Microchannel Reformate Cleanup: Water Gas Shift and Preferential Oxidation

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K.P. Brooks, R.A. Dagle, J.M. Davis, J. Holladay, M.J. Kapadia,
D.L. King, L.R. Pederson, B.Q. Roberts, V.S. Stenkamp, W.E. TeGrotenhuis, R.S. Wegeng

Pacific Northwest National Laboratory

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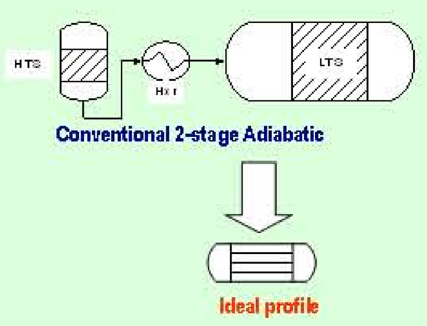
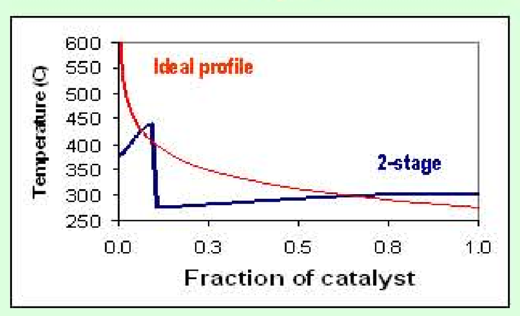
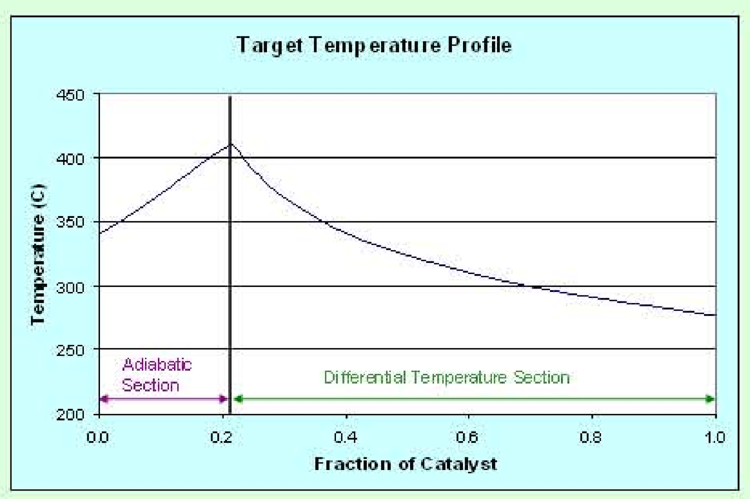
Differential Temperature Water Gas Shift

Approach





- **Objective:**
  - Smaller size – higher power density and specific power
  - Reduced cost
    - Improved catalyst efficiency
    - 3 devices collapsed into 1
  - Potential for higher energy efficiency
- **Approach:**
  - Precious metal catalyst for high activity
  - Integrate microchannel heat exchange for temperature control
  - Optimize thermal profile
    - Adiabatic front end
    - Differential temperature back end
  - Reduce catalyst loading by up to ½

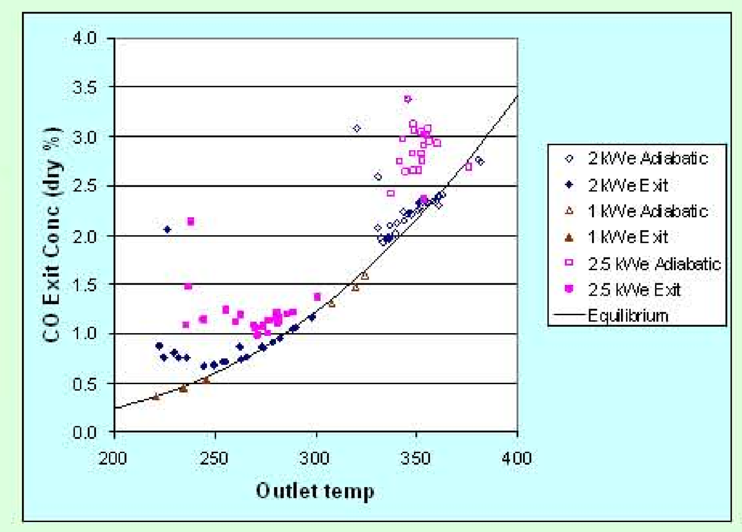


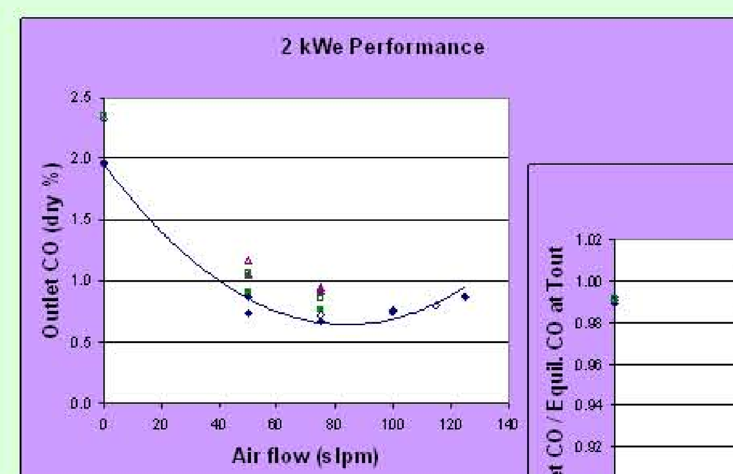
Experimental Results

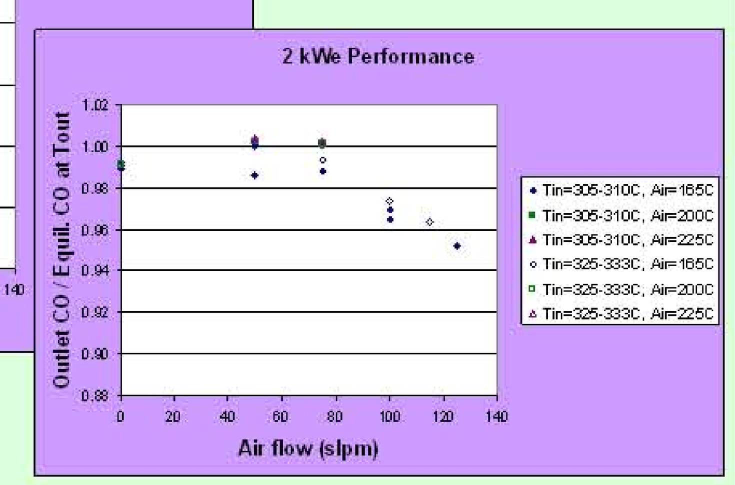
- **Tested with Steam Reformate**
  - Operated 50+ hours at 1-2.75 kWe
  - 12% CO and 14% CO_2 (dry)
  - 0.5 Steam : Dry gas
- **GHSV**

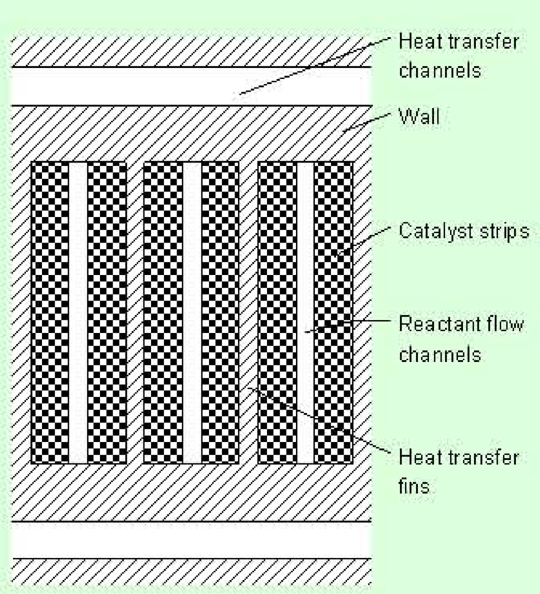
Capacity	Adiabatic Section	Diff Temp Section	Total
1 kWe	166,000	40,000	32,000
2 kWe	332,000	80,000	64,000
2.5 kWe	414,000	99,000	80,000

- **Parameters**
  - Syngas flow rate
  - Feed temperature
  - Cooling air flow
  - Cooling air temperature

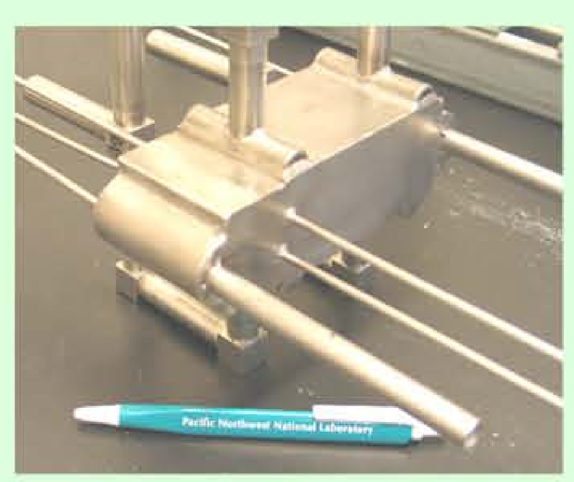








- **Problem**
  - WGS mildly exothermic
  - Interleaved approach gives too much heat transfer area
  - Reaction quenched prematurely
- **Solution**
  - Utilize concept of extended area in reaction channels
- **Result**
  - Heat exchange will support required heat flux
  - 52% of reactor volume is catalyst
  - ΔT in fins < 0.1°C



Full-scale 50 kWe Size and Weight Projections

	Volume	Weight	Pwr Density	Specific Pwr
2-Stage Adiabatic	8.9 L	–	5,600 We/L	--
Prototype @ 2 kWe	4.3 L	8.9 kg	11,600 We/L	5,600 We/kg
Prototype @ 2.5 kWe	3.4 L	7.2 kg	14,700 We/L	6,900 We/kg

- Assumptions for Conventional 2-Stage Adiabatic System
  - 350 g/L catalyst loading onto a 600 cpi monolith
  - Same catalyst activity as used in differential temperature design
  - Negligible mass transfer resistance
  - Total volume 25% greater than catalyst volume
  - 5 W/cm³ heat transfer power density in heat exchanger
  - Steam reformate with 3:1 original steam to carbon ratio
  - Conventional 2-stage adiabatic estimated at 8.9 L
    - 0.8 Liter Stage 1, 1.25 Liters heat exchanger, 7.8 Liters Stage 2
    - Does not include piping between devices

Background

Objectives

- **Overall Objectives**
  - Apply microchannel architectures where appropriate in fuel processing for transportation, stationary, and portable applications to reduce size and weight, improve fuel efficiency, and enhance operation.
  - Develop a prototype microchannel-steam-reforming fuel processor at 2 kWe scale that will meet DOE performance targets when scaled up to 50 kWe.

Performance Criteria	2004 Projected Performance	2004 Demo Target
Cold (20C) Start Time	12 sec, reformer only	<60 s to 90%
Start up Energy	<7 Mj (a)	2 MJ
Power Density	2307 W/L (a)	700 W/L
Efficiency	78%	78%
Durability	>1000 hr	2000 hr

(a) based on individual components only, excludes tube, duct, insulation etc.

- **Task Objectives**
  - Demonstrate **90%** CO conversion in a single-stage WGS reactor that scales to less than **3** liters at full-scale
  - Determine whether microchannel architecture provides opportunities for size and weight reduction for PROX reactor

Approach

- Compact size and weight to meet packaging requirements
  - rapid heat and mass transfer for high hardware productivity
- Thermal management
  - high heat transfer effectiveness in heat exchangers and reactors for maximum heat utilization and high fuel efficiency
- Rapid start-up
  - imbedded heat transfer in reactors facilitates rapid heating
- Cost
  - improved productivity of precious metal catalysts

Targets

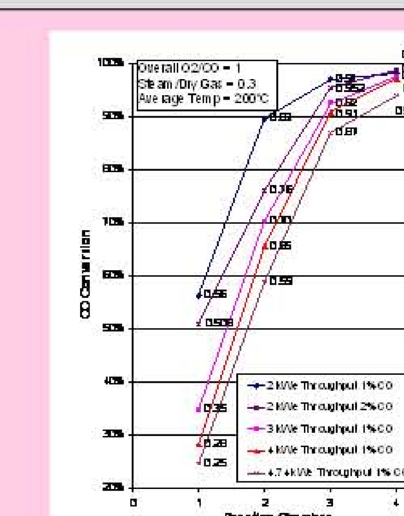
Key DOE Technical Targets Addressed:

- CO Content in Product Stream
  - (< 10 ppm steady-state, < 100 ppm transient)
- Power Density
  - (> 800 W/L)
- Specific Power
  - (> 800 W/kg)

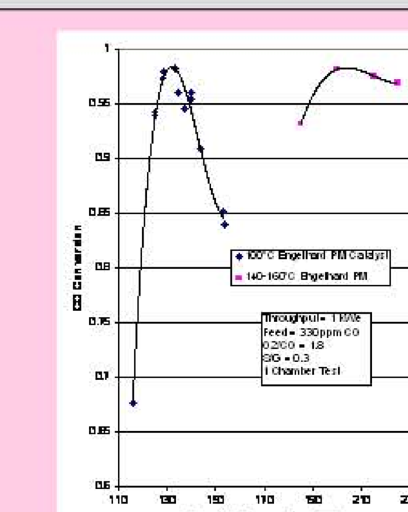
Preferential Oxidation

Microchannel PROX Reactor Investigations

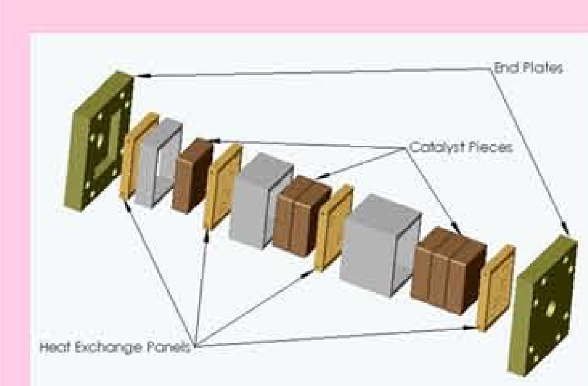
- **Objective**: Determine whether microchannel architecture provides opportunities for size and weight reduction for PROX reactor.
  - Support fast kinetics
  - Minimize H_2 Oxidation
  - Maximize CO Conversion
- **Approach:**
  - Single-channel, isothermal catalyst tests
    - Evaluate industrial PROX catalysts
    - Characterize kinetics
    - Identify temperature and oxygen sensitivities
  - Design and test a 2 kWe PROX reactor
    - Control temperature
    - Alternating catalyst pieces and microchannel heat exchangers
    - Conduction to remove heat from catalyst
    - Inject air within each chamber of the reactor
    - Adjust amount and type of catalyst in each chamber
- **Progress:**
  - 1st Stage PROX microchannel reactor demonstrated at 2 kWe scale – exhibits high productivity due to internal microchannel heat exchangers providing temperature control
  - Combined 1st and 2nd stage PROX reactor achieves 1% to 10 ppm CO reduction at a 2 kWe scale

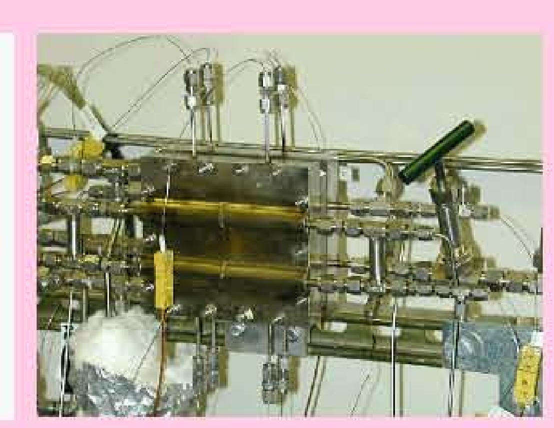


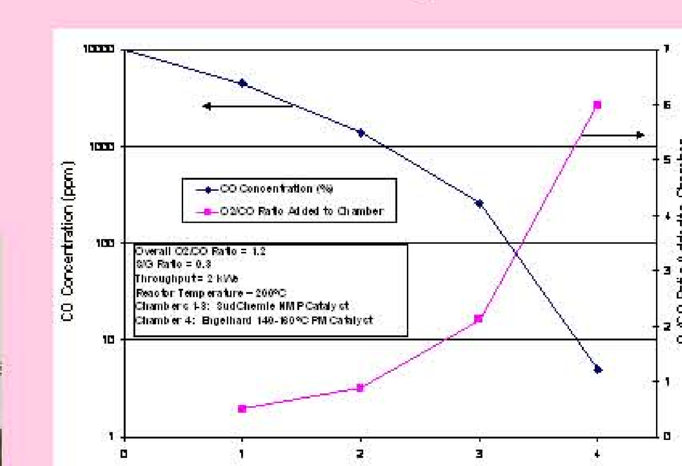
- **First Stage (1% CO)**
  - Sud-Chemie NPM Catalyst Results
  - Air addition after each stage results in high conversions up to 4 kWe with 1 and 2% CO Feed



- **Second Stage (330 ppm CO)**
  - Engelhard PM Catalyst Results
  - 140-160°C 2nd Stage Catalyst operates at the same temperature as NPM 1st Stage Catalyst







- **Combined 1st and 2nd Stage PROX**
  - Combined Sud Chemie NPM Catalyst and Engelhard PM Catalyst
  - Added higher ratios of O_2/CO in later chambers to increase conversion
  - Decreased CO from 1% to < 10 ppm at 2 kWe throughput with an overall O_2/CO ratio of 1.2 and a combined GHSV of 93,000

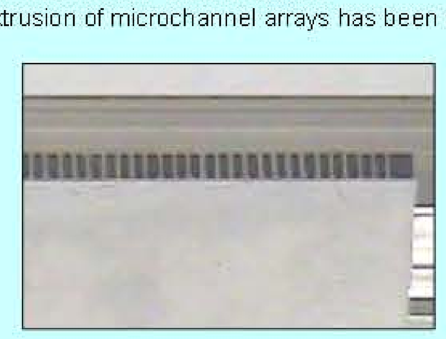
Future Work

Water Gas Shift

- Complete testing of 2 kWe WGS reactor
- Integrate PROX and WGS reactors with steam reformer at 2 kWe scale
  - Demonstrate rapid start
  - Evaluate the startup time, energy, and CO content versus time for this system
- Resolve durability technical challenges
  - Identify source of WGS deactivation with shutdown/restart
  - Demonstrate 2000 hour durability

Manufacturability

- Methods for loading catalyst powder in situ are being developed under other programs
- Extrusion of microchannel arrays has been demonstrated



- Additional investments in low cost manufacturing techniques are required for adoption of the technology

Preferential Oxidation

- Evaluate aluminum and titanium alloys for microchannel PROX reactor
  - Potential weight reductions
- Design a next generation 2 kWe reactor
  - Optimize size and weight
  - Facilitate heat integration within fuel processing system
  - Designed for rapid start and transient operation
- Test as part of integrated fuel processor with steam reformer, water-gas-shift and heat exchangers
- Couple to a PEM fuel cell