Microchannel Fuel Processing

Fuel Cells for Transportation/Fuels for Fuel Cells

2002 Annual Program/Lab R&D Review

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Objectives

- Demonstrate at ~1/10 scale a microchannel-based fuel processing system that meets FreedomCAR performance targets.

Performance Criteria	Current Performance	2004 FreedomCAR Targets
50 kWe System Volume	<1 cubic foot (<28L)	2.5 cubic foot (71 L)
Power Density, Specific Power	1800 W/L, 320 W/kg	700 W/L, 700 W/kg
System Efficiency	81%	76%
Durability	>1000 h	4000 h
Transient Response (10 to 90%)	5 s	5 s
Start-Up to Full Power, 20°C	30 s (low dP projection), 15 m (current reactor block)	<1 min
Steady State CO Content	15 ppm	10 ppm

- Engage industrial partner(s) to facilitate development of full scale fuel processing system.
- Develop reactors, vaporizers, recuperative heat exchangers, and condensers broadly applicable to other fuel processing options.

Approach

Steam Reformation

- Improve power density, specific power
- Demonstrate fuel flexibility, transient response, 1000-hour durability (catalyst and reactor)
- Redesign for rapid startup

Water Gas Shift Reactor

- Differential temperature design reduces reactor size
- Collaborate on catalyst formulations from industry

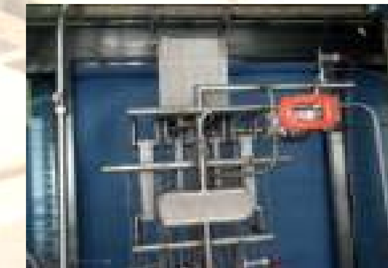
Preferential Oxidation Reactor

- Investigate advantages of microchannel design

Project Timeline

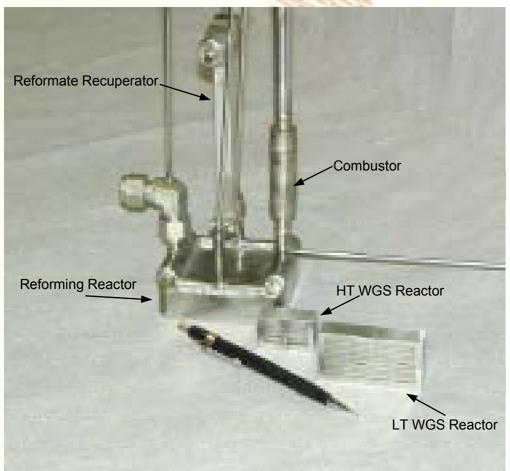
FY 1998
Full-size gasoline vaporizer/combustor
R&D100 Award

FY 1999
Fast SR kinetics demonstrated in a microchannel reactor



FY 2000
Designed and built
10 kWe SR with integrated HX network

FY2001
10 kWe reactor testing
First “low dP” vaporizers
Modular test stand established



FY 2002
SR fuel flexibility, durability testing
WGS/PROX catalyst studies
Differential temperature reactor concept
SR/WGS/PROX initial integration
Full-scale low dP vaporizers delivered

Engineered catalyst, reactor development

Demonstrate rapid startup

Sulfur management

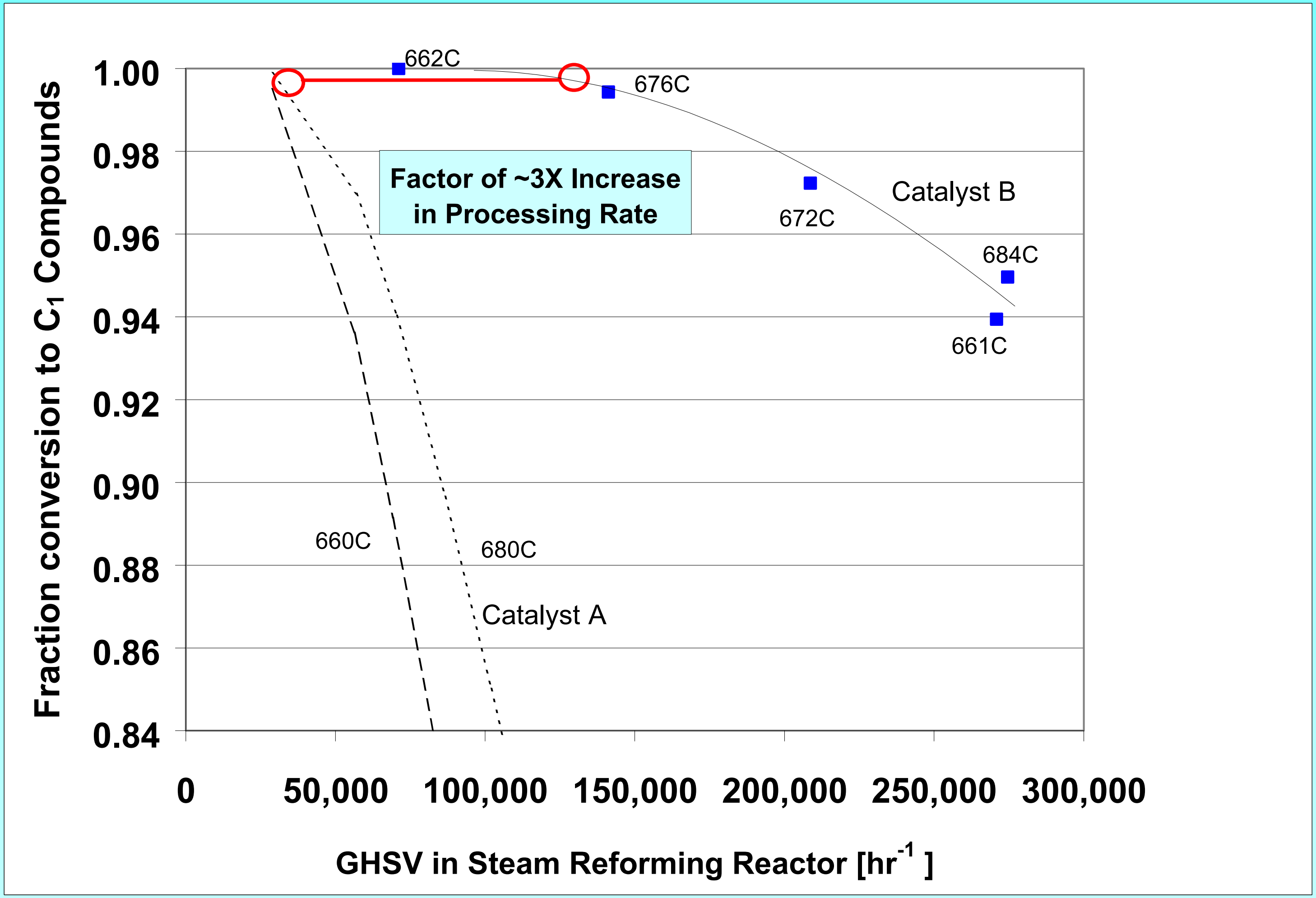
Integrated reformer/fuel cell demonstration at ~5 kWe

Collaborate with industrial partner(s) on manufacturing, field testing, lifetime, controls

2002 2003 2004 2005 2006 2007 2008

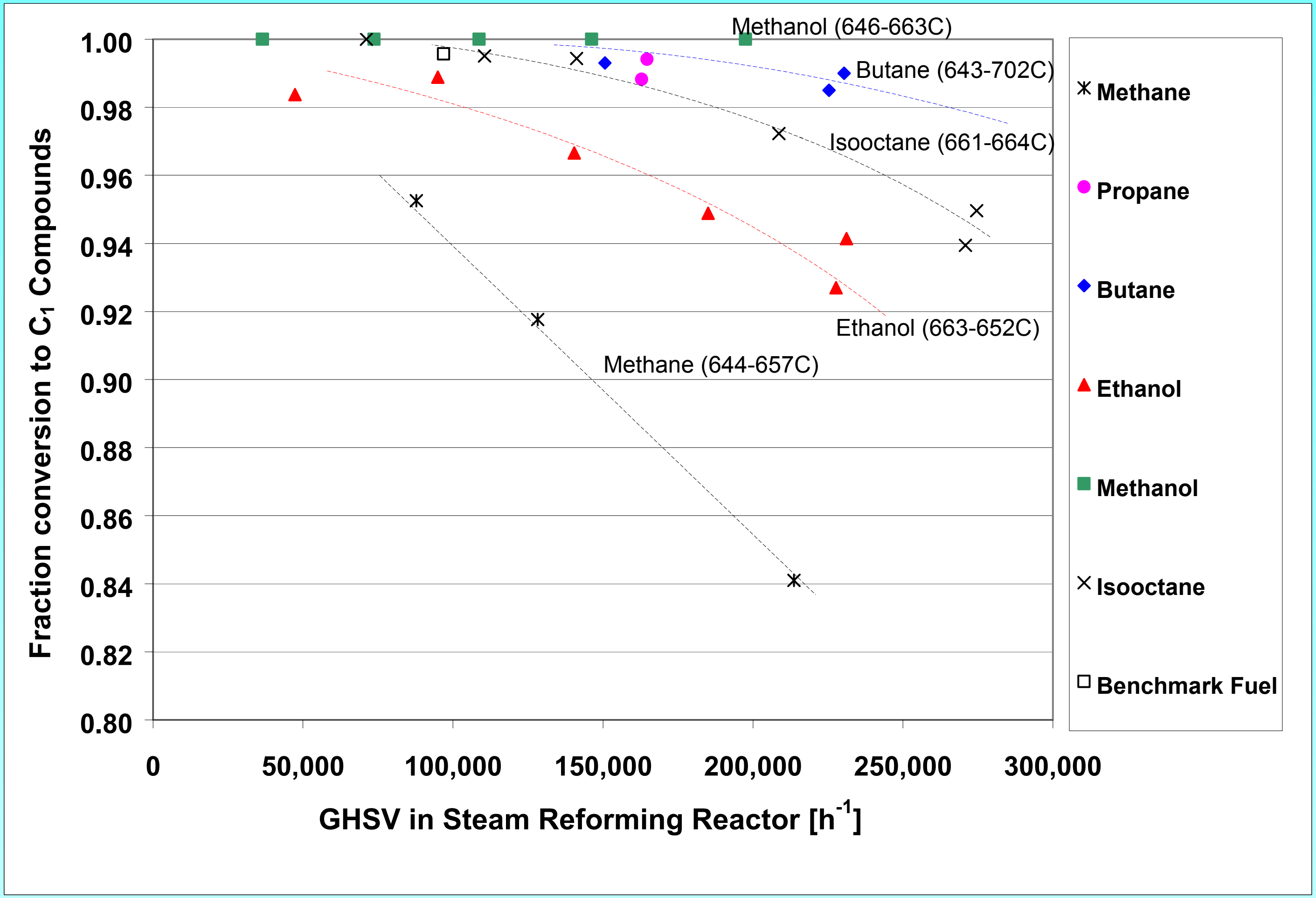
Reactor Volumetric Productivity Improved

(isooctane at 3:1 S:C / GHSV basis: 1atm, 25C, exit conditions, bulk catalyst volume)



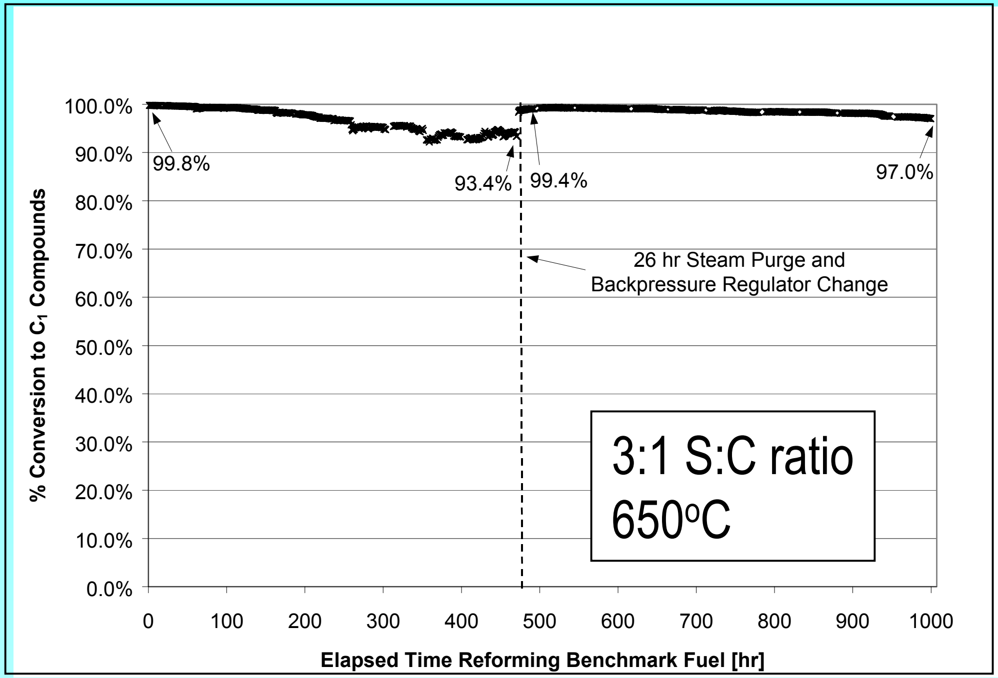
Fuel Flexibility Demonstrated

(cat. "B", 3:1 O:C / GHSV basis: 1atm, 25C, exit composition, bulk catalyst volume)

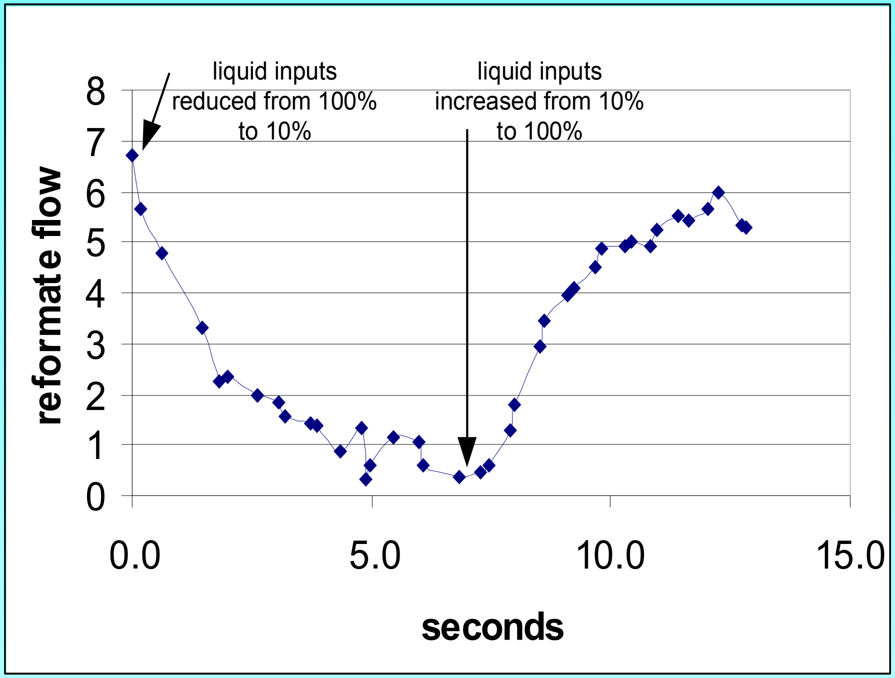


Durability and Transient Response

1000-Hour Reforming Test



5 Second Warm Transient Response

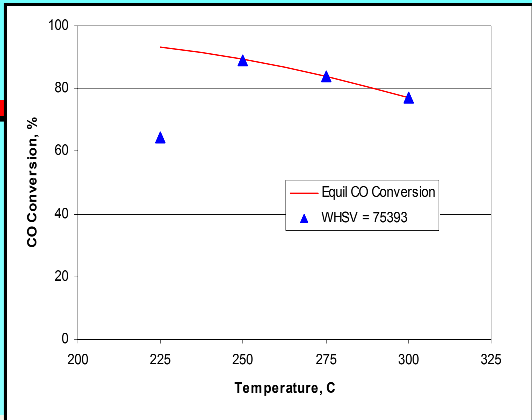


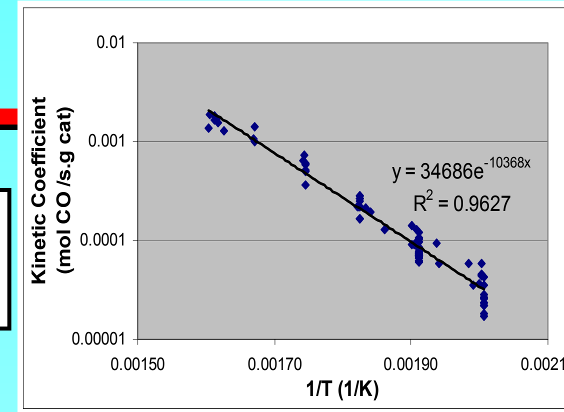
Benchmark Fuel	74 wt% isooctane
	20 wt% xylene
	5 wt% methyl cyclohexane
	1 wt% 1-pentene

Response to step changes in liquid fuel and water feed rates of 100% to 10% and 10% to 100% in 51 cc reactor

Water-Gas Shift Development

Approach / Progress





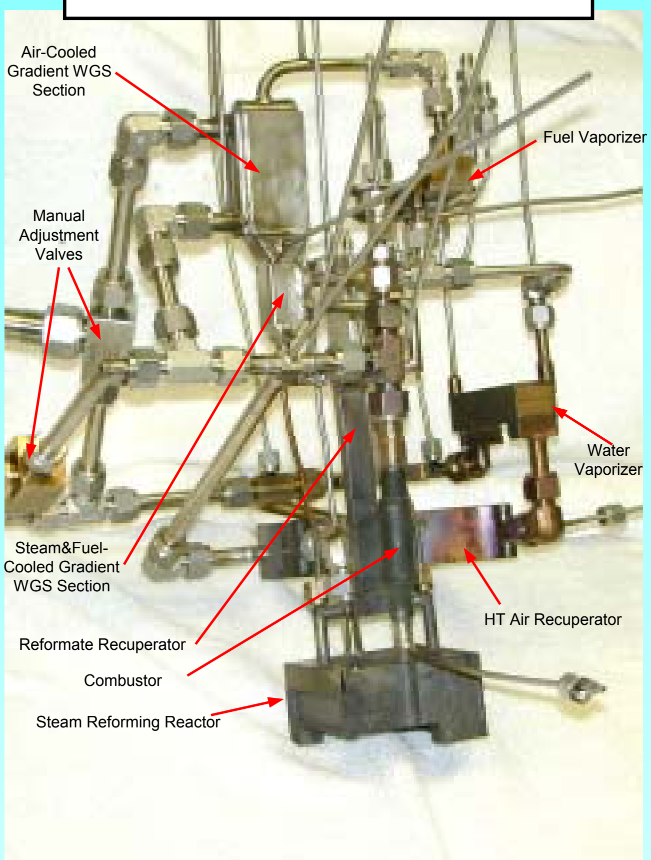
Catalyst Screening

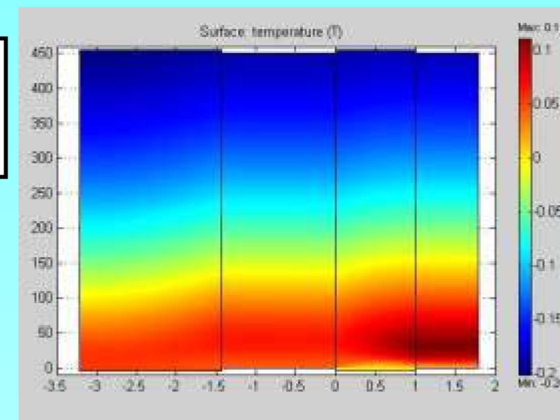
Kinetic Model

Reactor Modeling

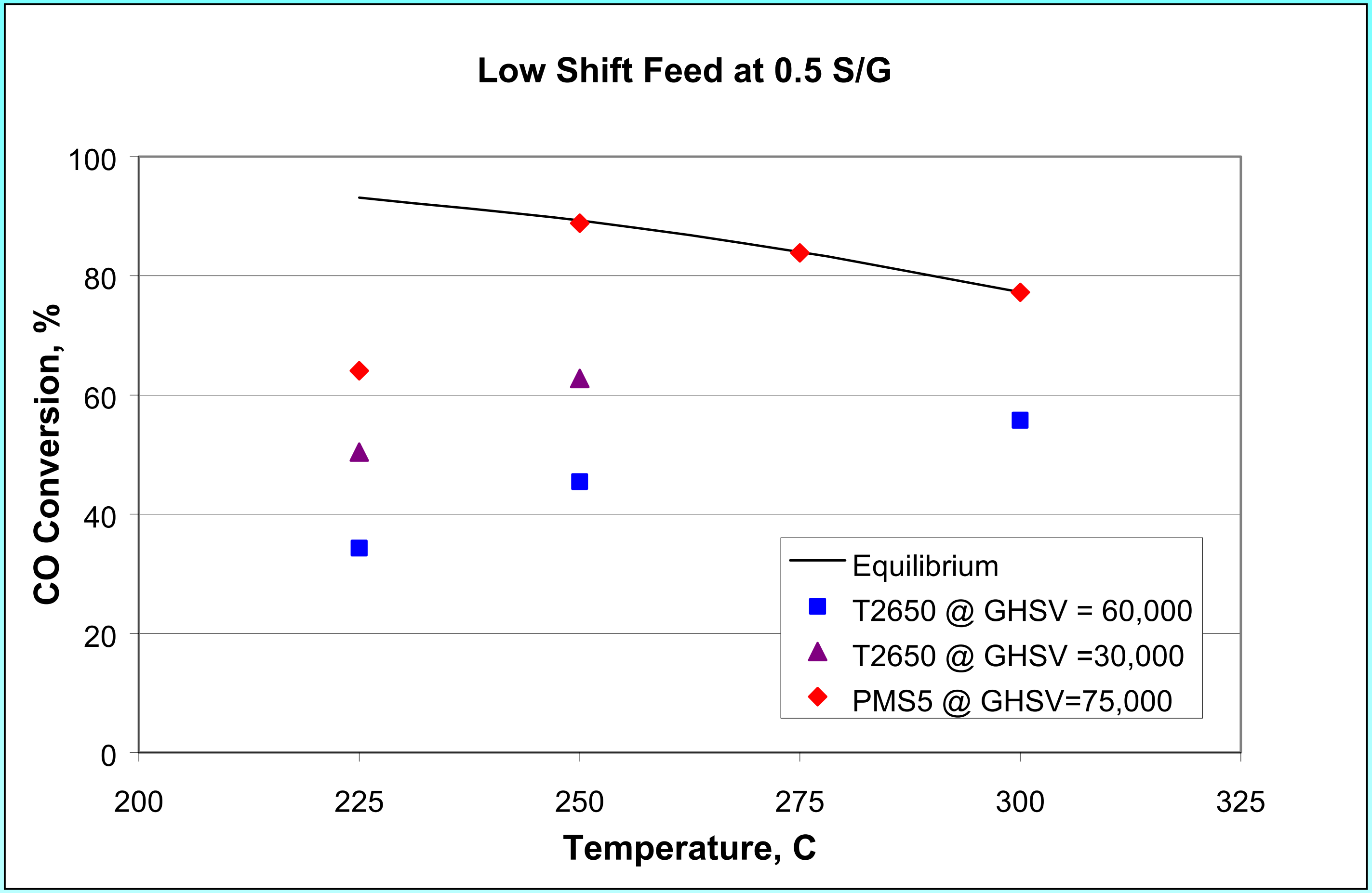
Reactor Prototypes

Integrate into system





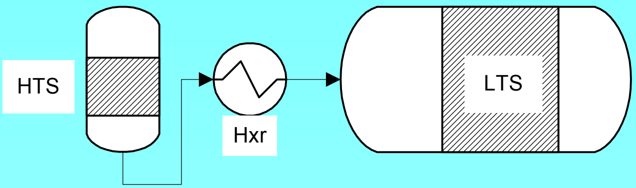
WGS Catalyst Screening
Sud-Chemie Copper-Zinc (T2650) and Precious Metal/Ceria (PMS5)



PMS5 preferred for microchannel WGS development

Water-Gas Shift

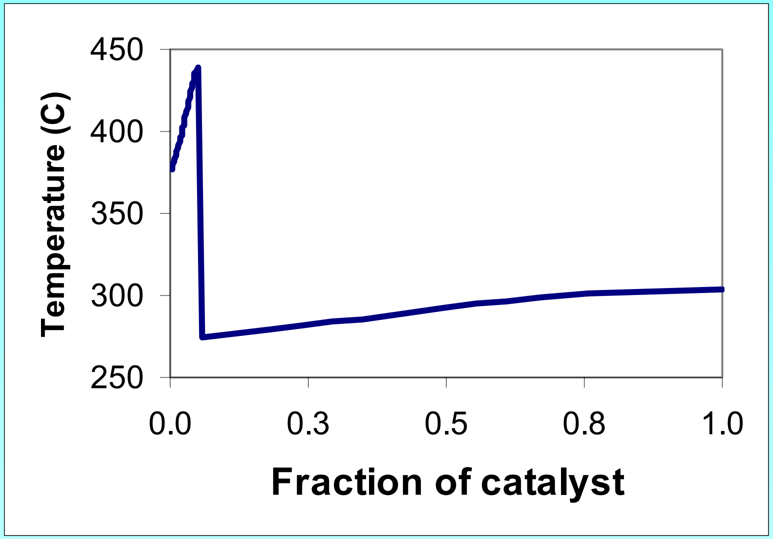
Why microchannels? – To control temperature profile



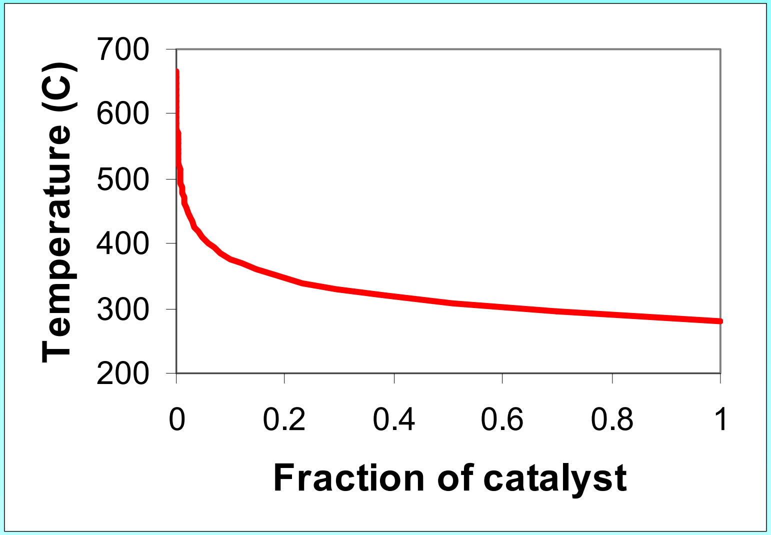
1 Integrated Unit

2.3X Less Catalyst

Conventional 2-stage Adiabatic



Ideal profile

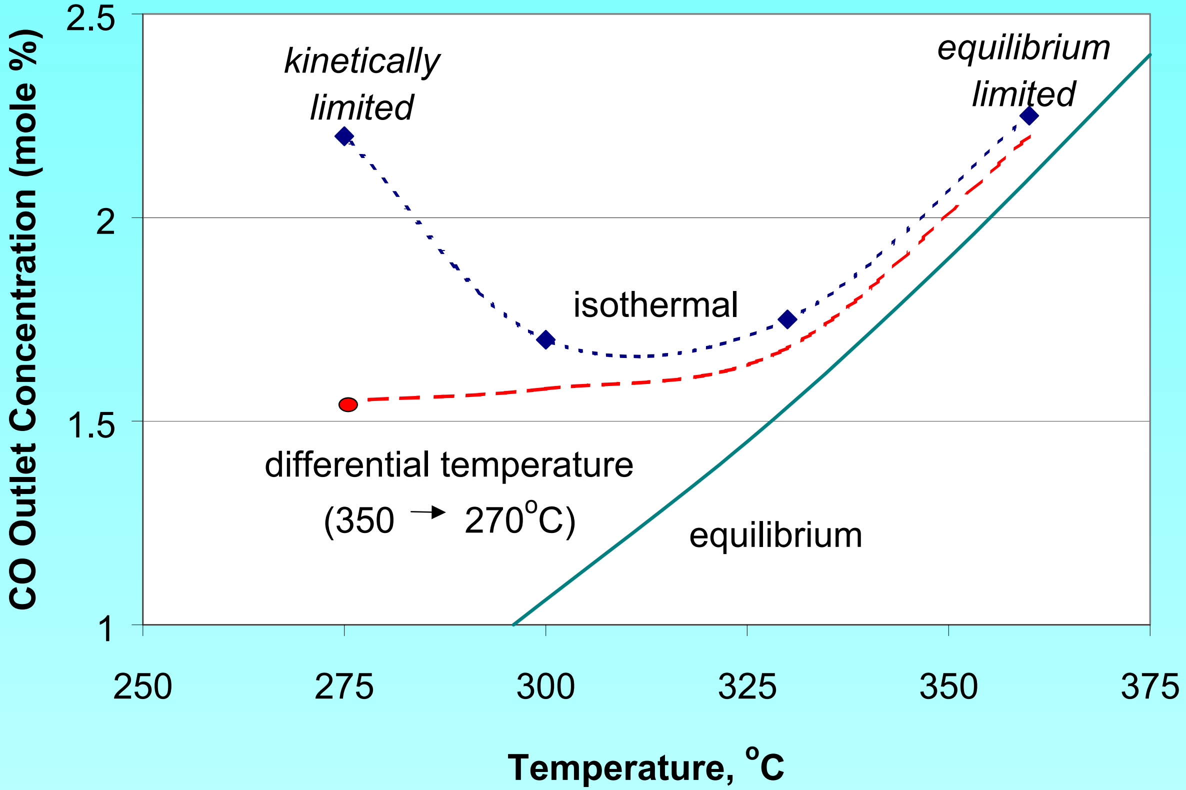


Based on Sud-Chemie PMS5 PM catalyst and SR reformate

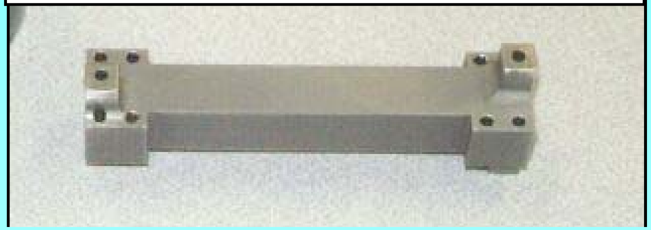
Differential Temperature Water-Gas Shift

Reactor volume < 3L projected from experimental results

150,000 GHSV, 0.5 Steam/Dry Gas, 4.6% CO Feed



Prototype 7-channel Reactor

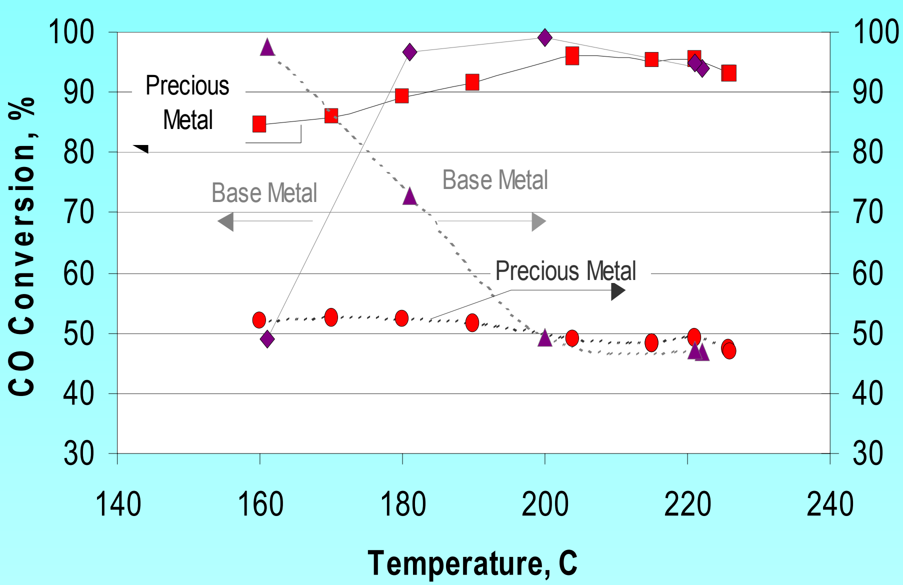


Reactor can be operated isothermally or with a temperature gradient

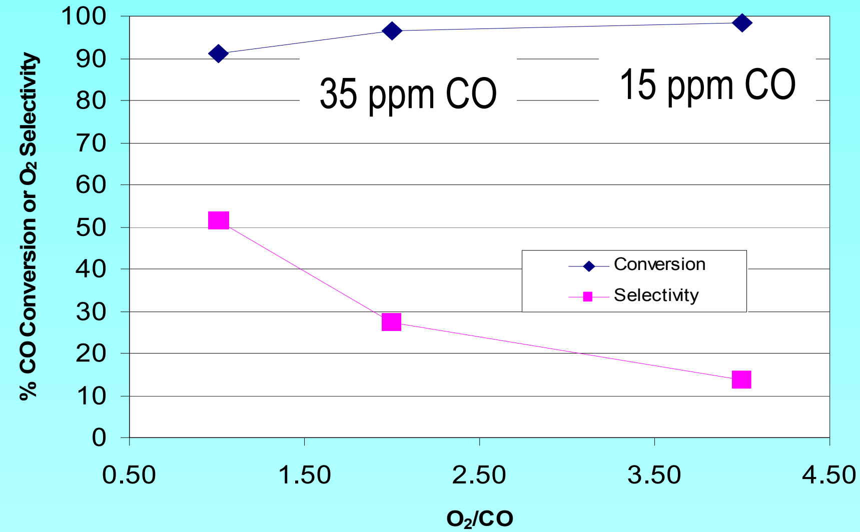
Differential temperature out performs isothermal operation

Performance of Engineered PROX Catalysts

Stage 1 PROX, Precious and Base Metal Catalysts ; 1% CO, O2/CO = 1, GHSV = 400K, S/G = 0.3

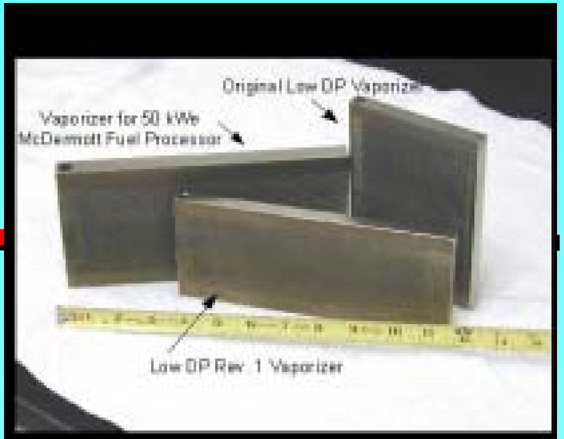


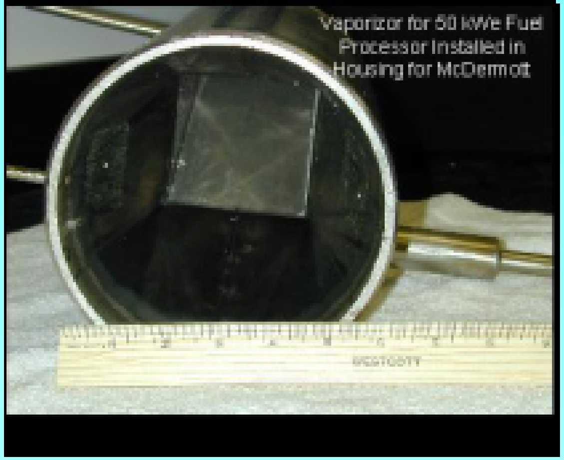
Stage 2 PROX Performance of Precious Metal Catalyst in a Single Channel Reactor: 0.1% CO, 100°C, GHSV = 200K; S/G=0.3



Base metal catalyst preferred for Stage 1; Precious metal catalyst preferred for Stage 2

Industry Interactions



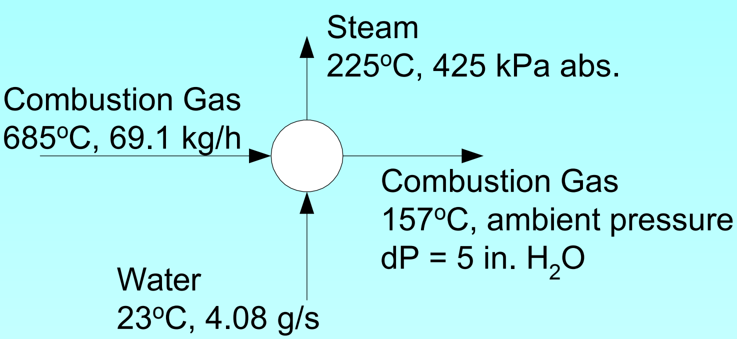


- Formally seeking to engage industrial partner
- Water Vaporizer for 50 kWe ATR designed, built, tested and delivered to McDermott Technology, Inc.
- Water Vaporizer delivered to Gas Technology Institute for boiler-related research, funded by OIT.
- Interaction with Engelhard, Süd Chemie, NexTech, and ANL for catalyst formulations
- Vaporizer and recuperator delivered to Innovatek for Army reformer demonstration

50 kWe Water Vaporizer Panel Size:
dimensions 22.2 cm x 10 cm x 1.8 cm
weight = 2.4 kg

At max operating point:
HX duty = 24.6 kW
HX intensity = 60 W/cm3

Sample Operating Point

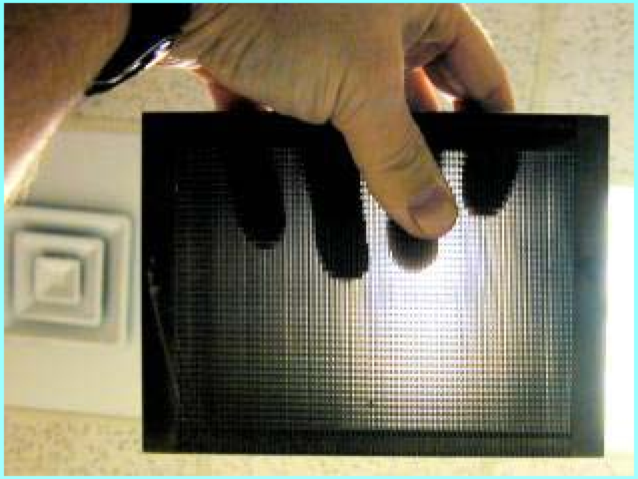


Plans, Future Milestones

- Complete catalyst optimization (FY03)
- WGS, PROX reactor development and integration (FY03)
- High temperature reformation/sulfur tolerance study complete (FY02)
- Demonstrate rapid start-up concepts based on low dP design (FY03)
- Develop sulfur management approach (FY03)
- Engage industrial partner(s) to facilitate development (FY03)
- Demonstrate fast-start, integrated fuel processor at 5 kWe, and operate with a PEM fuel cell (FY04)

Rapid Cold Start Concept for Steam Reformer

- Low combustion gas dP key to rapid startup (30 second start projected)
- Target test system has four reformer stages with one water vaporizer



Key Data For 30-Second Startup Calculation - 2.4 kWe System

Component	Mass	ΔP at Normal Cond. (~60 SLPM, Air)	ΔP at Startup (~800 SLPM, Air)
Reforming Reactor, 650C (4 stages, 600We each)	720 g (180 g, per stage)	1.6 in H_2O (0.4 in H_2O, per stage)	21.3 in H_2O (5.33 in H_2O, per stage)
Water Vaporizer (1 stage)	91 g	0.1 in H_2O	1.3 in H_2O

Responses to Comments from Last Year

- *An effort should be made to test this reformer with methanol:* Tests conducted showed that methanol was the most easily reformed of all fuels evaluated. Productivity is >2x higher than rate for benchmark gasoline, or ~4 kWe/L.
- *Engage an industrial partner to build a complete reforming system:* Formal process underway.
- *More studies evaluating catalyst performance and life:*
  - Completed 1000 hour reformer durability test on benchmark gasoline.
  - Commercial and prototype WGS and PROX catalysts extensively studied in powder and engineered form.
  - Developed single channel reactors that provide flexibility in testing of engineered catalysts, provide data to develop kinetic model.