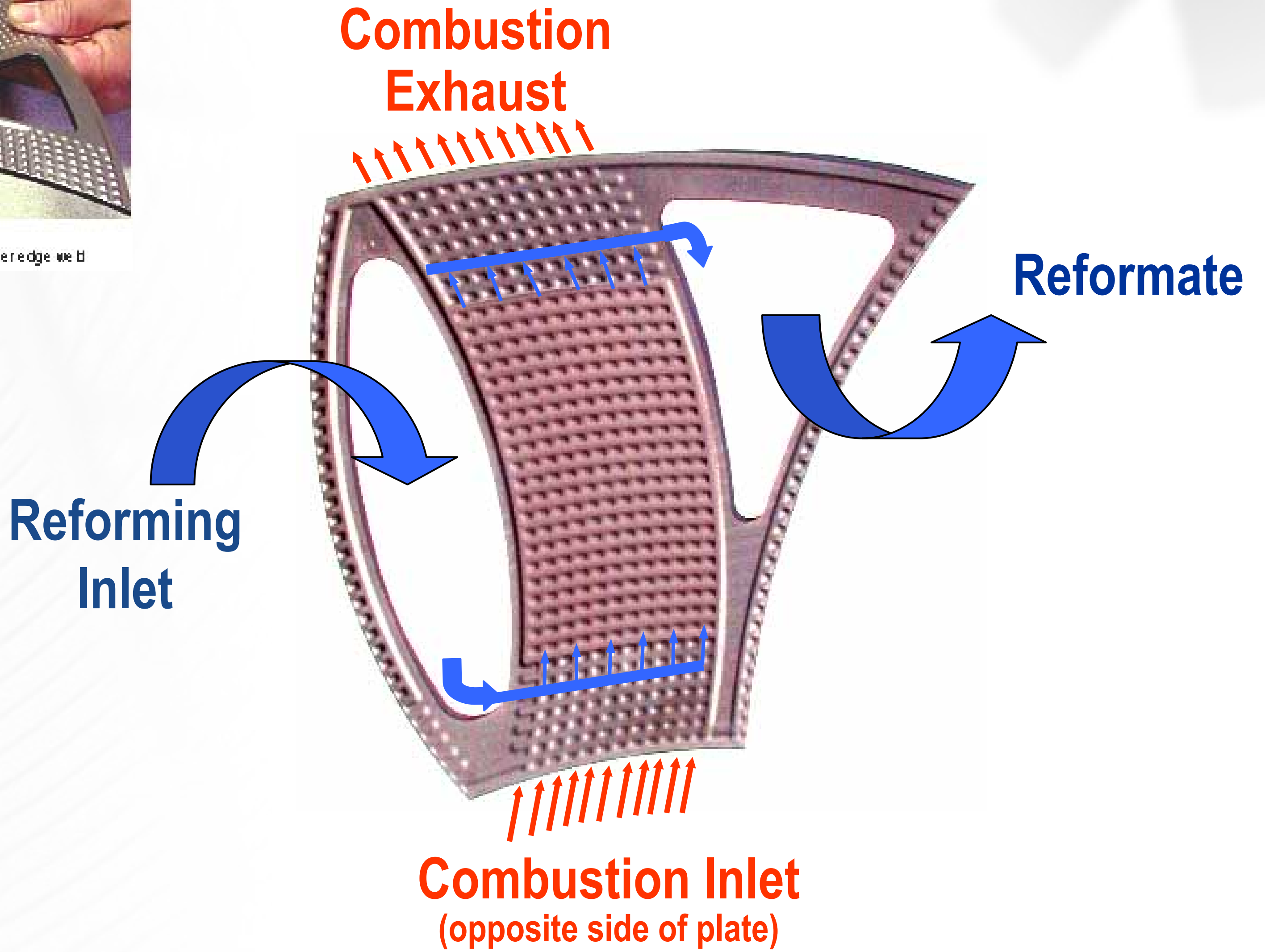
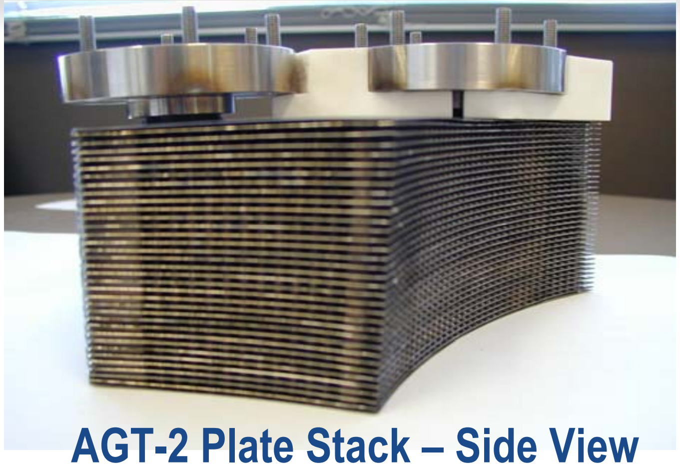
Details of First Prototype Plate



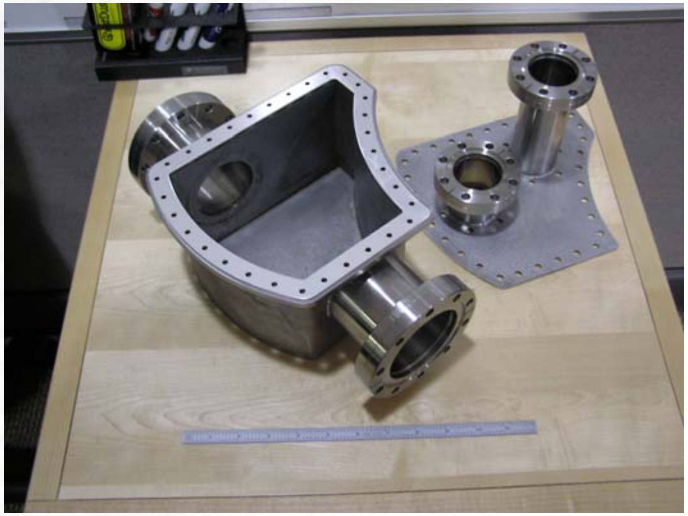


First Prototype Assembly

AGT-2 Plate Stack



AGT-2 Plate Stack – Side View



AGT-2 Manifold-Box

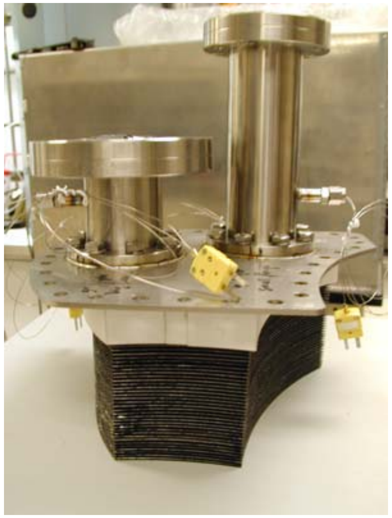
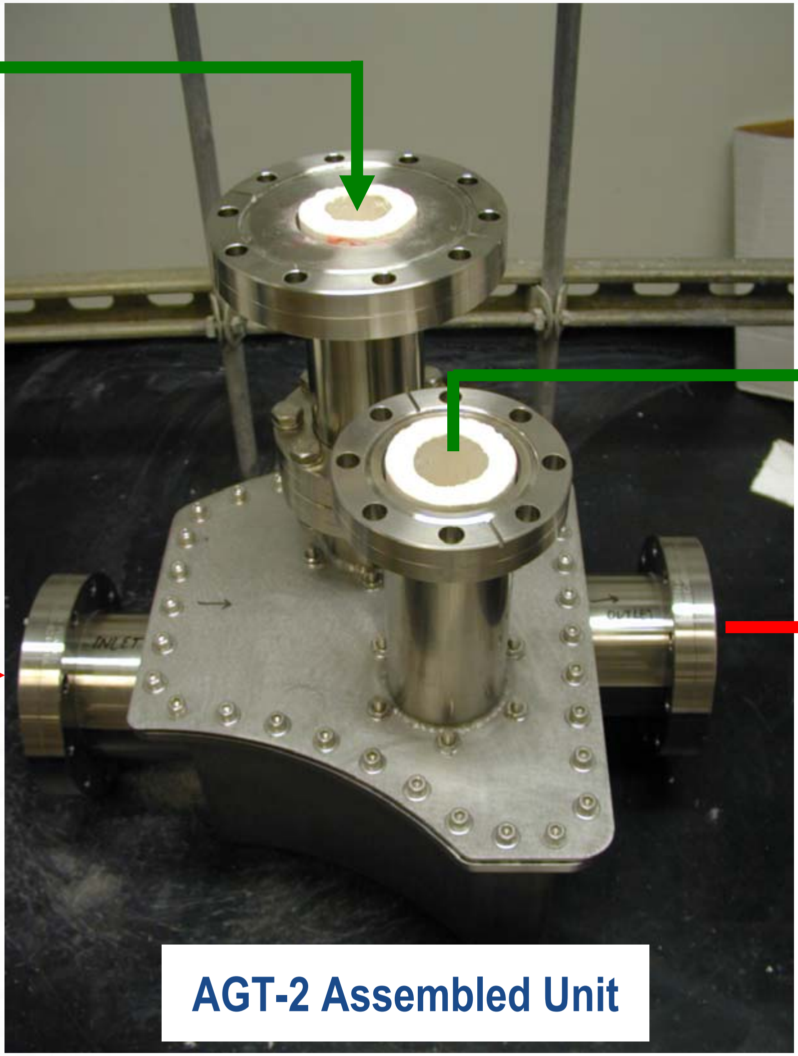


Plate Stack attached to Reforming side Manifold

First Prototype Assembly



AGT-2 Assembled Unit

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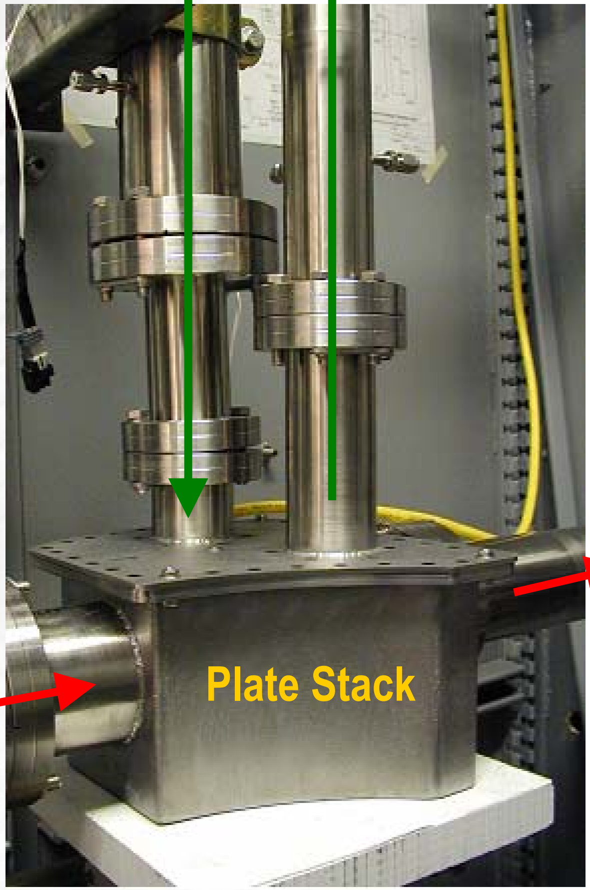
Prototype Test Cell

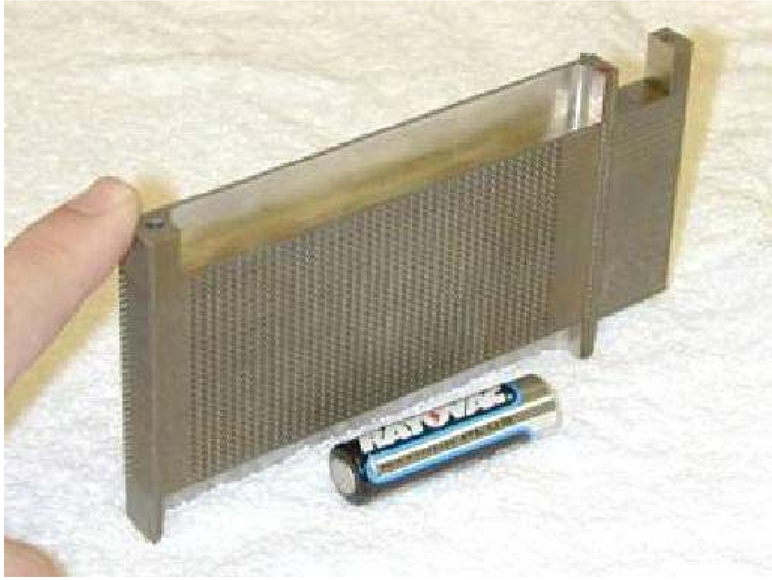


Steam Generator

- Combustor – provides high temperature air to vaporizer

Xonon ® Catalyst to complete combustion

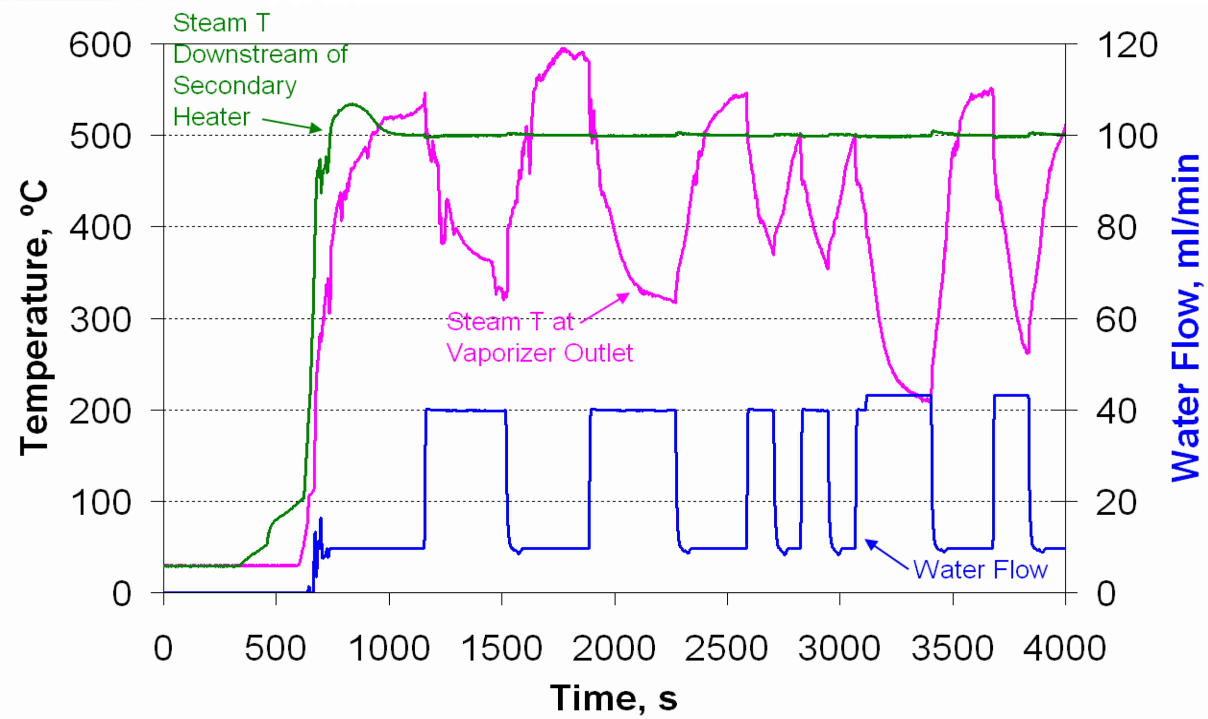
- PNNL's Micro-channel vaporizer – vaporizes water and preheats the steam



The combination of these two components results in an efficient and flexible steam generator for testing purposes

Steam Generator and Secondary Heater Performance

- Steam generator is operated with constant thermal input
- As the steam flow changes, a secondary heater provides supplemental heat to maintain the steam at the desired operating temperature



Steam generator and secondary heater combined can maintain constant steam reformer inlet temperature at different loads

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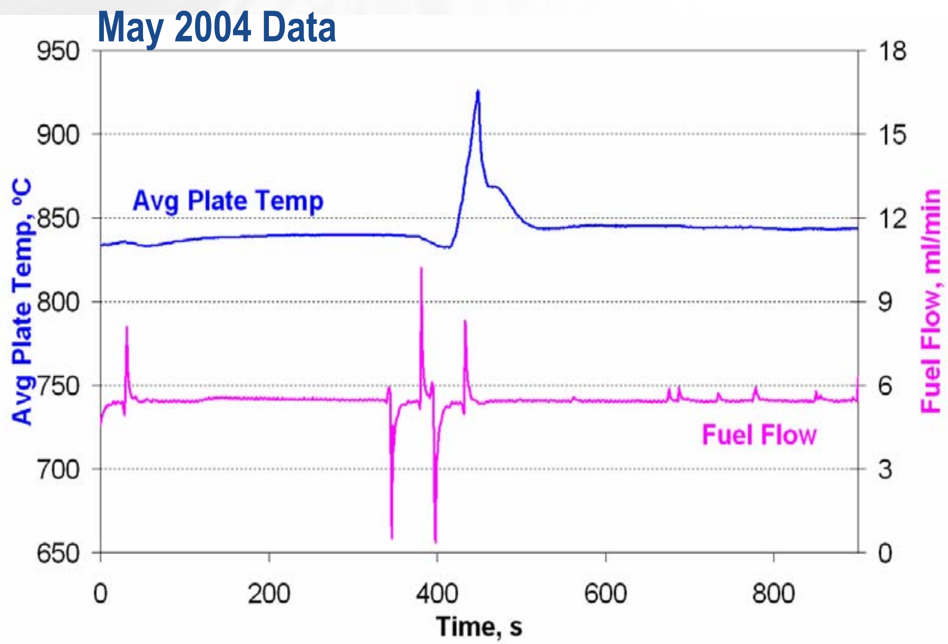
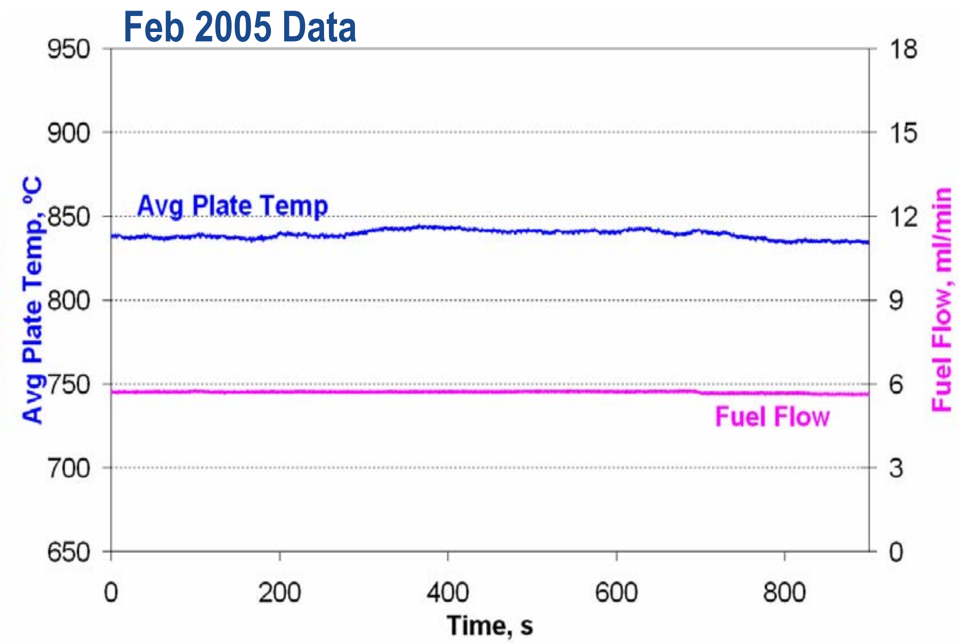
3 kW(e) Prototype Steady State Performance

- Previous equipment and controls resulted in significant perturbations during steady state
- Upgraded equipment and controls to achieve stable operating conditions during steady state





Improved fuel delivery system and PID control scheme resulted in less perturbations during steady state operation

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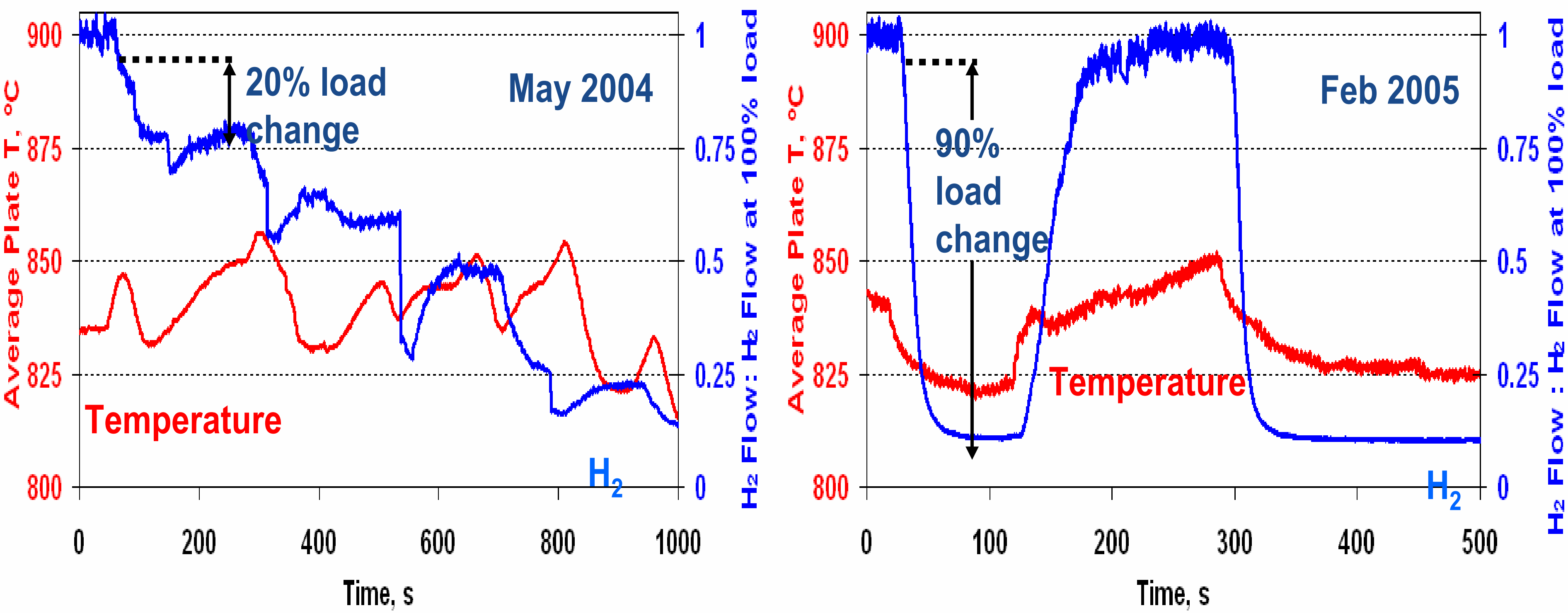
3 kW(e) Prototype Transient Performance

- Previous equipment and controls were limited to a 20% load change for a 1 second transient
- Upgraded equipment and controls permit 90% load change for a 1 second transient



Implemented improvements allow for faster and smoother transients

Modification of 3 kW(e) Prototype System

- Major performance improvements are due to:
  - Integration of automated control features
  - New low-flow fuel pumps for liquid delivery
  - Introduction and refinement of PID control loops
  - New quicker response steam generator
  - Use of secondary steam heater to more precisely control the temperature of steam entering the reformer

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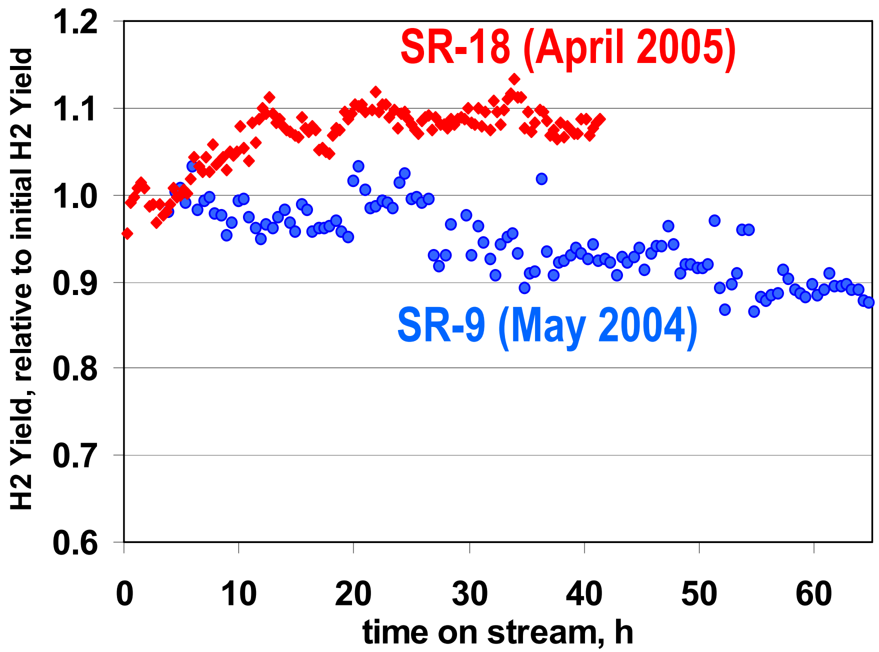
Gasoline Steam Reforming Catalyst Improvements

- Steam Reforming (SR) catalyst improvements focused on lowering steam to carbon ratio, lowering operating temperature requirement, increasing catalyst activity and reducing catalyst cost
- Gasoline = ANL Benchmark I Fuel containing 10 ppm Sulfur



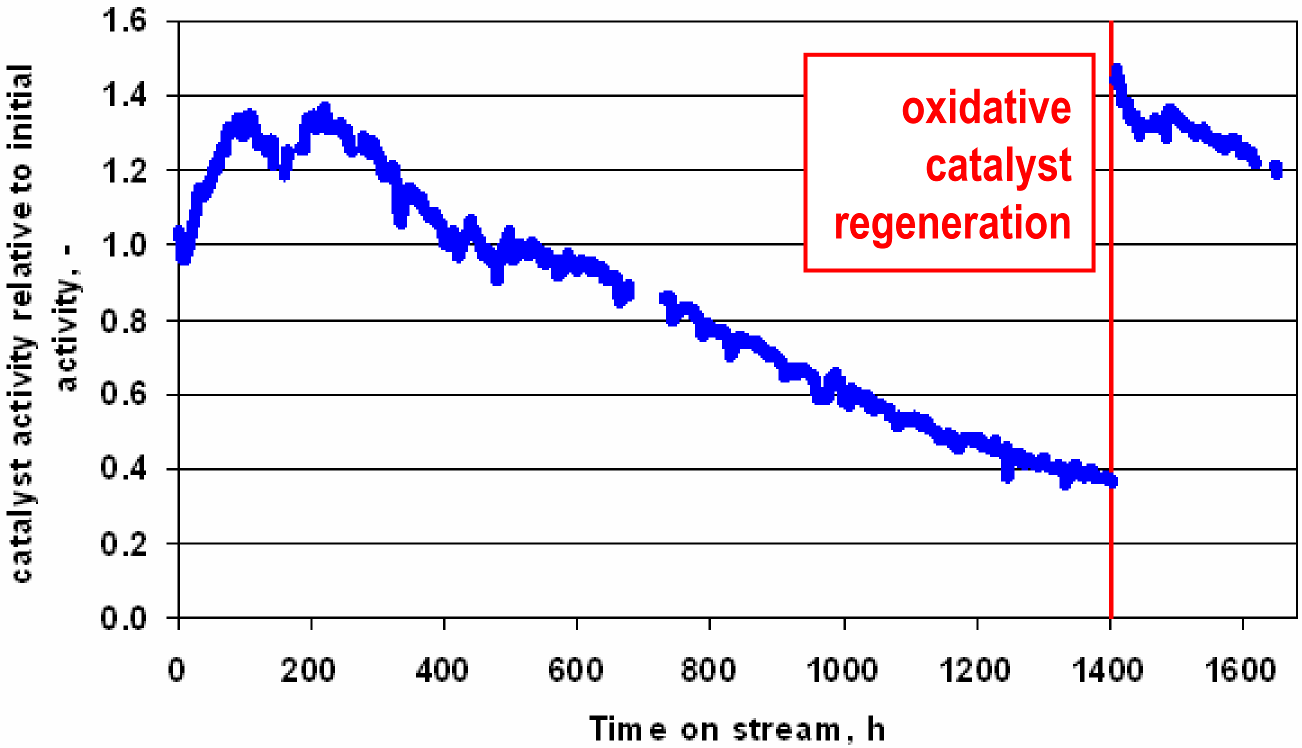
Catalyst performance summary

		SR-9 (May 2004)	SR-18 (April 2005)
Steam to carbon ratio	mol/mol	3.8	3.0
Lowest T of operation	°C	825	785
Initial catalyst activity	a.u.	1.00	1.57
Catalyst cost	$/kW(e)	20.15	2.56

Significant improvements in catalyst durability, operability and cost

Water Gas Shift Catalyst Durability

- Water Gas Shift (WGS) catalyst durability test performed to measure rate of deactivation
- WGS catalyst will be sized for 2x operating margin (assuming regeneration every 1000 hours)
- Durability testing will continue



WGS catalyst activity can be fully recovered with regeneration cycle

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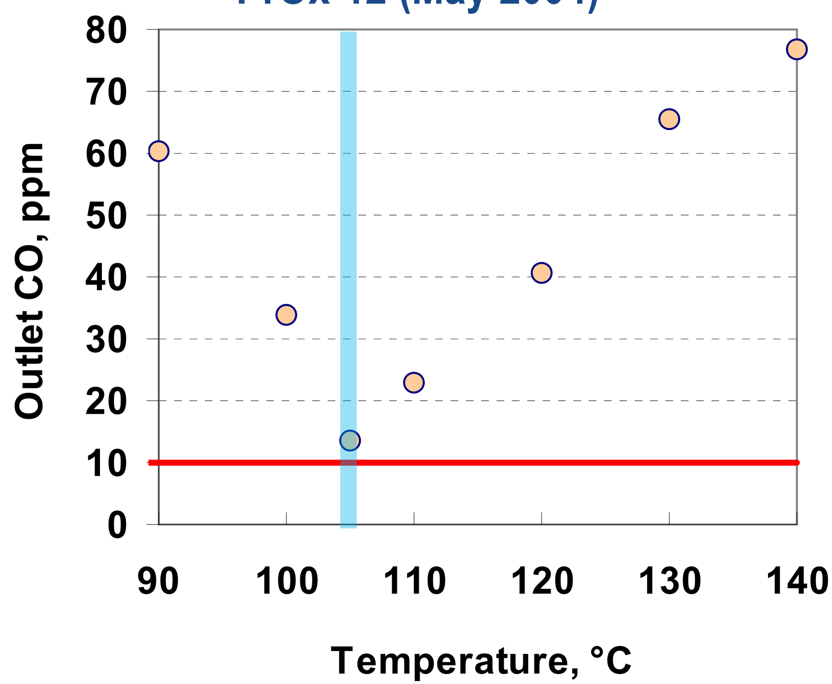
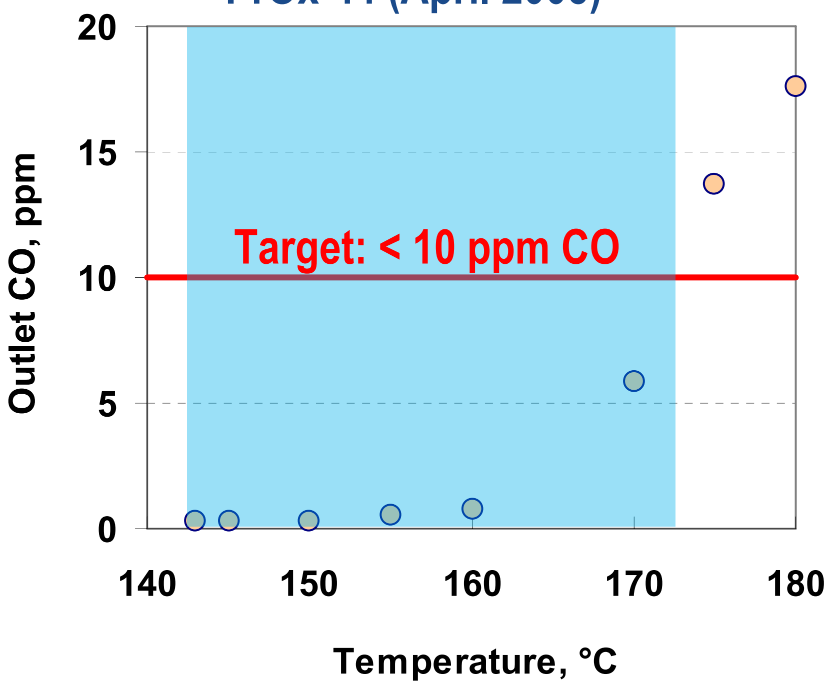
Preferential Oxidation Catalyst Improvements

- Preferential Oxidation (PrOx) catalyst improvements focused on achieving the < 10 ppm CO target over a wide temperature range

PrOx-12 (May 2004)



PrOx-44 (April 2005)



Significant improvement in the < 10 ppm CO operating temperature range

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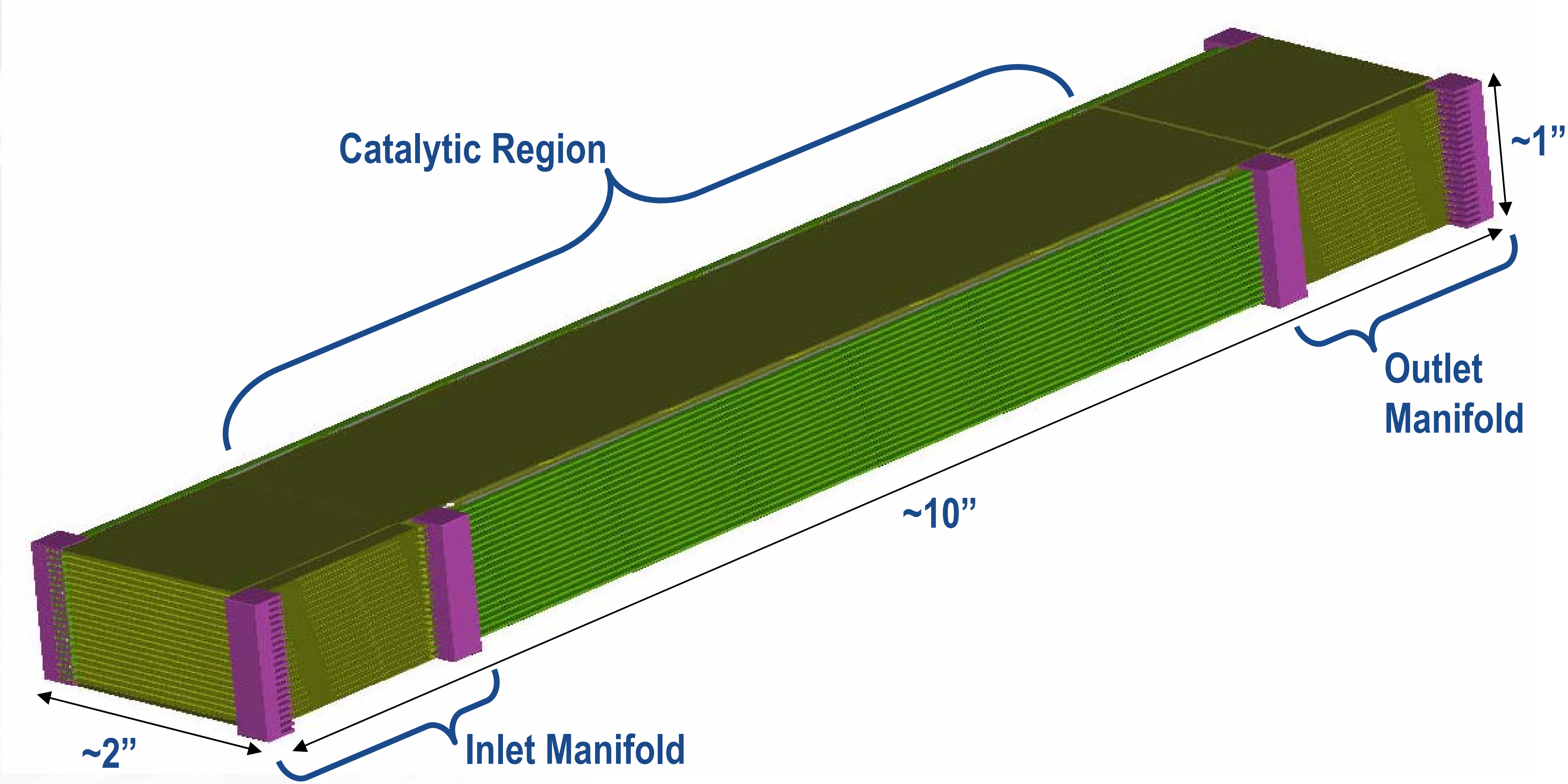
Next Steam Reforming Prototypes

- Advantages of New Prototypes:
  - Custom stamped plates for more efficient use of plate surface area
    - Increased active surface area per plate
    - Higher power density
  - Features that reduce thermal mass for more rapid start-up and transient response
    - Thinner plates
    - Improved structural design to support new plate stack
  - More commercial fabrication and assembly process
- Developing 2 different prototypes in parallel

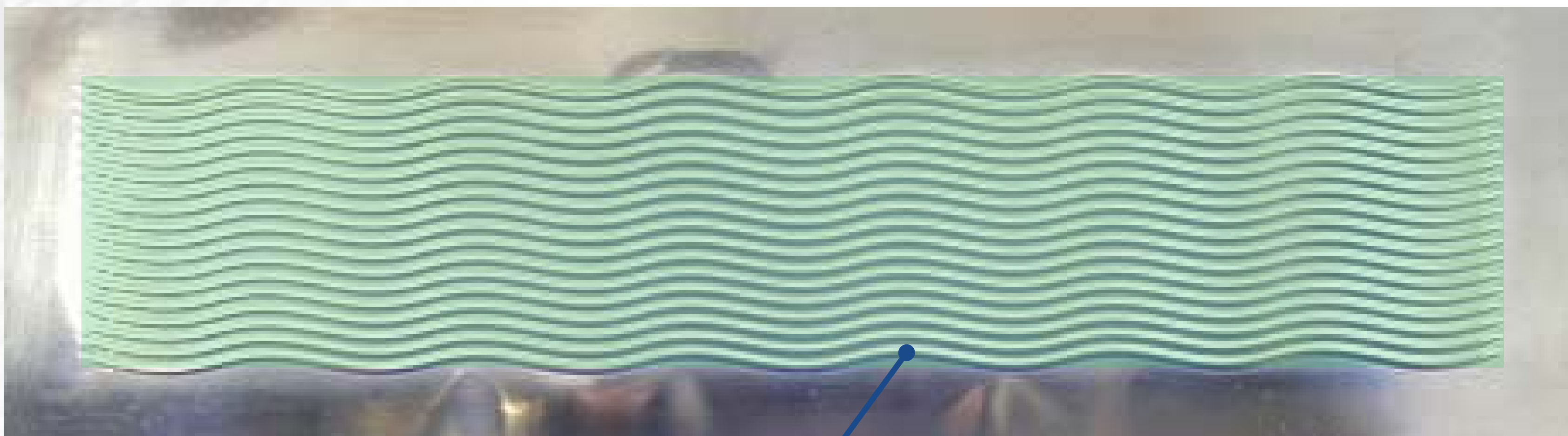
Next 3kW(e) Steam Reforming Plate Stack

Solid model of low thermal mass plate stack prototype



Custom Stamped Plate

- A series of custom stamped plates will be used for the next steam reforming plate stacks
- Custom stamped plates are 0.002” (0.05 mm) thick, significantly thinner than the first prototype plates
- Plate design maximizes catalyst active surface area per plate



Corrugated region will be coated with catalyst
(shaded for illustration purposes)

Alternative Applications for Plate Base Fuel Processing System

- Office of Naval Research (ONR) has a need for a compact, high-power density, man-portable 1 kW(e) fuel cell power generating system fueled by JP-8
- US Army Tank Automotive Research Development and Engineering Center (TARDEC) has a need for 5 – 20 kW(e) ground vehicle fuel cell auxiliary power units (APUs) fueled by JP-8

Alternative applications exist for plate base fuel processing technology developed under this contract

Future Work

- Demonstrate improved start-up and transient performance with new reactor prototypes
- Demonstrate steam reforming and preferential oxidation catalyst durability (1000 hours)
- Explore alternative applications for the technology developed under this contract
- Complete final report to document results and close-out the program

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Publications and Presentations

Publications:

- J. M. Zalc, D. G. Löffler, Fuel processing for PEM fuel cells: transport and kinetic issues of system design, *J. Power Sources* 111 (2002) 58-64.
- J. M. Zalc, V. Sokolovskii, D. G. Löffler, Are Noble Metal-Based Water–Gas Shift Catalysts Practical for Automotive Fuel Processing?, *J. Catal.,* 206 (2002) 169–171.

Presentations:

- System Integration Issues for a Plate Reactor-Based Automotive Fuel Processor – Am. Institute of Chemical Engineers Annual Meeting, 8 November 2002, Indianapolis, IN.
- Plate Based Fuel Processing System – FreedomCAR Technical Team Review, 19 March 2003, Detroit, MI.
- Non-noble Metal Water-Gas Shift Catalysts for Automotive Fuel Cell Application – American Chemical Society Meeting, April 2003.
- Plate Based Fuel Processing System – 2003 DOE Hydrogen, Fuel Cells and Infrastructure Technologies Program Review Meeting, 19-22 May 2003, Berkeley, CA.
- System Integration of a Plate Reactor for Gasoline Steam Reforming for Automotive Applications – 2003 Grove Fuel Cell Symposium, October 2003, London, UK.
- System Integration of a Plate Reactor for Gasoline Steam Reforming for Automotive Applications – 2003 Fuel Cell Seminar, November 2003, Miami Beach, FL.
- Plate Based Fuel Processing System – FreedomCAR Technical Team Review, 18 February 2004, Washington, DC.
- Plate Based Fuel Processing System – 2004 DOE Hydrogen, Fuel Cells and Infrastructure Technologies Program Review Meeting, 24-27 May 2004, Philadelphia, PA.
- Modeling and Test Results of Plate Reactors for a Gasoline Fuel Processor System – 2004 Fuel Cell Seminar, November 2004, San Antonio, TX.
- Modeling and Test Results of Plate Reactors for a Gasoline Fuel Processor System – 2005 Meeting of the Pacific Coast Catalysis Society, March 2004, Berkeley, CA.

Hydrogen Safety

- The most significant hydrogen hazard associated with this project is with undesired combustion of the hydrogen within the steam reforming prototype plate reactor.
  - Hydrogen is flammable and therefore, fire is the most significant hydrogen hazard if it results in injury to personnel and/or destruction or loss of equipment. A fire can result when hydrogen (from a leak in the 3 atm reformer side of the prototype) and an oxidizer (air on the 1 atm combustion side of the prototype) forms a combustible mixture, the combustible mixture contacts an ignition source (combustion catalyst on the combustion side of the prototype), and ignition occurs.
  - A burn can result from direct contact to a hydrogen fire, thermal radiation from a hydrogen fire, or contact with a surface that has been exposed to a hydrogen fire.

Hydrogen Safety

- Our approach to deal with the fire hazards associated with the steam reforming prototype plate reactor is:
  - Ensure a leak free plate reactor by pressure testing all welds during plate stack assembly, after final assembly of the plate stack and before installing the plate stack for steam reforming testing
  - Pressure testing the plate stack on a daily basis prior to the day's steam reforming testing
  - Prohibiting access into the prototype test cell while the plate reactor is fueled
- The test cell is continuously monitored by a lower explosive limit (LEL) detector. When the hydrogen concentration in the test cell is > 20% of the LEL, the monitoring system will automatically:
  - Shut-down power and fuel flow to the prototype system
  - Initiate a nitrogen purge through the prototype hardware
  - Trigger a laboratory evacuation alarm
- In the event a fire develops during a steam reforming experiment, thermocouples monitoring temperature of the prototype will initiate an automatic power and fuel shut-down sequence when the plate temperature exceeds 900°C (well below the hydrogen flame temperature).

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