DOE H Program Review, May 2003

Novel Catalytic Fuel Reforming Using Micro-Technology with Advanced Separations Technology

May 2003

InnovaTek, Inc

Richland, WA

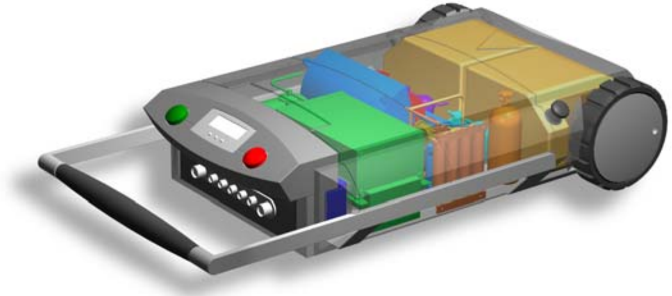
InnovaTek Program Goal

Develop fuel processors to supply clean hydrogen to fuel cells for portable and stationary power.

- **Produce H_2 for fuel cell-powered vehicle refueling stations.**
- **Provide auxiliary power units for transportation power needs.**

Industrial Design -- Use Concept

Refueling Station



Portable or Stationary APU

Development Objectives

Produce pure hydrogen from available fuels using highly efficient, micro-channel catalytic steam reforming and membrane purification technologies.

2002: Component development for 12 LPM hydrogen from natural gas and diesel with >50 ppm S (250 ppm)

2003: Component optimization and design for 60 LPM hydrogen from natural gas and diesel with >100 ppm S (500 ppm)

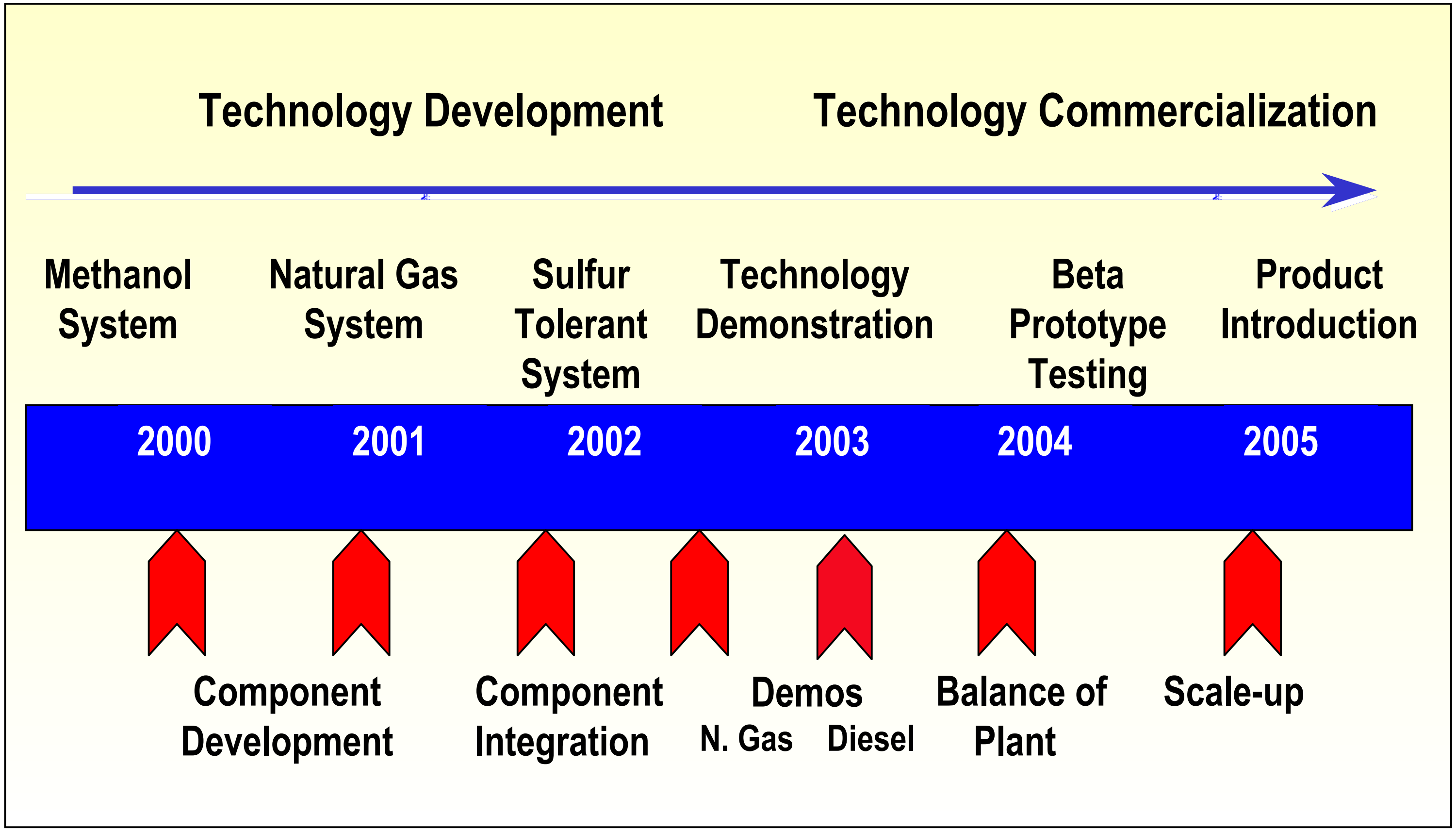
Goals and Methods

Sulfur-tolerant **steam reforming catalyst** reforms fuel without need for prior sulfur removal.

Advanced **membrane technology** produces nearly pure hydrogen output thereby enabling higher fuel cell power densities & no potential for electrode poisoning.

Micro technology for reactor, heat exchanger, combustor, and fuel vaporizer improves system efficiency through optimized thermal management and fluid dynamics.

Project Timeline



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System Development Status

Develop and test core technology

Design process configurations

Evaluate configurations with model simulation

Predict component requirements with model simulation

Design and fabricate components

Conduct iterative testing of components

Demonstrate integrated system

Further development and optimization of core components

Integrated System

System design and optimization is complex

- Micro-channel heat exchangers
- Catalytic steam reformer and burner
- Hydrogen purification < 5 ppm CO
- Condensate removal and recovery
- Diesel and steam injector and mixing
- Fuel and water delivery

Integration schemes evaluated using process model

Process Simulation & Configuration Options

Developed model to track mass and enthalpy flows.

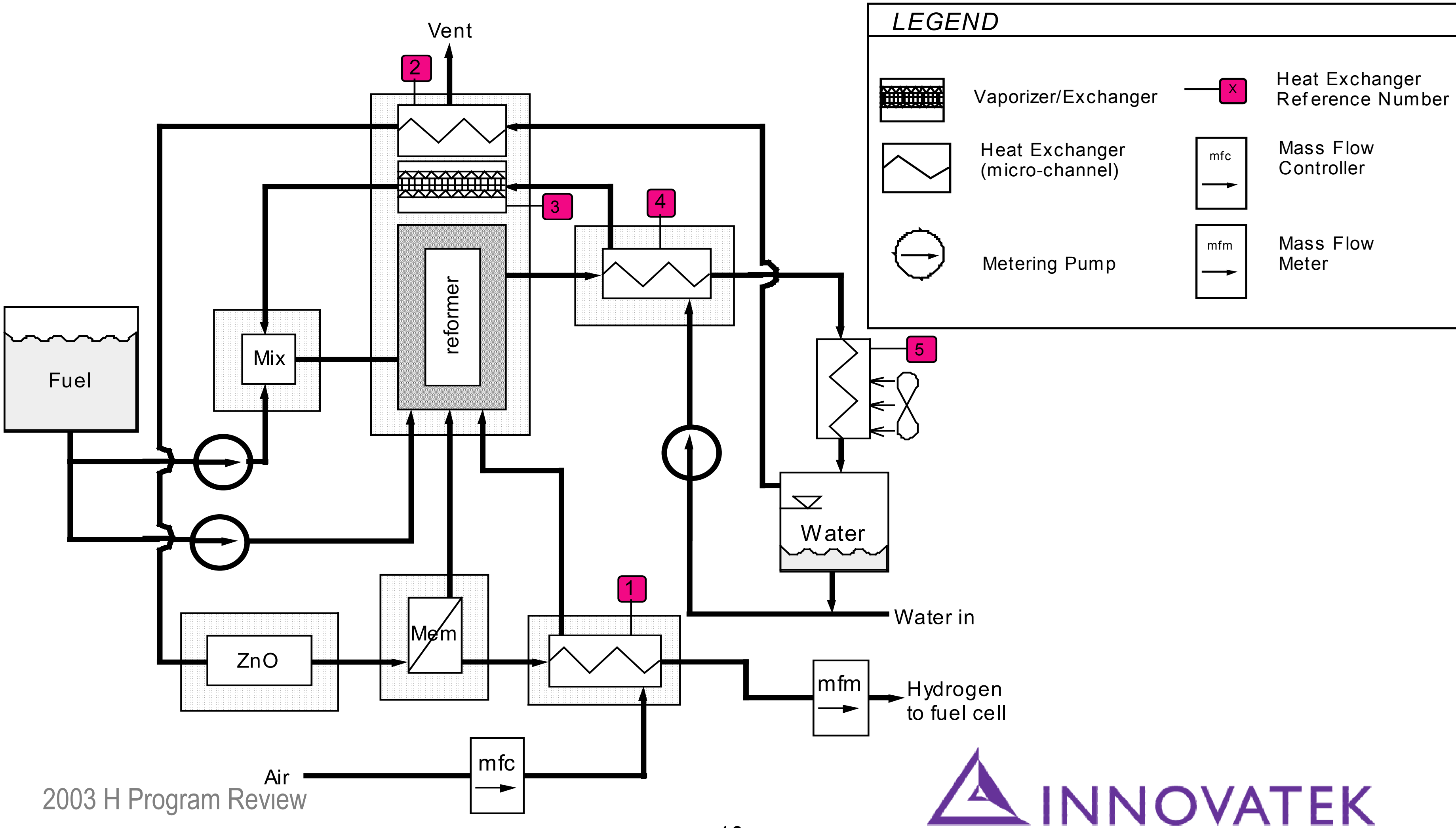
Estimates molar flows of reforming products by solving for equilibrium concentrations at given temperature and pressure.

Thermodynamic properties determine heat transfer, water removal, and air & heat required to achieve energy balance.

Model output helps size system components and select range for operating conditions.

Options for thermal management and water management – major influence on effective system operation and integration

Integrated System Schematic



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Heat Exchange Components

Ref #	Description	Hot Fluid	Cold Fluid
1	H_2 Cooler	Hydrogen Product	Air Feed
2	Reformate Heater	Combustion Exhaust	Dry Reformate
3	Steam Super Heater	Combustion Exhaust	H_2O 80% Steam
4	Reformate Cooler	Wet Reformate	H_2O Feed
5	Reformate Condenser	Wet Reformate	Blower Air

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InnovaGen™ Steam Reforming Catalyst

Proprietary bi-metallic formula supported on modified Al_2O_3

Optimized for activity, selectivity, and stability

Tested using diesel, gasoline, and natural gas

Determined optimized reforming conditions for diesel: reaction temp, steam/carbon, space velocity

Patent pending

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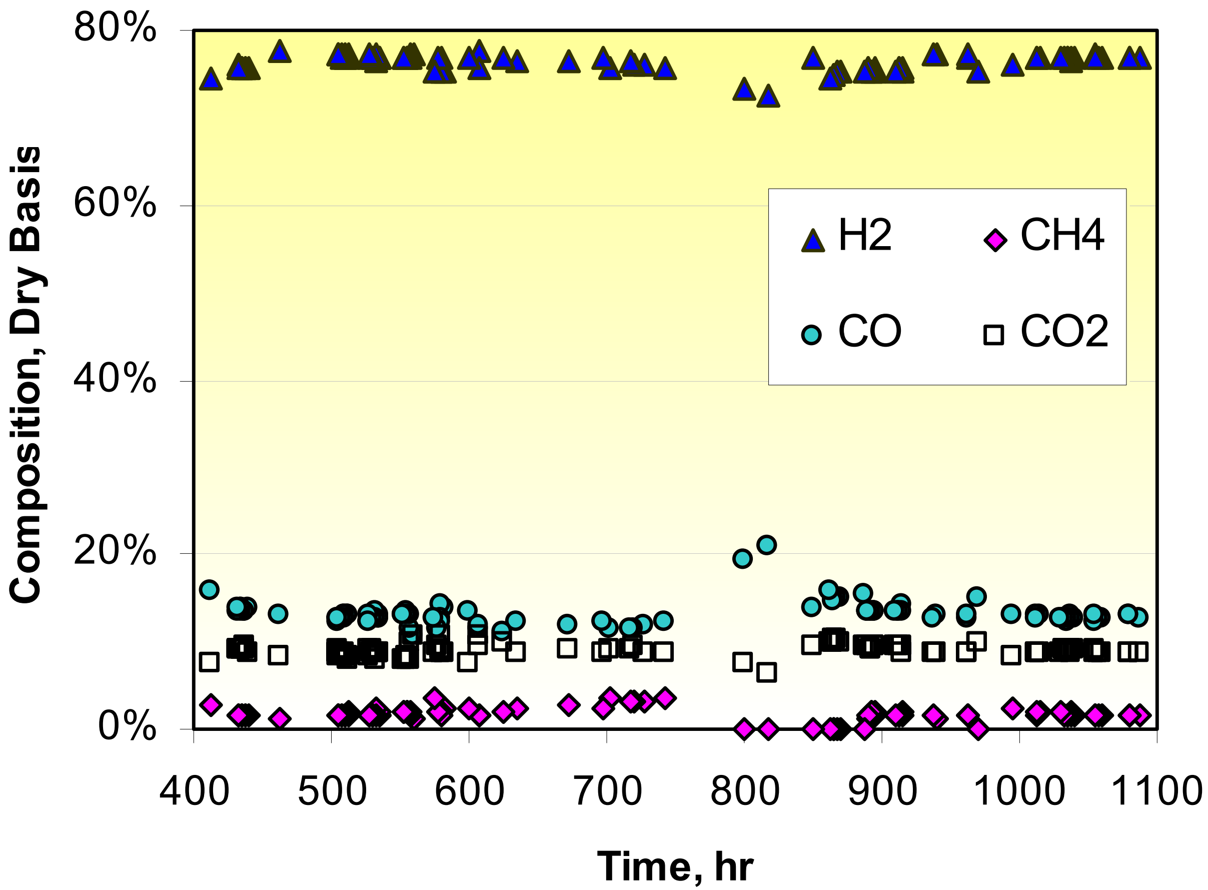
Catalyst Characterization

BET Surface Area:	101 m^2/gram
Metal ratio:	specific ratio produces higher sulfur resistance and low methane production
Metal loading:	High loading needed (>1 wt%) for sustained sulfur tolerance

Long-Term Natural Gas Reforming Tests



Using InnovaTek's proprietary catalyst, ITC-1148.

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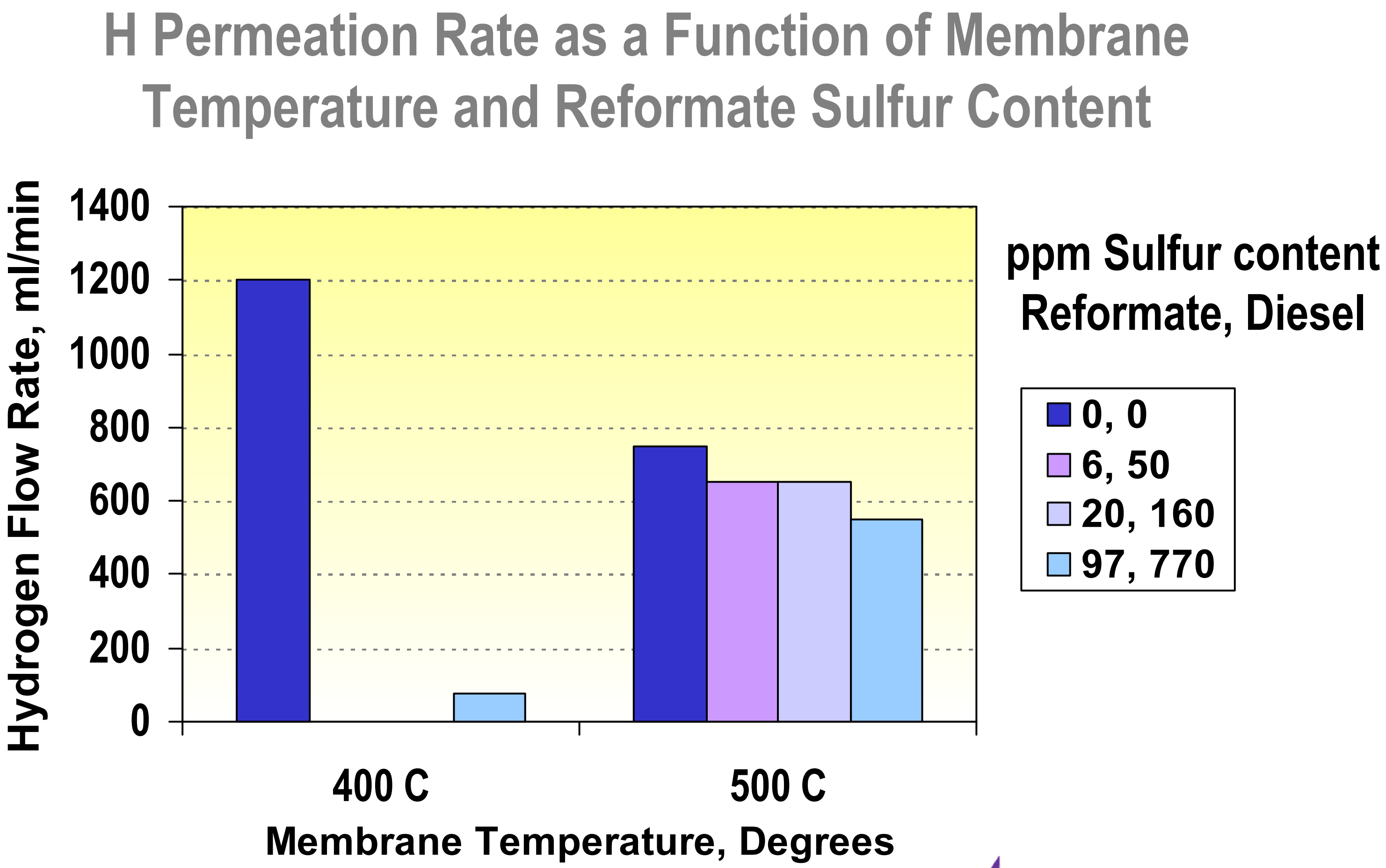
InnovaTek S-Tolerant Membrane Tests



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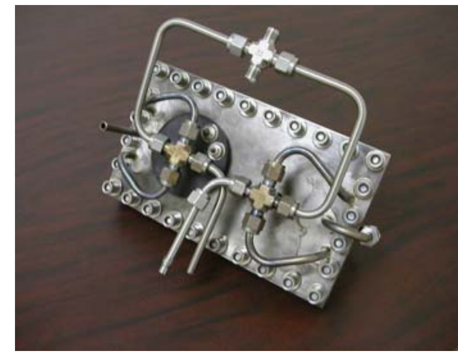
InnovaGen™ 1 kW Fuel Processor Components

Steam Reformer with Integrated Burner & Heat Exchanger

Micro-channel
Heat Exchanger



H-Permeable Membrane Module

Burner Components

Heat Exchangers

Zinc Oxide Purifier for Sulfur Removal

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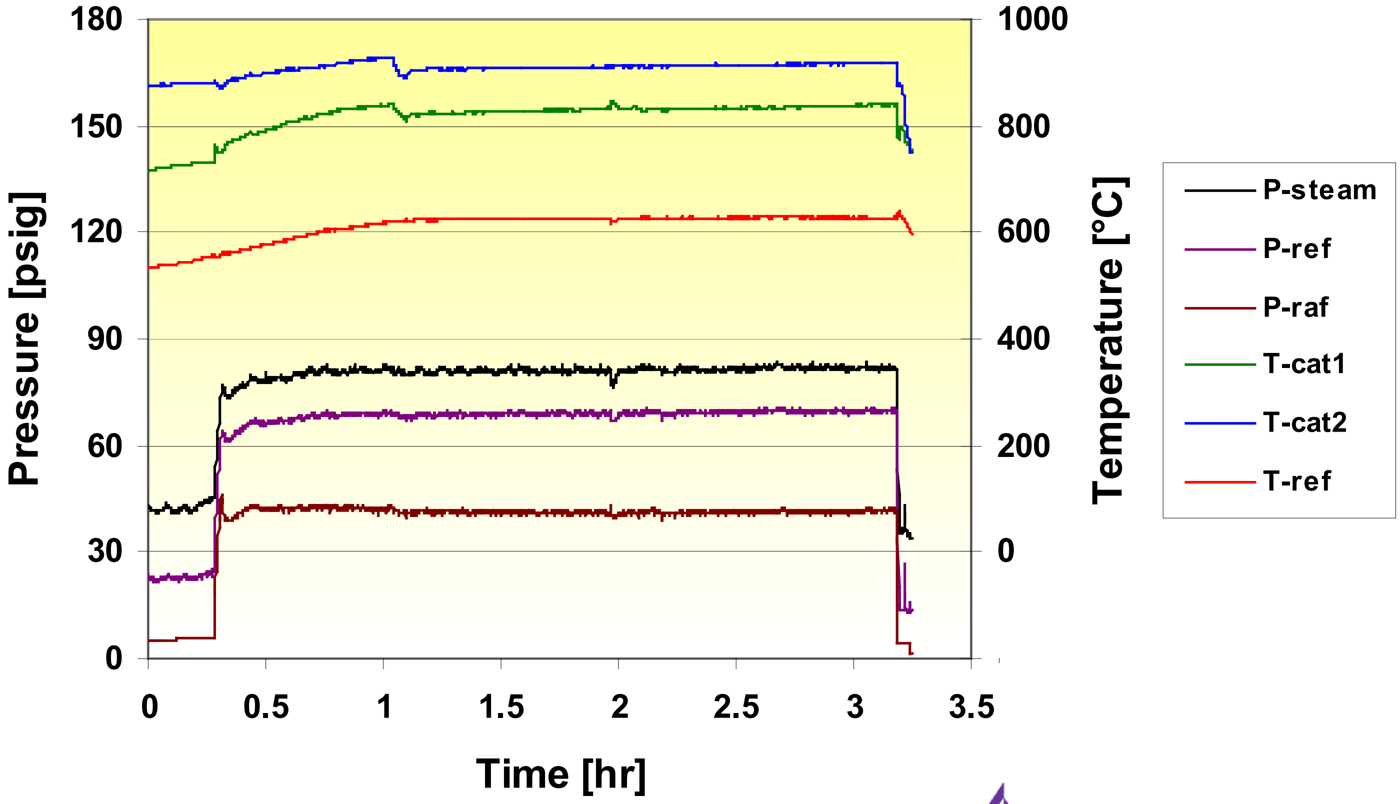
System Pressures and Temperatures

Sample data from diesel test with 50 ppm sulfur.



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Target Specifications and Objectives

Hydrogen Purity, CO Content	99.99%, < 5 ppm
Hydrogen Output and Temperature	12 L/min at STP, 60 °C max.
System Reliability	90% at 1,000 hours
Turn-Down Ratio	Idle and full-load only
Operating Temperature Range	1 to 40 °C
Storage Temperature Range	-20 to 50 °C
Cold Start-up to Full Output	40 minutes
System Volume, Weight (no fuel)	50 L, 30 kg
System Weight (no fuel)	30 kg
Thermal Efficiency	50% $HV_{L,hydrogen}/HV_{L,diesel}$
Diesel Fuel Sulfur Content	500 ppm by weight

Responses to 2002 Panel Review

Mass Balance	Rate, [gm/hr}
In	**7,049**
Diesel for reforming	218
Diesel for combustion	124
Combustion air	5,308
Feedwater	1,399
Out	**7,049**
Product hydrogen	59
Condensate from reformate	937
Burner exhaust	6,053

System Mass Balance:

- **Based upon 1 kW electrical output.**
- **Process parameters calculated from system model.**

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Responses to 2002 Panel Review

Energy Balance	Rate, [W}
In	4,090
Diesel for reforming	2,603
Diesel for combustion	1,487
Out	4,090
Product hydrogen	1,977
Shell losses	500
Condenser heat rejection	690
Exhaust losses	632
Condensate losses	291

System Energy Balance:

- 48% thermal efficiency based upon lower heating values.
- Combustion of diesel and raffinate provides heat for reforming

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Interactions & Collaborations

University of WA: Dr. Phil Malte - injector and burner design project; laser-based determinations of fuel evaporation and mixing.

WA State University: Prof. Pat Pedro - plasma catalyst deposition

PNNL: Larry Pederson - micro-channel heat exchangers; EMSL – catalyst characterization

Micro-Fabricators: working with several commercial partners

Irving, P. M., Q. Ming, and D.R. Stephens, "Development of a Fuel Processor that Generates Hydrogen from Conventional Fuels", In: Proceedings of the 14th Annual U.S. Hydrogen Meeting, March 4-6, 2003, Washington DC.

Irving, P.M., "Novel Catalytic Fuel Reforming", Global Climate Energy Project, April 14-15, 2003, Stanford University.