CO Clean-up Development

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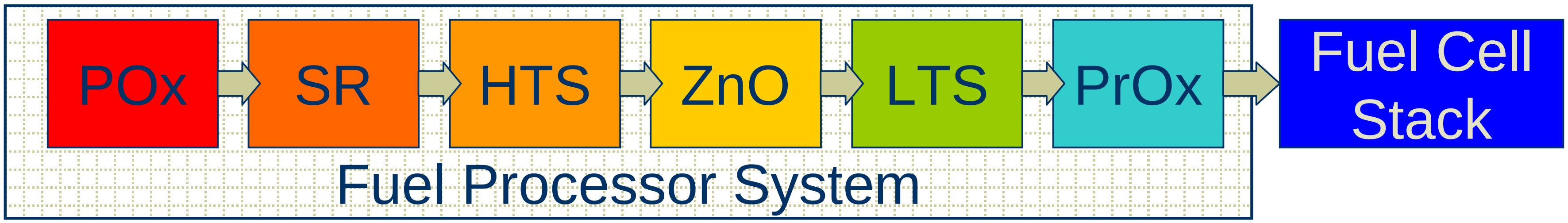
Relevance:
Meet PNGV Fuel Processor Targets



- PrOx (CO Clean-Up Device) is the last unit operation in the fuel processor process stream.
- Primary function is to remove contaminants to levels acceptable to the fuel cell stack
  - CO < 10 ppm steady-state, < 100 ppm transient
  - NH_3, H_2S to specified levels
- Overcome critical barriers for maintaining fuel purity requirements during transient operations
- Meet fuel processor targets for energy efficiency, power density, specific power, and cost

Technical Objective: Catalytic Clean-Up of Gas Streams

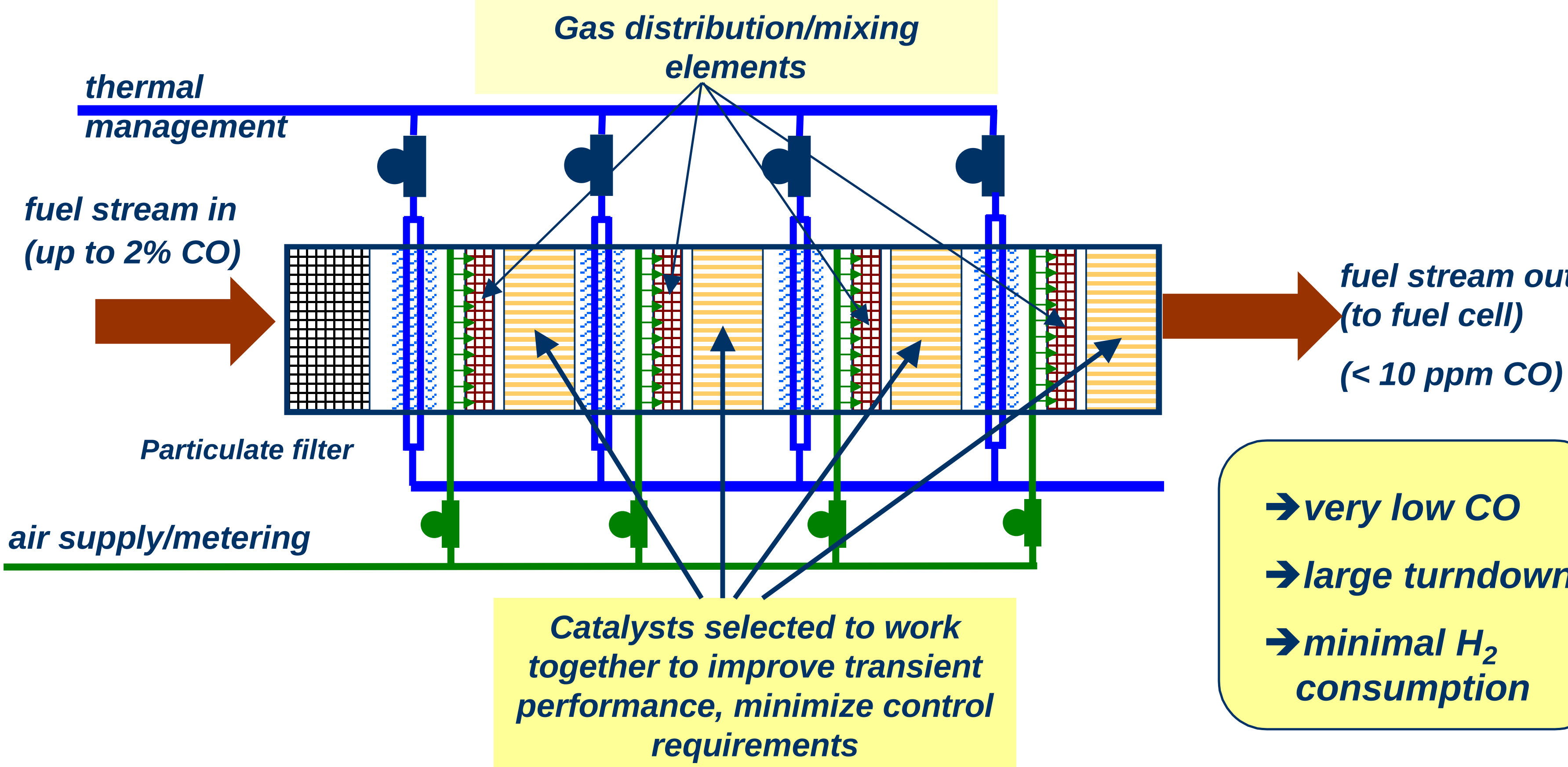
- Develop reformate clean-up technology for integration into fuel processor systems that enables them to meet the fuel purity requirements for a fuel cell stack
  - Remove trace contaminants – CO, NH_3, H_2S, soot, HCs
  - Maintain system performance – efficiency, minimum hydrogen consumption
  - Handle automotive transients – power, start-up, shutdown
  - Meet automotive requirements – cost, volume, weight, durability

Approach: Laboratory Investigation With Industrial Collaboration

- Investigate and develop Reformate clean-up technology
  - Investigate catalysts and catalyst performance
  - Use carefully instrumented and controlled experiments at the component level to measure performance
  - Develop proof-of-concept on a laboratory scale
  - Develop design tools for application
- Work with fuel processor developer(s) to integrate reformate clean-up technology into fuel processor systems and test.

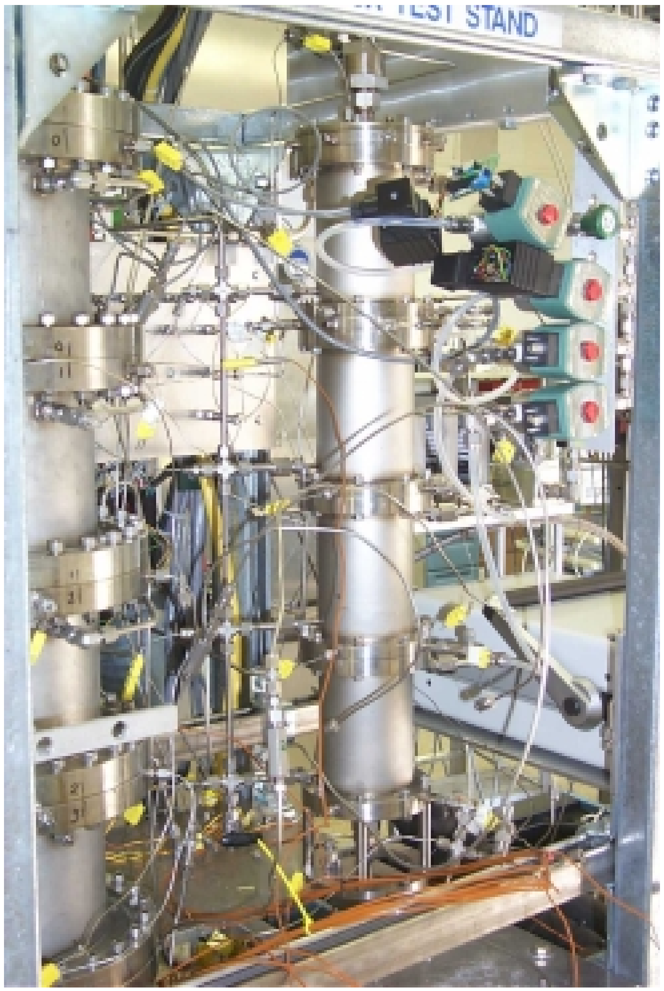
Gas Clean-Up Approach: PrOx Schematic

PrOx operates as a series of short residence time reactors, each with thermal management, gas mixing and catalyst volume



- ➔very low CO
- ➔large turndown
- ➔minimal H_2 consumption

Laboratory PrOx Works as Baseline System for Testing Concepts

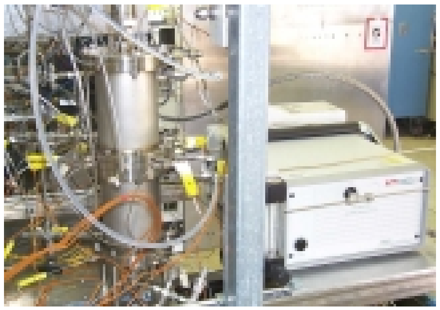


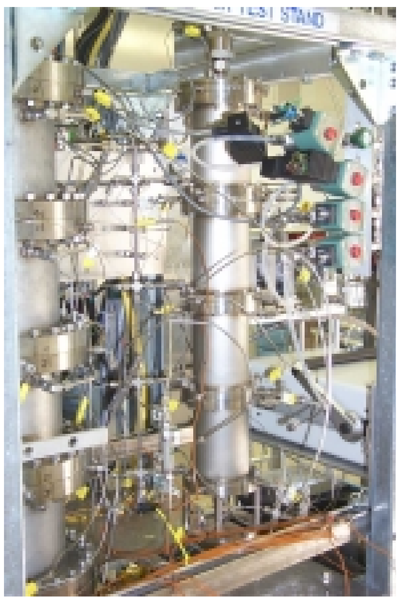
- 2% CO inlet to 10 ppm CO outlet
  - Simulated gasoline reformate
  - Natural gas system at energy partners
- Modular laboratory design gives flexibility to test:
  - Catalysts
  - Configuration options
  - Control schemes
- Design and lightweight internal components enhance transient performance
- Uniform air distribution and mixing
- Inlet temperature control

Work-in-Progress: Enabling an Automotive PrOx System

- Catalyst volume
  - Evaluate catalysts on foams and monoliths
- Size
  - Evaluate configurations for reducing PrOx size
- Air injection controls/coolant controls/sensors
  - Evaluate needs for ancillary components
  - Evaluate simplified control strategies
- Manufacturability
  - Prepare design tools/methodology
  - Trade-off evaluations
  - Develop collaborations with fuel processor manufacturers

Experimental Work in Progress





- Catalyst/catalyst support evaluation
  - Single-stage PrOx reactor – instrumented catalyst volume to measure temperature and species profiles
  - Simulated Reformate
  - Pellet, monolith, foams
  - Use microscale reactor to measure kinetics
- Transient experiments
  - Transients - change in power level or change in gas composition, startup?
  - Identify need for controls - target to simplify
  - Identify need for sensors, especially requirements for an online CO sensor
  - Control strategy for PrOx transients

Progress Summary

- Single-stage PrOx- catalyst evaluation
  - Individual stage evaluation-profiles of catalyst volume of our baseline configuration
  - Initial tests on catalyzed ceramic foams
  - Tests on newly obtained catalyst/catalyst supports- June – Sept 00
    - Combined particulate filter/PrOx catalyst
    - Higher density ppi monoliths
- Transient PrOx experiments
  - Conducted testing on inlet CO concentration variation
  - Power transient testing – June 00
  - Start-up transient testing – July 00
- Microscale catalyst evaluation
  - Kinetic data obtained on precious metal catalysts

Milestone Status

- Dec 99 – complete testing using catalyzed foams
  – Ongoing, iterating to improve performance
- March 00 – evaluate compact gas mixers for air injection/mixing
  – Incorporated into PrOx design, working to eliminate need for separate gas mixing components
- June 00 – select industrial partner for transfer of PrOx technology and initiate joint ‘design for manufacturing activities
- Sept 00 – complete design of compact gas clean-up hardware
- Sept 00 – design, fabricate, and evaluate compact gas clean-up device

Collaborations

- McDermott Technology/Catalytica
  - Beginning collaboration to transfer PrOx technology
  - Work together to design PrOx for commercial system
- Argonne National Laboratory
  - Collaborating to integrate a LANL PrOx design into ANL's fuel processor
- Others?
- SBIR/STTR Interactions
  - NexTech – Future testing of CO sensor
  - Hydrogen Burner Technology

Reviewer's Comments: FY 99 Annual Review

- *Operate on real gasoline reformate*
  - FY99 presentation focused on a natural gas system.
  - We test on simulated gasoline reformate - identifies effects of major constituents and provides controlled experiments.
  - In-house fuel processors operate on gasoline/collaborations with fuel processor developers.
- *Develop PrOx for any system, not just one system*
  - PrOx technology is applicable for most systems.
  - Specific configuration will depend on the system requirements -e.G., % CO inlet and outlet,gas composition, contaminants, operating pressures and temperatures
  - Modular approach allows easy adaptation to a particular system
- *Need for more work on catalysts and design-for-manufacture/ include strong effort to reduce size, weight, and cost*
  - This is the focus of this year's program. Our prior focus was on a working system.
- *Activity appropriate for industrial development rather than national lab*
  - Technology transfer and industrial collaboration is a part of the program.
  - Gas clean-up still has major research issues - transients, startup, efficiency

Reviewer's Comments: 2000 Industrial Review

- Appropriate role for national laboratory research is in gaining fundamental understanding of critical aspects of the technology
- PrOx system design is system dependent, therefore
  - Focus on developing information required by developers for their own PrOx designs
  - Provide detailed information on performance of individual stages
  - Develop methodology for PrOx design along with information to model the system
- Investigate behavior of the catalytic systems on a fundamental level
  - Provide understanding that can have applicability to a wide range of systems
  - Reformate composition effects, hydrogen consumption, transients

Future Work

- Continue catalyst testing and testing of multi-stage PrOx hardware
  - Reformate composition effects, hydrogen consumption, transients
  - Data input for PrOx reactor modeling
- Continue development of PrOx design methodology, delineate successful understanding of PrOx mechanisms
- Work on tech transfer/industrial collaborations

Gas Clean-up Future Directions

- Fuels effects - identify fuels issues for Reformate clean-up performance
  - Lifetime, durability issues
- Catalyst development/characterization
- Minimize hydrogen consumption - low stoichiometries
- PrOx geometries/operational modes that enhance catalyst performance
- Transient operation: 100:1 turndown
- CO sensor - required or can the need be eliminated?
- Shift focus to other contaminants than CO
  - Soot, NH_3, H_2S, HCs, species identified in fuels testing

Gas Clean-up Future Directions
Cold-start/startup Issues

- Gas clean-up operation at low temperatures
  - Catalyst operation at lower temperatures
  - Water condensation concerns
- Gas clean-up rapid start
  - Light weight catalyst supports/ reactor design
- High CO gas clean-up reactor
  - Apply PrOx concept to high inlet CO concentration (>5%)
  - Sacrifice some hydrogen consumption to obtain a fuel cell quality gas earlier in the start-up sequence

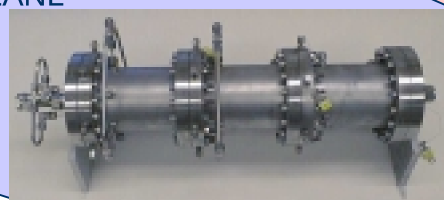
Gas Clean-Up Timeline

Start-Up
High CO Gas Clean-Up/ Tech Transfer

FY00
Automotive PrOx/Tech Transfer

50 kWe Prox
3 or 4 Stage,
steady-state and transient experiments

First demonstration of Gasoline-Fuelled PEM Fuel Cell System - A.D. Little/Plug Power/LANL
1998 PNGV Award



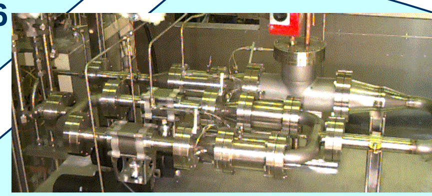
10 kW Prox
EP Natural Gas System
Laboratory Test Reactor

50 kW PrOx
June 1998

LANL Transient Prox experiments,
1999 ongoing

Improved Gasoline PrOx
October 1997

Gasoline PrOx
December 1996



First demonstration of Gasoline-Fuelled Reformer produced PEM Fuel Cell quality feed stream - A.D. Little/LANL

through 1995

GM/DOE Methanol Fuel Cell Program
Methanol PrOx

Early LANL PrOx Work
Patent

Summary

- Laboratory PrOx configuration serves as a baseline for fundamental studies and for developing automotive configurations
  – Test bed for catalyst testing – details of catalytic reactor performance
  – PrOx configuration development
  – Developing PrOx design methodology
- Tech Transfer/Collaborations starting
  – Develop and apply PrOx technology to a specific system