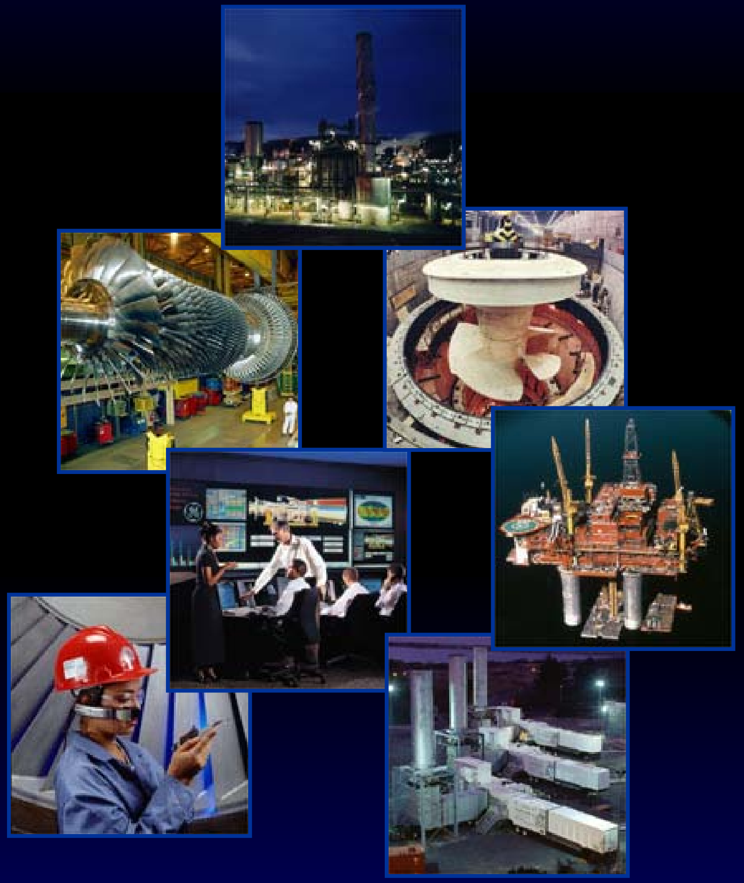
Fuel Cell Distributed Power Package Unit: Fuel Processing Based On Autothermal Cyclic Reforming

Parag Kulkarni, Court Moorefield, Shawn Barge,
Ravi Kumar and Vladimir Zamansky
GE Energy & Environmental Research



Review on
DOE Contract # DE-FC02-97EE50488

May 2003

Objectives & Approach

DOE Targets

- Reduce cost of fuel processor
- Improve reliability of fuel processor
- Improve efficiency of fuel processor

DOE (1999-2000)
Bread-Board Fuel Processor Development

- ❑ Design, fabricate & operate breadboard fuel processor
- ❑ Assess the technical & economic feasibility of the design

DOE (2001-3)
Integrated Fuel Processor Development

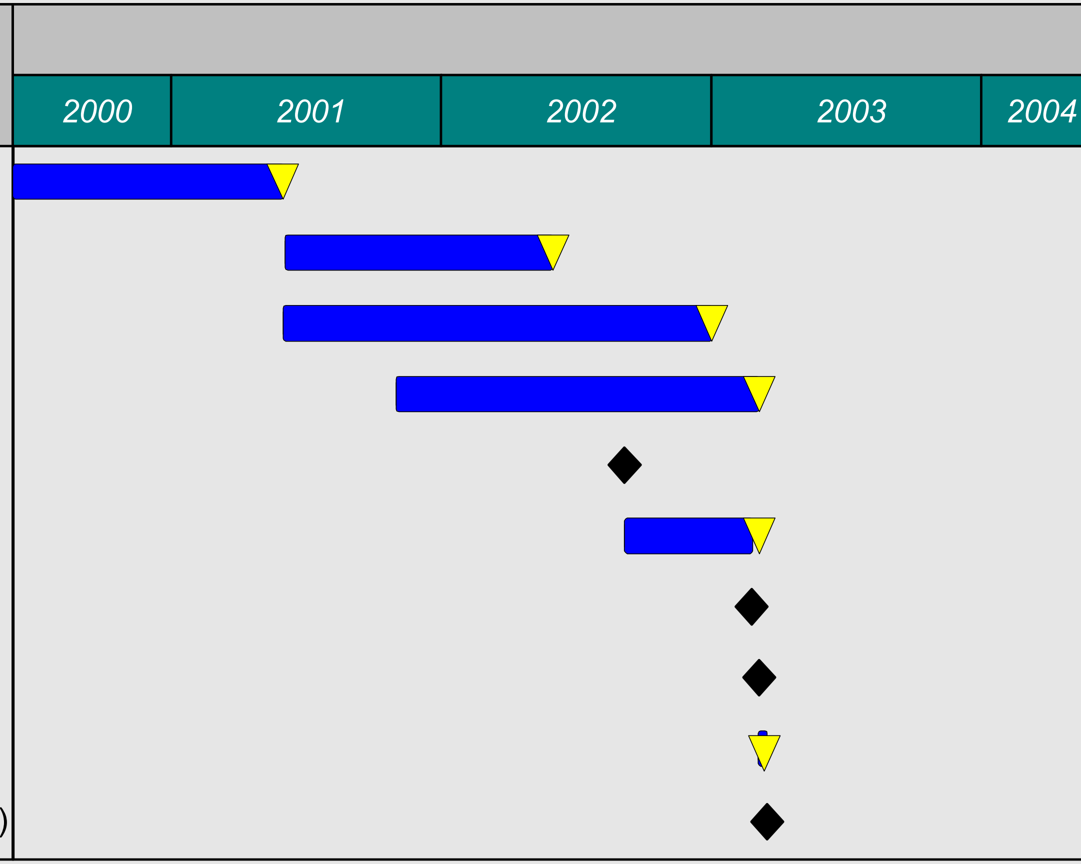
- ❑ Design, fabricate and operate an integrated fuel processor
- ❑ Assess the reliability, cost and performance of the fuel processor

CEC/ARB (2002-4)
Integration of ACR Fuel processor with PEM Fuel Cell

- ❑ Integrate fuel processor with the fuel cell
- ❑ Improve efficiency & reliability of the fuel processor
- ❑ CEC – California Energy Commission
- ❑ ARB – California Air Resources Board

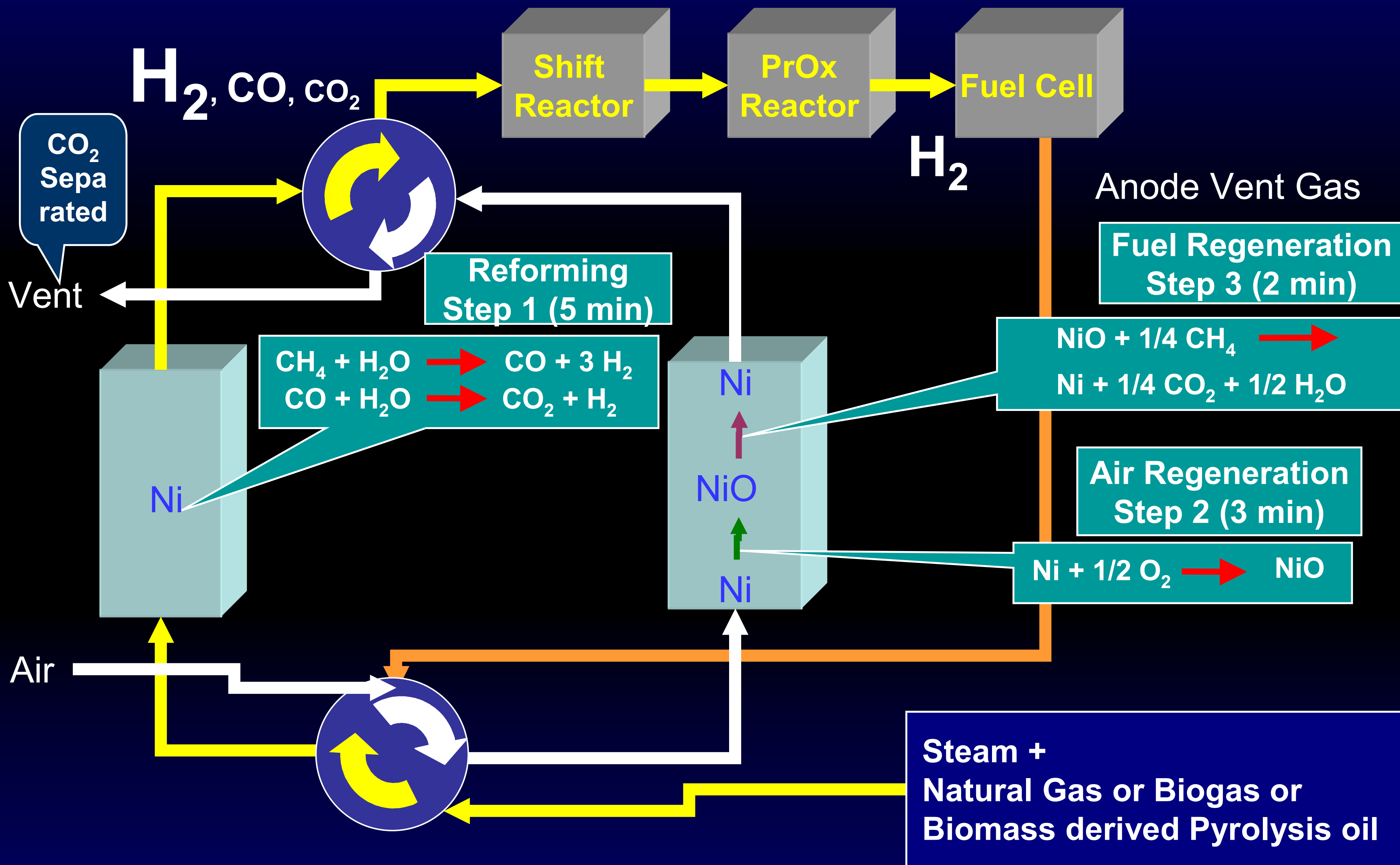
Schedule and Milestones

ID	Task Name
1	Operation of Breadboard ACR Reformer
2	Design of Integrated Fuel Processor Unit
3	Economic Feasibility Analysis
4	Fabrication of Integrated Unit
5	Operation of ACR Reactors
6	Optimization of ACR Reactor Operation
7	Production of Continuous H_2 Stream
8	Shift and PrOx Reactor Operation
9	Integrated operation of ACR Fuel Processor
10	Continuous production of H_2 stream (<50 ppm CO)



All milestones have been met

Autothermal Cyclic Reforming for PEM Fuel Cell



In-situ heat generation on catalyst lowers capital cost

Advantages of ACR Process for PEM Fuel Cell

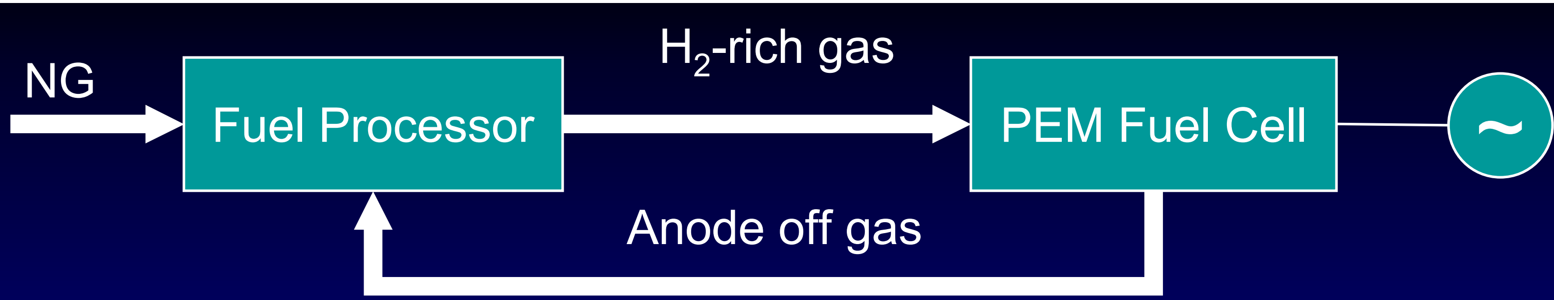
Metric	Autothermal Cyclic Reformer (ACR)	Advantages
High H_2 Purity from Reformer	70-80%	• Air is not mixed with fuel
High Efficiency (HHV)	70-80%	• Better system integration leads to higher efficiency, since anode off gas is used for fuel regeneration
Capital Cost	Low	• In-situ heat generation lowers metal temperatures and thus lowers capital costs (< 600C)
Fuel Flexibility	Diesel, NG, Propane, Biogas, Biomass Pyrolysis Oil	• Coke is burnt off during regeneration
Inherent CO_2 Separation	Yes	• Fuel regeneration step
Sulfur Tolerance	Yes	• Catalyst is sulfur tolerant
Turndown/ On-Off Cycling	Yes	• Lower metal temperature allows turndown & on-off cycling

ACR has advantages over competing technologies

Process Analysis & System Efficiencies

- Several process configurations were analyzed for the desired performance targets using process model

Fuel Processor Conversion Efficiency	(HHV of H_2-rich gas – HHV of Anode off gas)/ HHV of NG Fed	70-80%
Fuel Cell Efficiency	Electricity Generated/ (HHV of H_2-rich gas – HHV of Anode off gas)	45-55%
Net Electrical Efficiency	Electricity Generated/ HHV of NG Fed	30-40%
Total System Efficiency (includes cogeneration benefit)	(Electricity Generated + Cogeneration Credit)/ HHV of NG Fed	60-85%



Efficiencies depend on system size

ACR Reactor Design

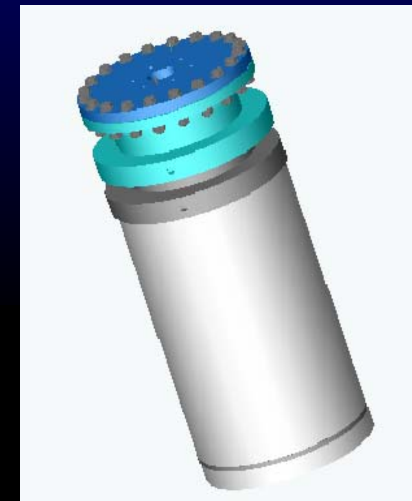
Performance Metric	Bread-Board Design	Integrated Design A	Integrated Design B
CH_4 Conversion	> 90%	> 95%	> 95%
Pressure drop (psig)	< 1	< 1	< 1

- Several reactor design configurations were analyzed for the desired performance targets and two integrated designs were chosen
- Both the selected integrated ACR reactor designs showed better performance than the bread-board design. Both the designs were implemented.
- Dynamic process model was used to optimize the process conditions.

Reformer Reactor Design Met all of the Performance Metrics

Design of System Components

ACR Reactor:
Single Catalyst Bed



Shift Reactor:
Single Catalyst Bed

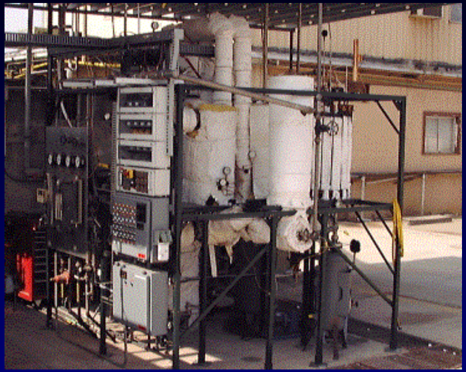
PrOx Reactor:
Multi-bed reactor with multiple air injection ports

Program Status

- 10 kWe Diesel unit was operated
- 35 kWe Bread-board natural gas (NG) unit was operated
- 50 kWe Integrated NG unit was operated

10 kWe Diesel Unit

35 kWe Bread-Board NG Unit

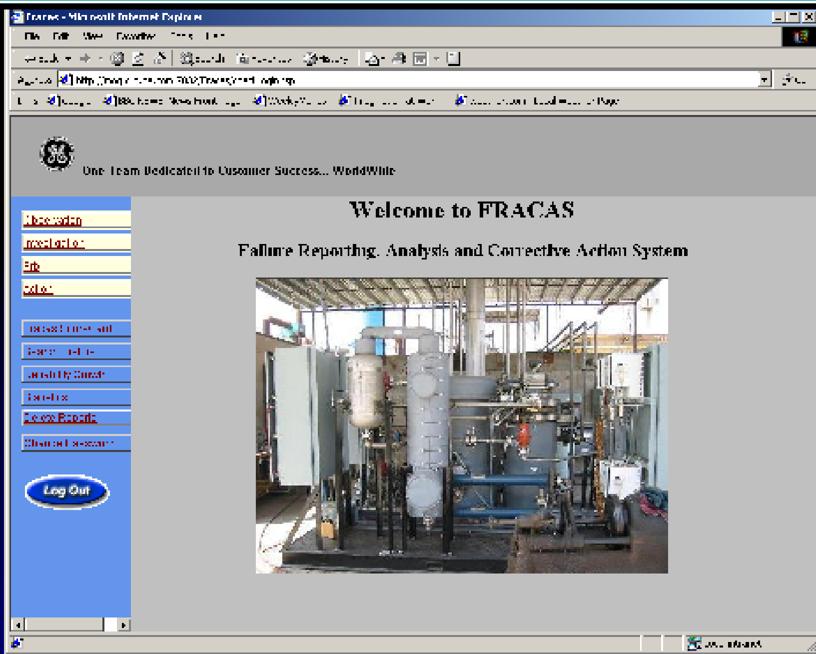


50 kWe Integrated NG Unit

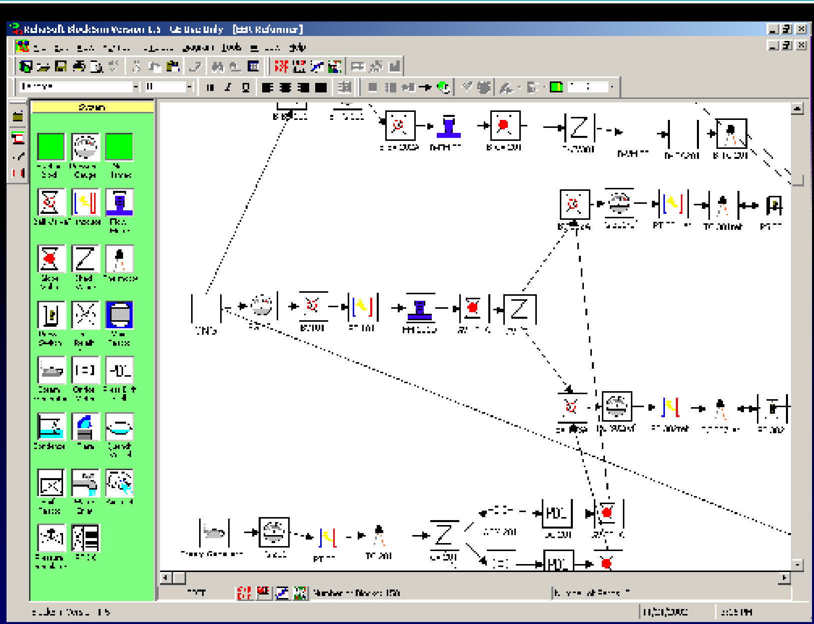
Reliability of ACR-based Fuel Processor

- Reliability Tracking:
  - FRACAS (Failure Reporting, Analysis and Corrective Action System) web-based tool has been developed for the ACR fuel processor. This system is being populated to calculate reliability information.
- Calculation of System Reliability:
  - Reliasoft block diagram is being used for quantification of reliability

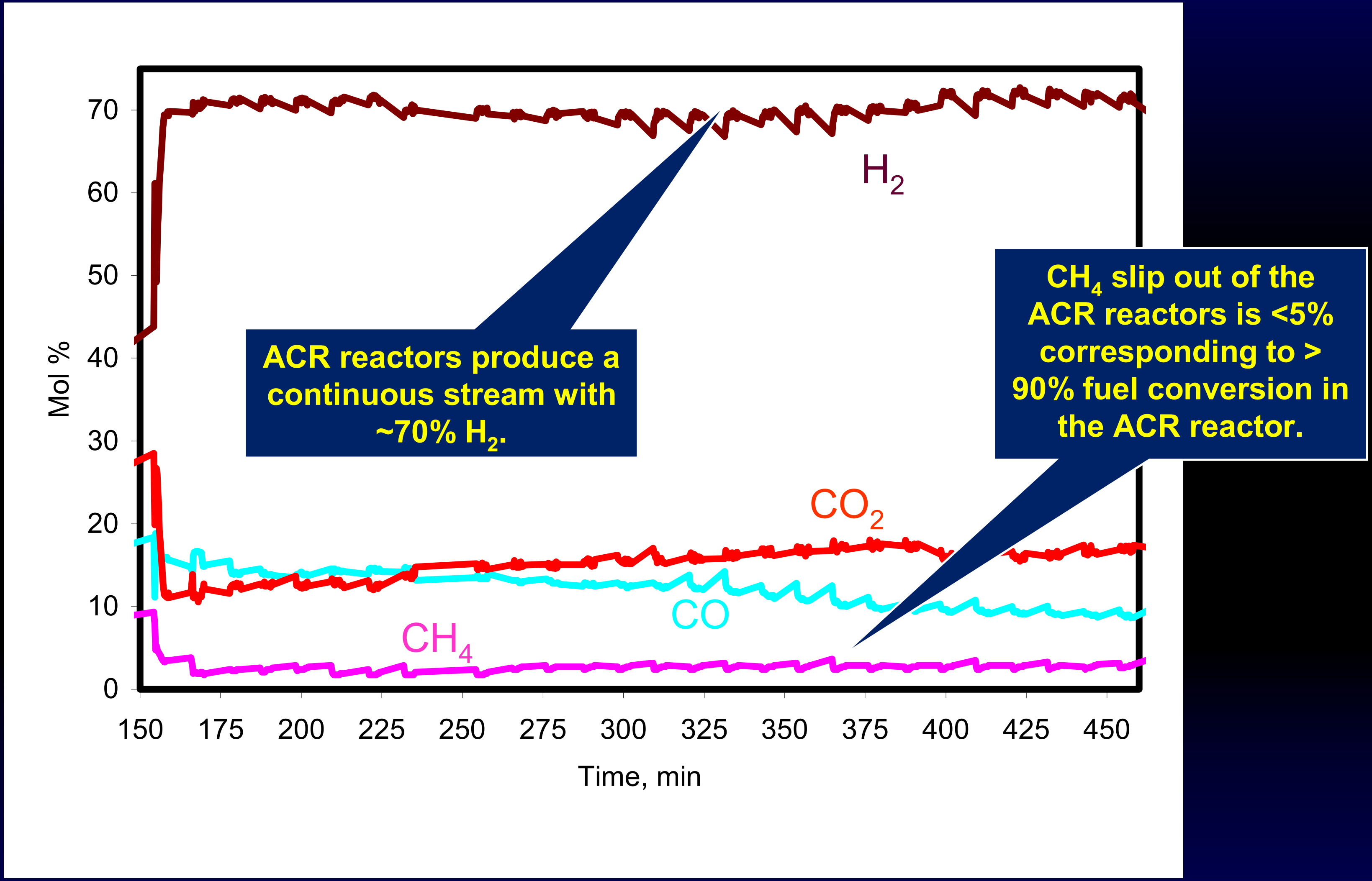
FRACAS Tool for Reliability Tracking



Reliasoft Block Diagram

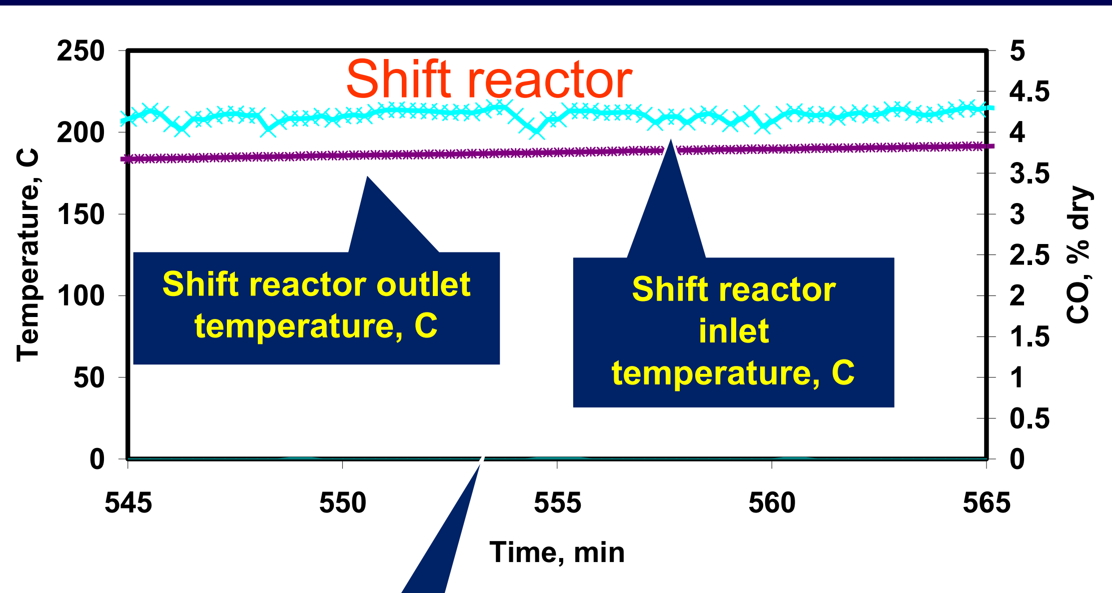


Performance of ACR Reactor



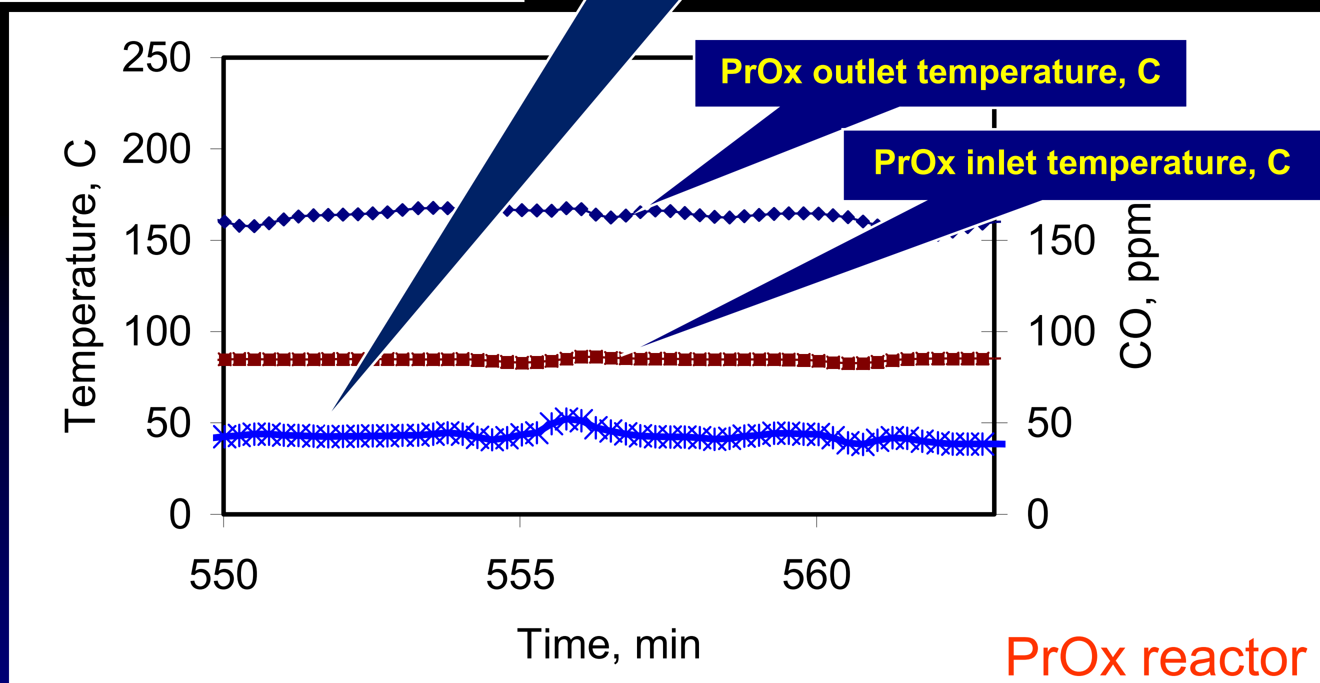
Shift reactor dampens fluctuations from ACR reactor

Performance of Shift and PrOx Reactors

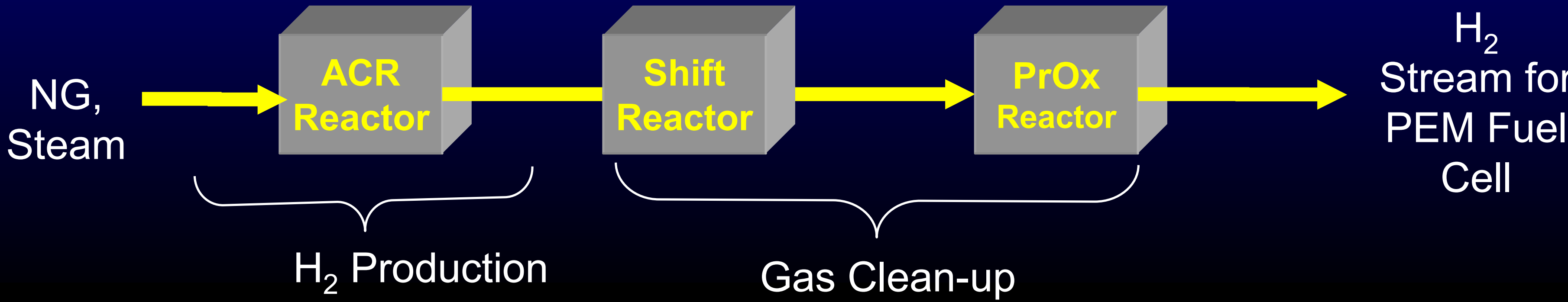


PrOx reactor reduced CO to < 50 ppm. Further optimization is being performed to reduce CO to < 10 ppm

Shift reactor reduced the CO to < 0.5%



Purity of Hydrogen Stream in the ACR Fuel Processor



	H_2	CO	CO_2	CH_4
ACR Reactor Outlet	69%	9%	19%	3%
Shift Outlet	73%	0.6%	23%	3%
PrOx Outlet	72%	< 50 ppm	25%	3%

ACR Fuel Processor produces a continuous H_2 stream with < 50 ppm CO

ACR Catalyst Development

ACR catalyst development is being carried out in a bench scale test stand.

- 30 commercial and custom made reforming catalysts have been tested.
- A reforming catalyst durable for 2000 hrs has been developed using accelerated durability testing techniques.
- Current tests are targeted toward developing an active and durable catalyst for >5000 hrs.

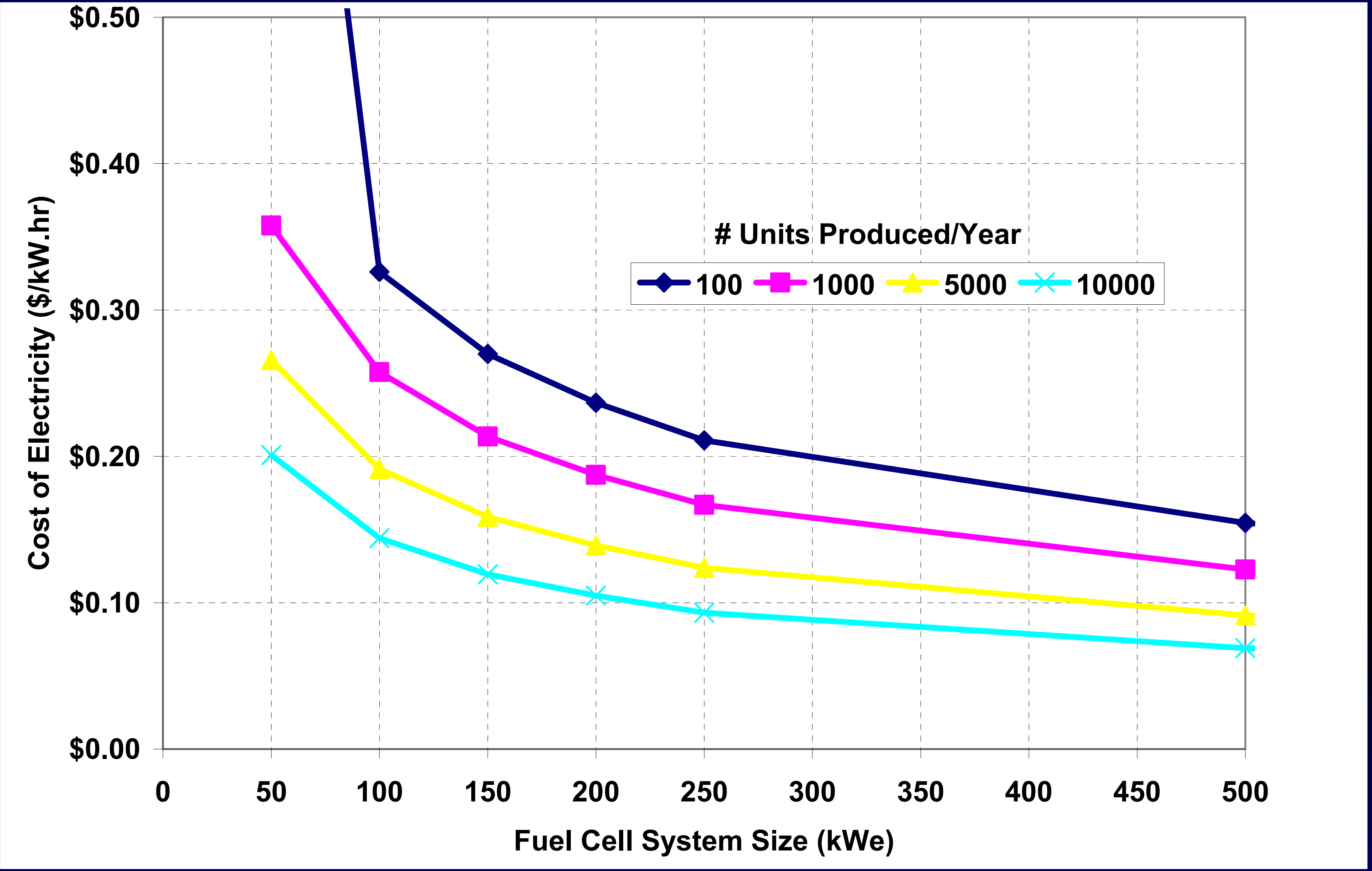
Stationary Fuel Cell System Economic Model

- Detailed Cost Estimates
  - Prototype Hardware Costs
  - Subsystem Quotes
  - Mechanical and Electrical Fabrication Cost
- Scaling Laws
  - System Sizing
  - Mass Production Factors

- O&M
- Consumables
- Annualized Capital Cost
- Facility Charge

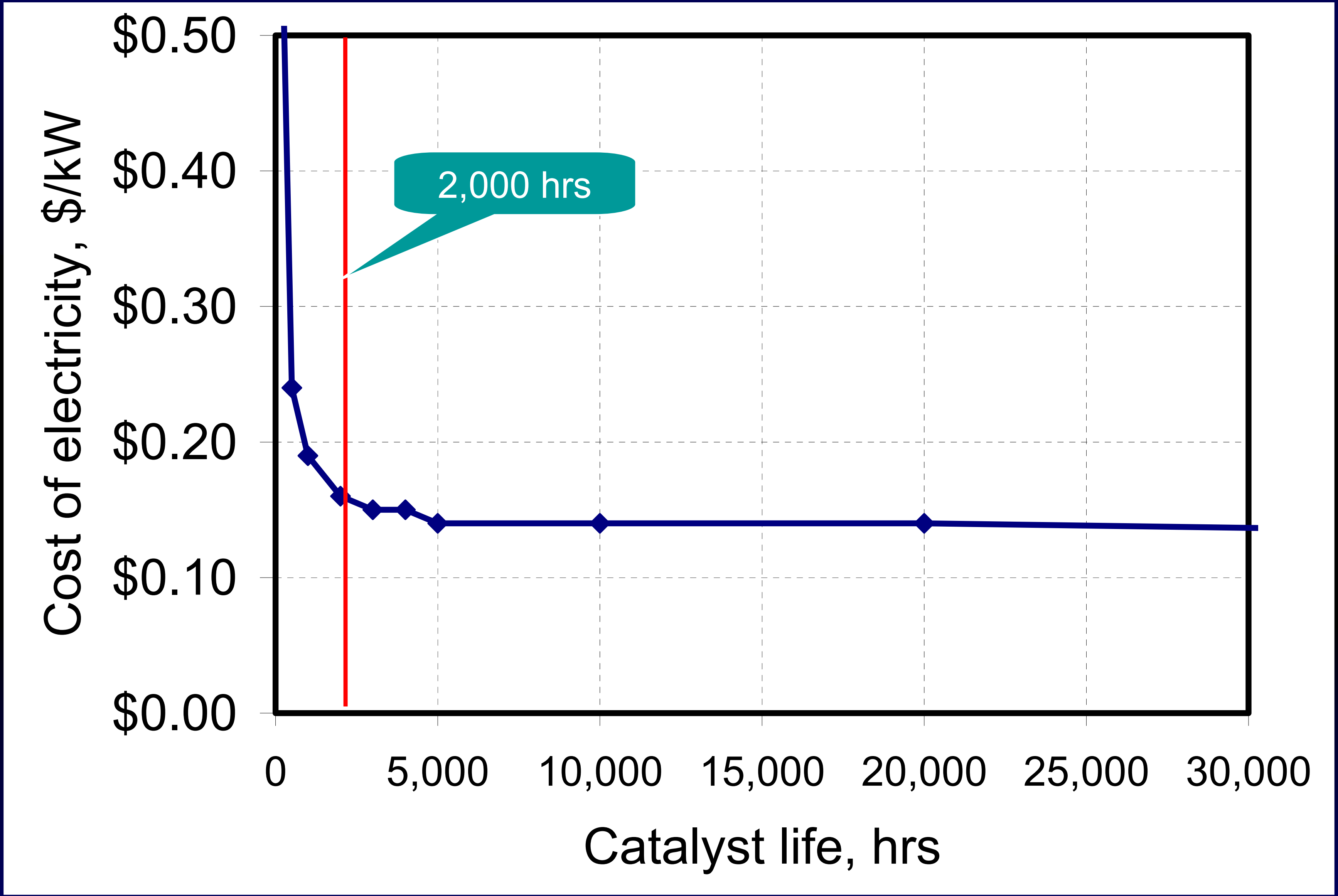
Model is based on actual experience

Stationary Fuel Cell System Economics



Fuel cell system cost competitive at large scales and when mass-produced
Further Technology Advances Can Reduce Costs

Impact of Catalyst Life on the Cost of Electricity



ACR catalyst should have at least 2,000 hr life

Future Work: CEC and ARB Project

- ACR Based Fuel Processor Prototype optimization
  - **Optimization of CO clean-up system to lower the CO concentration from 50 to < 10 ppm in the product stream.**
- Integration of the Fuel Processor with PEM Fuel Cell in partnership with National Fuel Cell Research Center (NFCRC) which is run by University of California at Irvine (UCI).
- Improve Reliability

Acknowledgements

- DOE: Kathi Epping, Jill Jankouwski, Ron Fiskum, Mark Paster, Pete Devlin, Sig Gronich
- CEC: Avtar Bining, Art Soinski, Mike Batham
- AQMD: Gary Dixon
- CARB: Steve Church