NUVERA FUEL CELLS

THE FUTURE OF ENERGY™

Advanced High Efficiency, Quick Start Fuel Processors for Transportation Application

Presented to	Department of Energy
Location	Philadelphia, PA
Date	May 25, 2004
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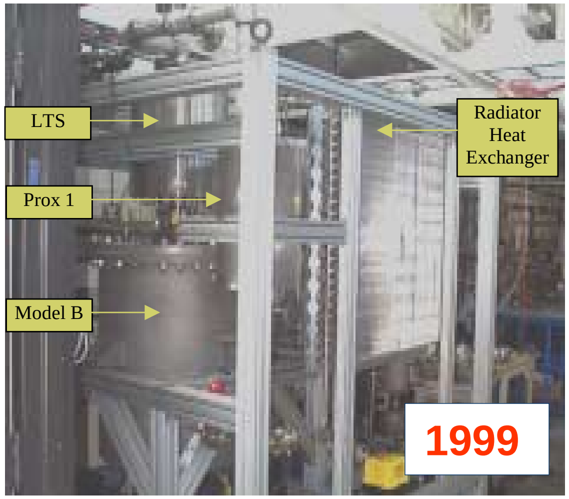
Overall Program Objectives / Progress Review

Goal: **Develop an automotive fuel processor for PEM fuel cells that is small enough and powerful enough for vehicle integration.**

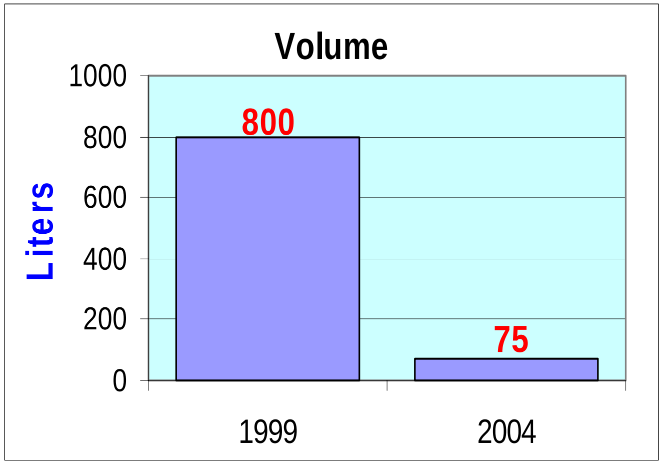
Review: **From Jan 2000 to May 2003, Nuvera developed a new compact fuel processor technology (STAR)**

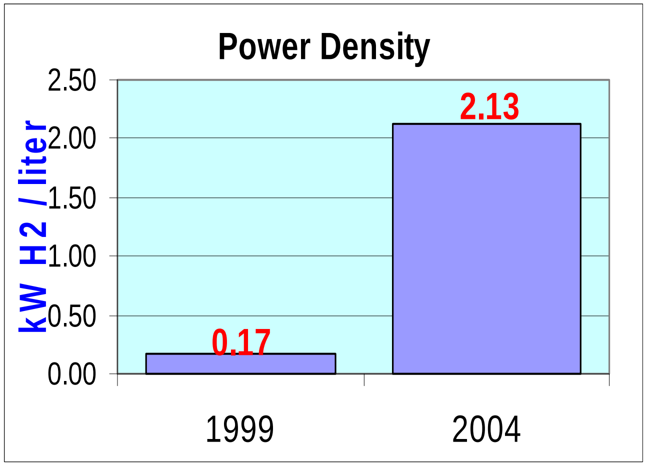
- **STAR - Substrate-based Transportation Autothermal Reformer**
- **Substrate-based catalysts researched to reduce volume**
  - **Developed new technology with leading catalyst companies**
  - **FP designed with substrate catalysts / custom heat exchangers**
- **Automotive volume achieved (75 liters)**
  - **Under-vehicle, "flat" aspect ratio (height < 9 in)**
- **Automotive power achieved**
  - **200 kWth gasoline**

Power Density Progress



Nuvera has achieved onboard volume and power density!





STAR Fuel Processor

2003-2004 Objectives

Goal: Continue characterizing and advancing the STAR fuel processor technology toward the DOE targets

- **Continue characterizing the STAR fuel processor on gasoline**
- **Characterize the STAR fuel processor on CNG and Ethanol**
- **Verify gasoline performance at ANL**
- **Improve durability**
- **Improve startup time**

Technical Barriers and Targets

- **Barriers (section 3.4.4.2)**
  - **D – Fuel Cell Power System Benchmarking**
  - **I – Fuel Processor Startup / Transient Operation**
  - **J – Durability**
  - **K – Hydrogen Purification / Carbon Monoxide Cleanup**
  - **M – Fuel Processor System Integration and Efficiency**

- **Key Targets**

CHARACTERISTIC	2005 TARGET
•Energy Efficiency	78%
•Power Density	700 W / L
•Specific Power	700 W / kg
•Cold Startup time	<2 min
•Transient Response	5 sec
•Emissions	<Tier 2 bin 5
•Durability	5000 hours
•CO content	10 ppm steady, 100 ppm transient

2003-2004 Technical Approach

- Multi-fuel testing
  - Performance measurements at Nuvera
- Performance verification at ANL
  - Testing from 50 to 200 kWth (input) on gasoline
  - Data useful for ANL models
- Durability improvement
  - Micro reactor testing of catalysts (ATR, WGS, PROX)
  - New design of PROX reactor
- Startup time improvement
  - Burner development
  - Controls optimization

Project Safety

- Project follows company safety procedures and policies
- Detailed "What if" analysis identifies possible issues from component failures and generates changes to the system P&ID
- Mechanical safety devices
  - Each vessel is rated for pressure and temperature with safety factor
  - Add pressure relief valves and burst disks where appropriate
  - Add check valves where appropriate
  - Insulation / local ventilation / warning signs to protect operators
  - All valves chosen to go to safe condition when de-energized
- Automated Safety systems
  - E-STOP code written into Data Acquisition and Control computer
  - Any parameter can be set to trigger a shutdown when out of normal range
- System modifications must be tracked and reviewed for safety

Program Gantt Chart

1/2000 – 6/2001	6/2001 – 6/2002	6/2002 – 6/2004
Research	Initial Design	Validation / Design Iterations
1 2 3	4 5 6	7 8 9 10 11 12 13 14 15 16

Research

1 Substrate/catalyst development and testing, compact HX development, sulfur removal technologies

2 First attempt of all substrate-based fuel processor

Initial Design

3 STAR fuel processor design concept chosen

4 Fuel processor core #1 testing

5 Fuel processor core #2 testing

Validation and Design Iterations

6 Integrated fuel processor testing on gasoline

7 250 hour endurance run on gasoline

8 Integrated fuel processor testing on gasoline

9 Fuel processor / fuel cell integration on gasoline

10 Gasoline optimization (200 kWth, 78% efficiency, 30 ppm CO)

11 CNG testing (180 kWth, 75% H2 efficiency, 40 ppm CO)

12 Ethanol testing (175 kWth, 77% H2 efficiency, 50 ppm CO)

13 Testing at ANL

14 <10 min startup demonstrated

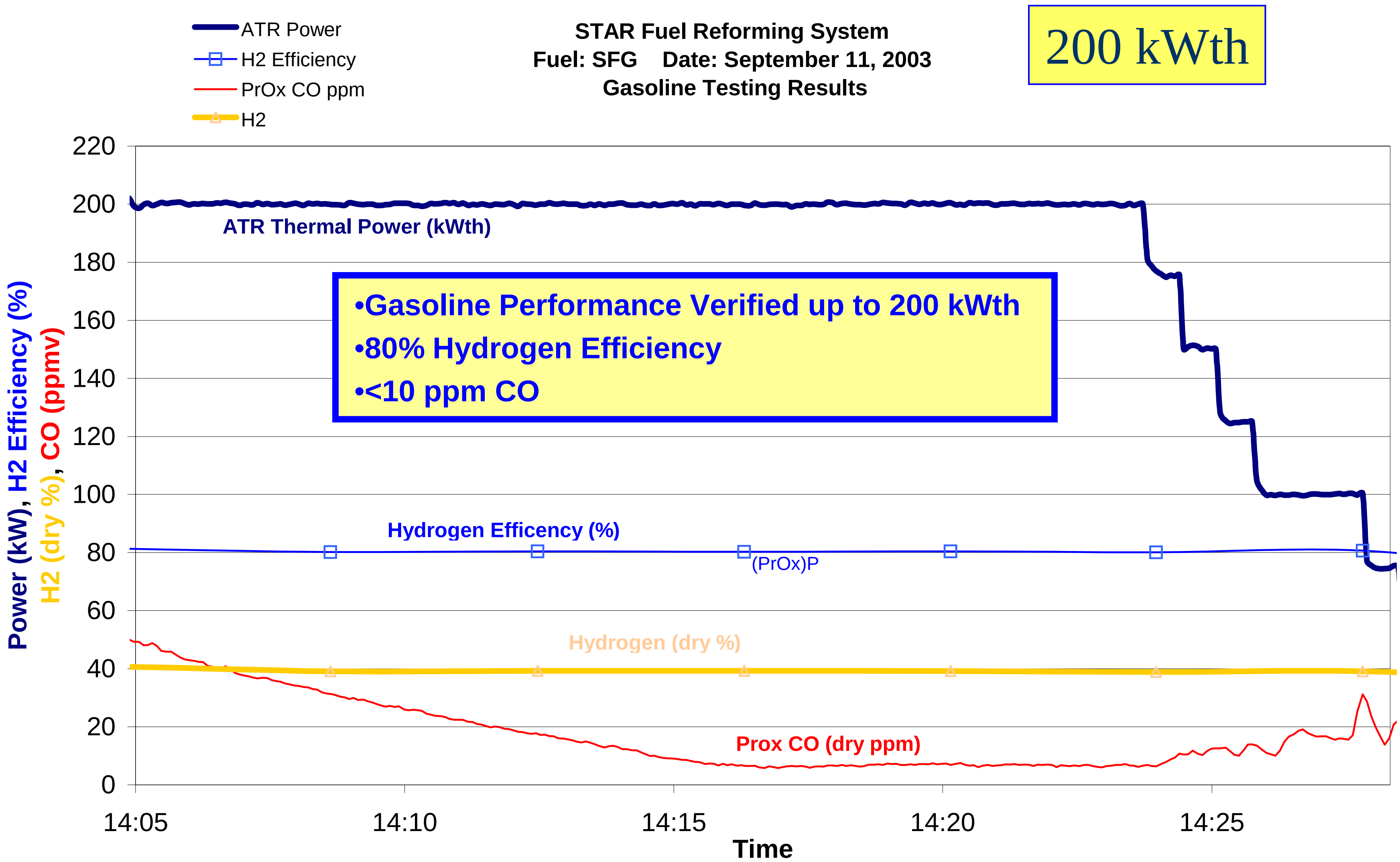
15 New PROX concept validated

16 Final durability test

2003-2004 Technical Accomplishments

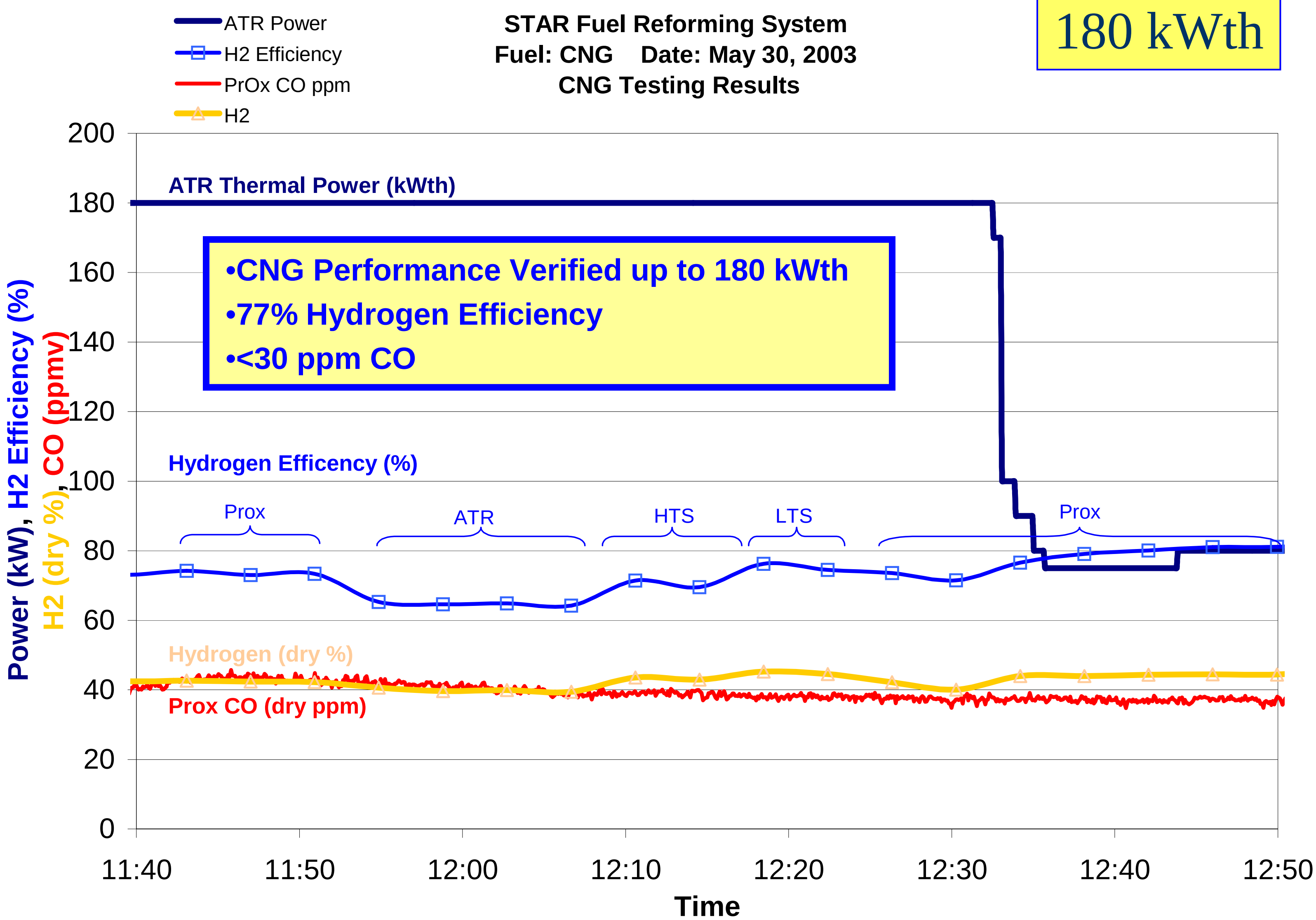
- **Gasoline Testing**
  - 200 kWth, 81±3% H_2 efficiency, 10 ppm CO
- **CNG testing**
  - 175 kWth, 77% H_2 efficiency, 40 ppm CO
- **Ethanol Testing**
  - 180 kWth, 75% H_2 efficiency, 50 ppm CO
- **Performance verification at ANL**
  - 50 - 200 kWth on gasoline, 76±2% H_2 efficiency, 30 ppm CO
- **Durability improvement**
  - 1000 hour micro reactor testing of catalysts (ATR, WGS, PROX)
  - New PROX reactor validated – durability being tested
- **Startup improvement**
  - New burner / controls gave <10 min startup (improved from ~25 min)
- **Controls Hardware and Packaging**
  - Work with automotive partner improves response time and shows system can be packaged in a vehicle

STAR Gasoline Testing



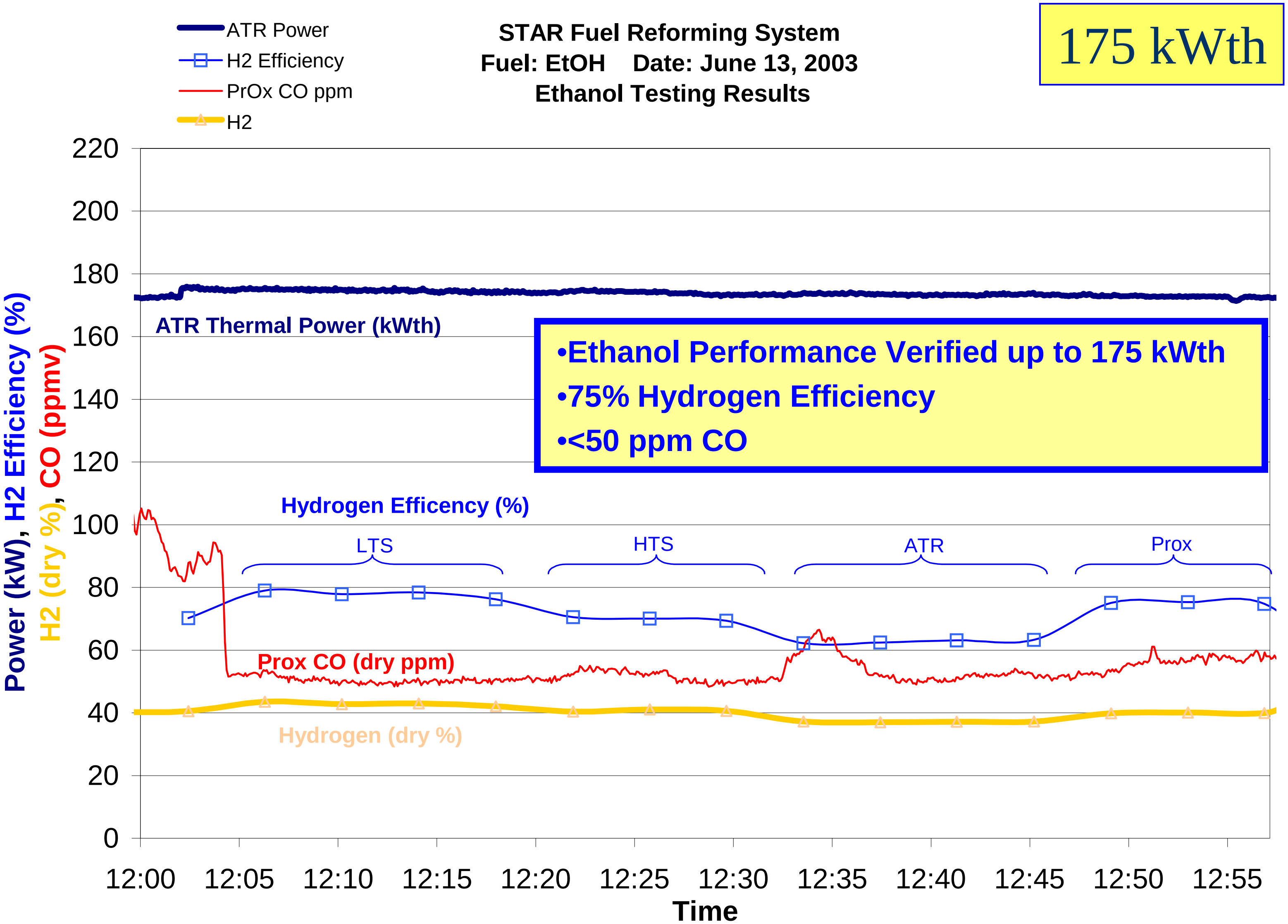
STAR CNG Testing

180 kWth



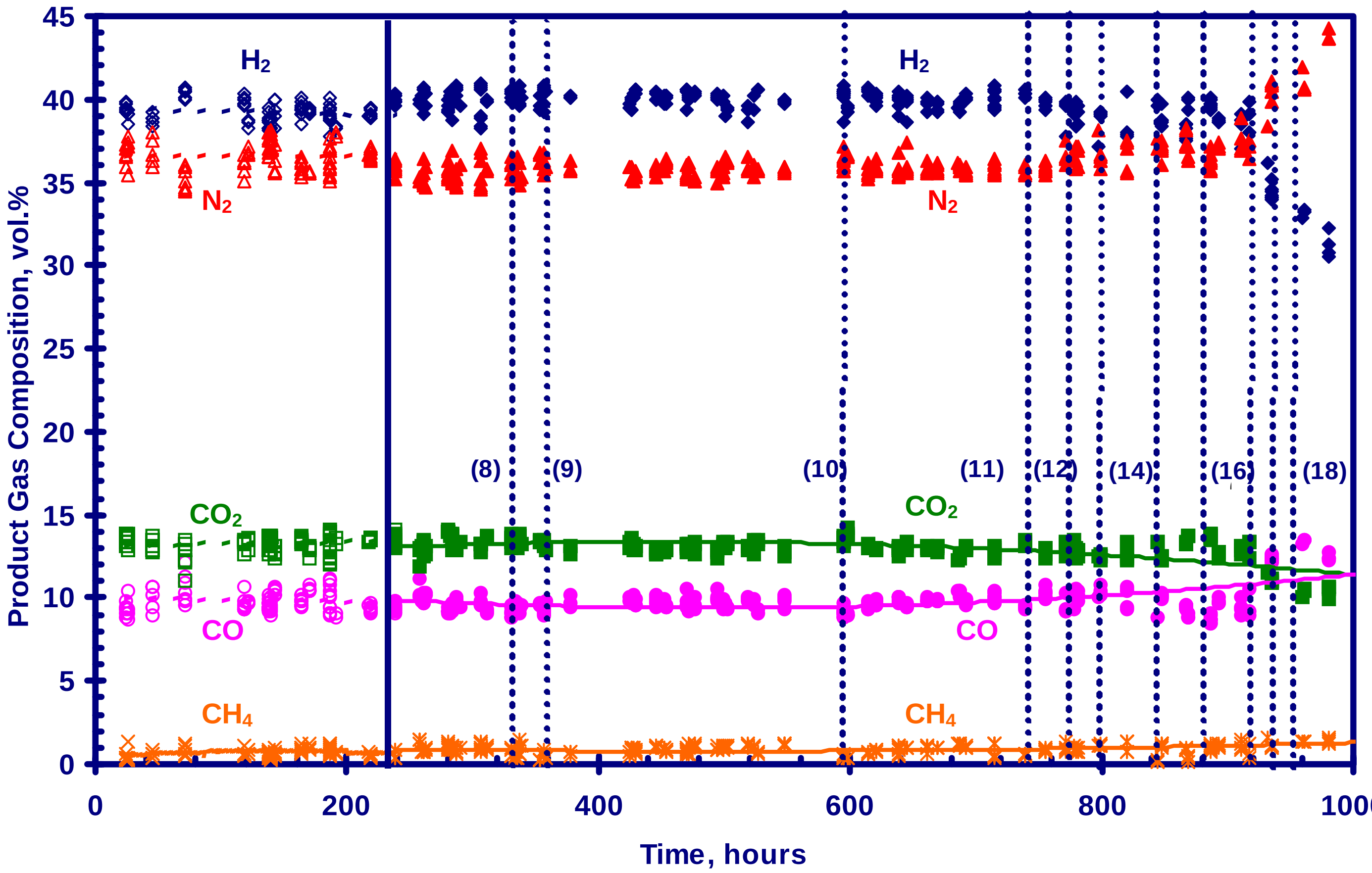
STAR Ethanol Testing

175 kWth



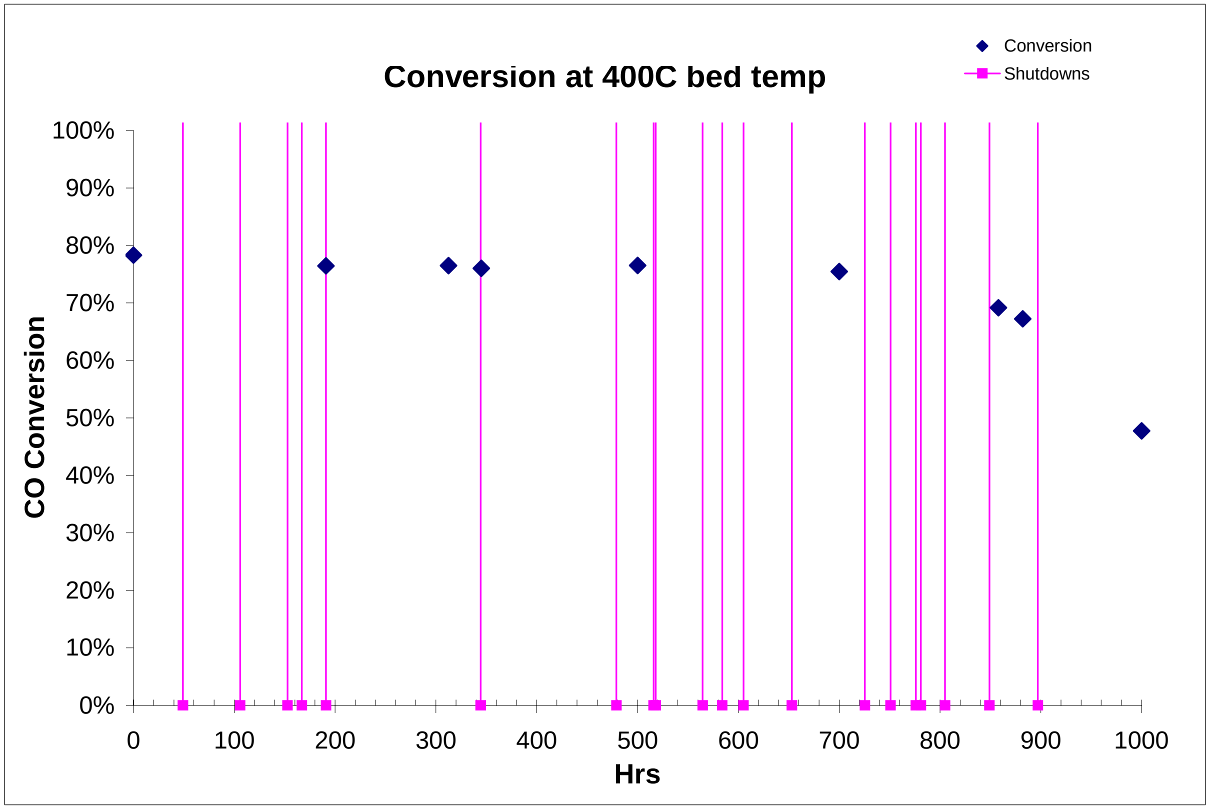
ATRC Durability Testing

- **ATR performance steady through ~ 800 hours**
- **Decline after 800 hours due to reactor malfunction**

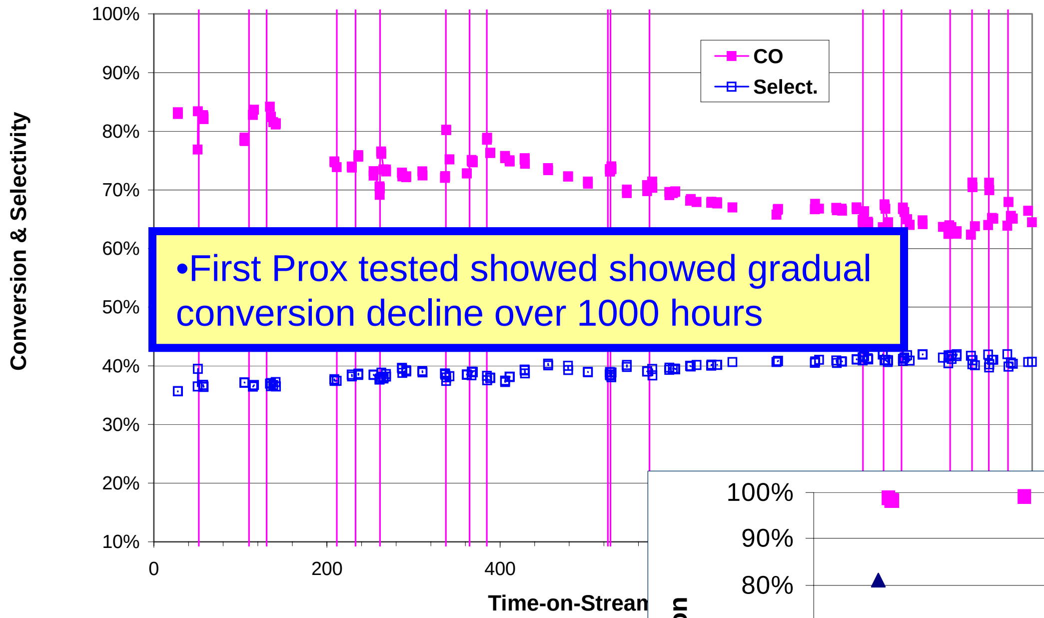


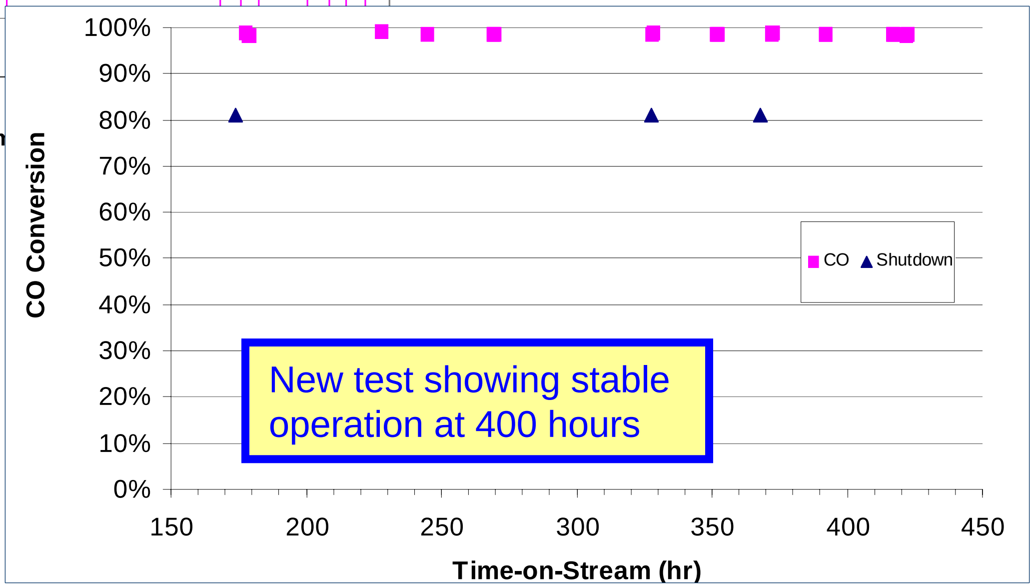
WGSC Durability

•WGS showed degradation that appeared at ~ 800 hours

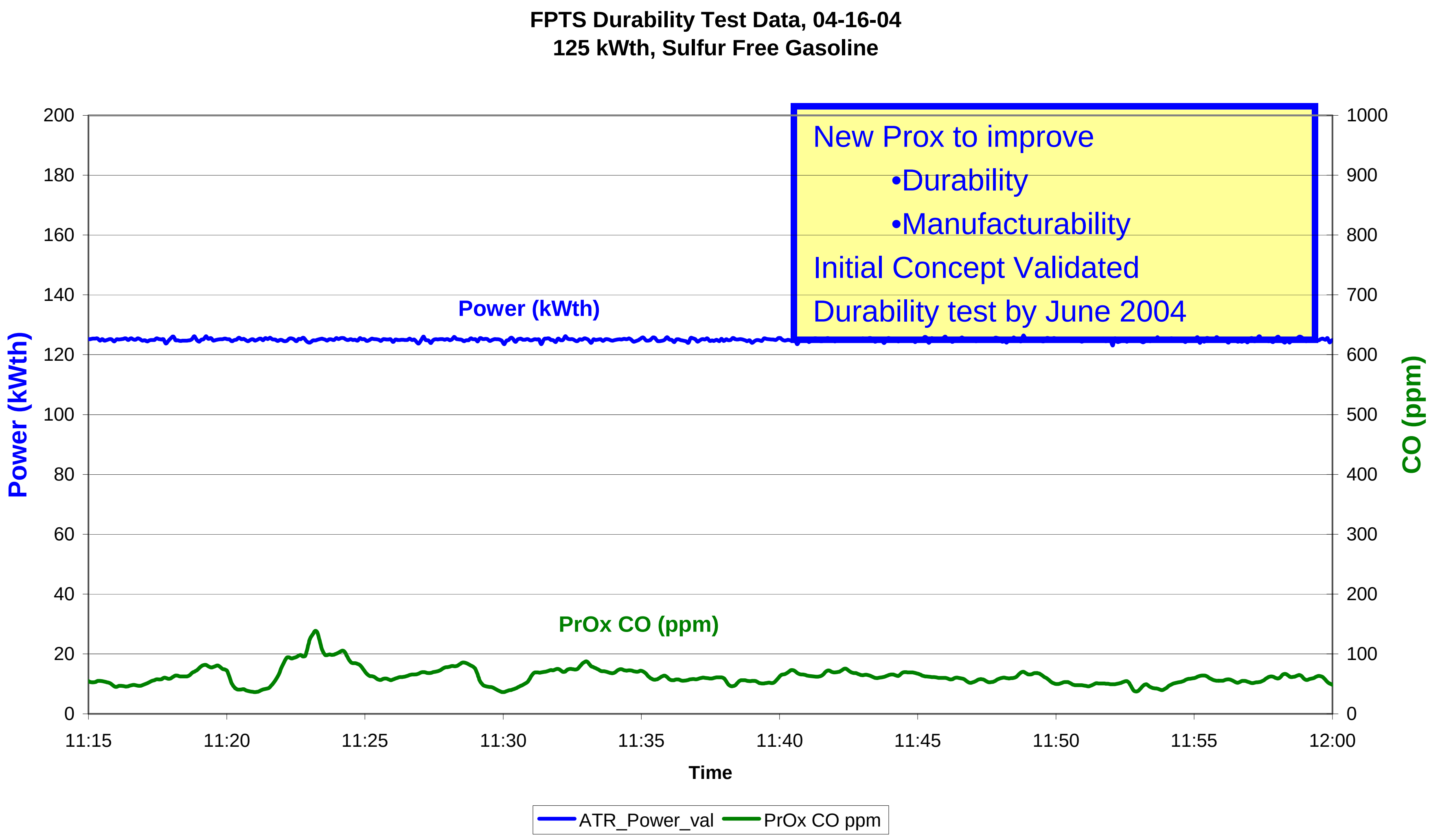


PROX Catalyst Durability – 2003 vs 2004

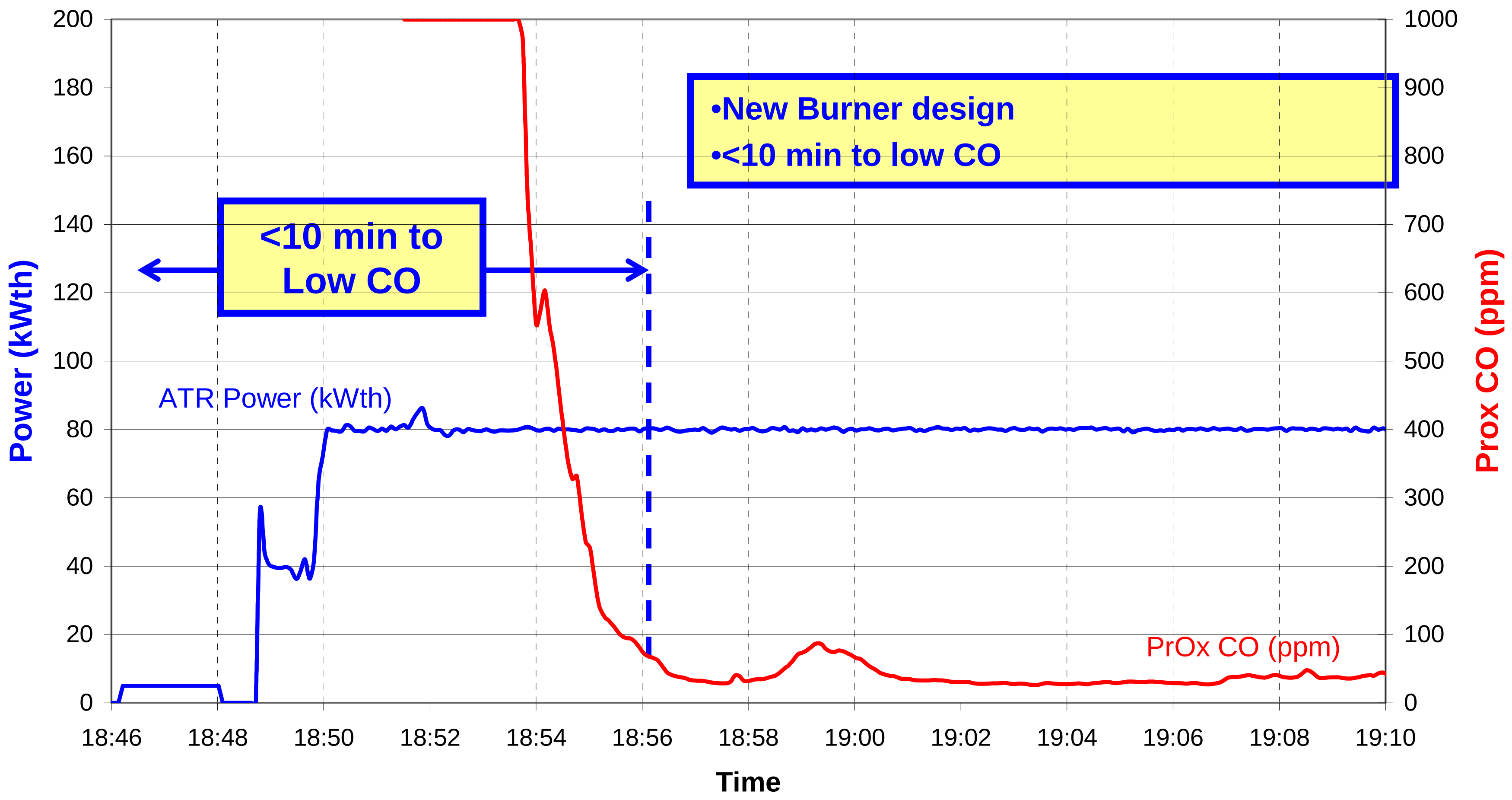




New PROX Validation

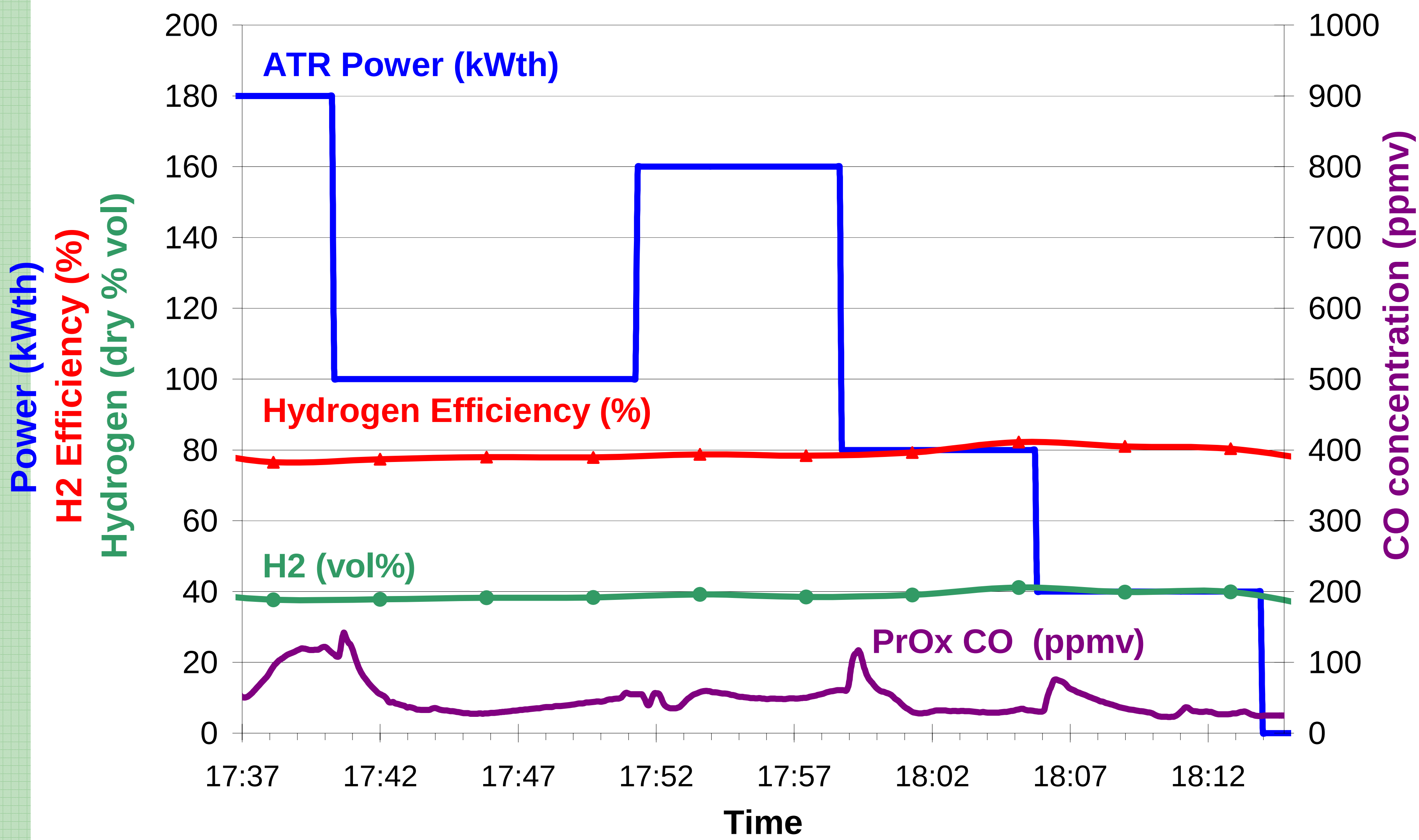


Startup Time Optimization



Controls Advancements

Date: 20 November 2003   Fuel: Sulfur Free Gasoline



Interactions and Collaborations

- **Automotive OEM**
  - Renault
- **National Laboratories**
  - Argonne National Lab
- **Catalyst Vendors and Subcontractors**
  - SudChemie
  - STC Catalysts, Inc.
  - Corning
  - EU suppliers
- **Sensors**
  - NexTech Materials

Response to Reviewers' Comments

- **More data in the presentations**
- **Technology transfer**
- **Define off-ramps in the program**

Future Plans

- **This work**
  - Complete durability testing by June 30, 2004
  - Submit Final Report
- **Suggestions for future DOE projects**
  - Develop improved catalysts (and other materials) and validate performance in integrated fuel processor
  - Further cost reduction via design iterations of STAR type fuel processor
  - Optimization of “systems” approach

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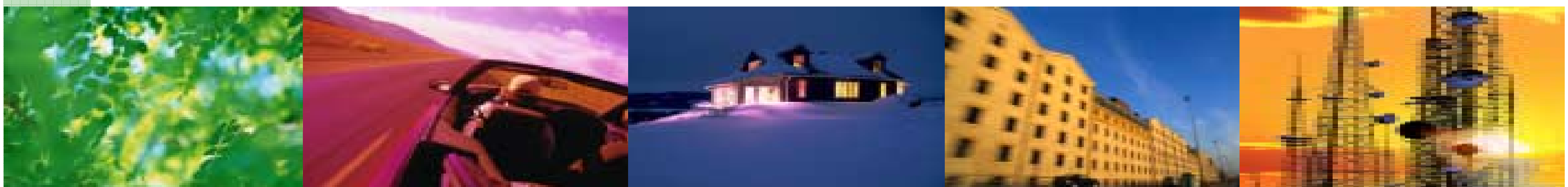
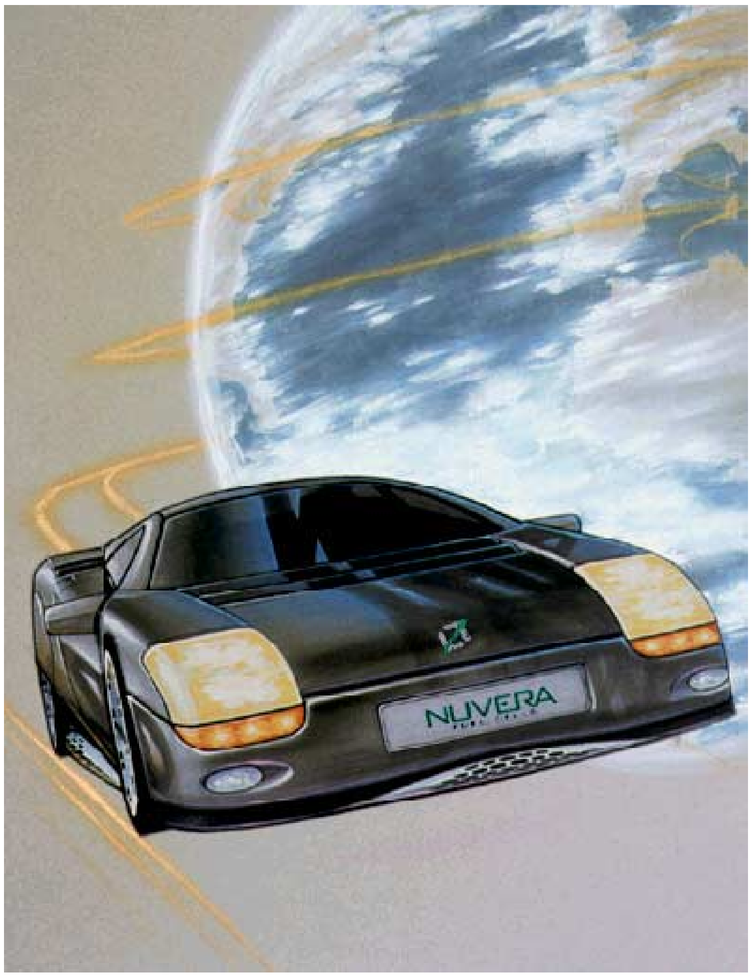


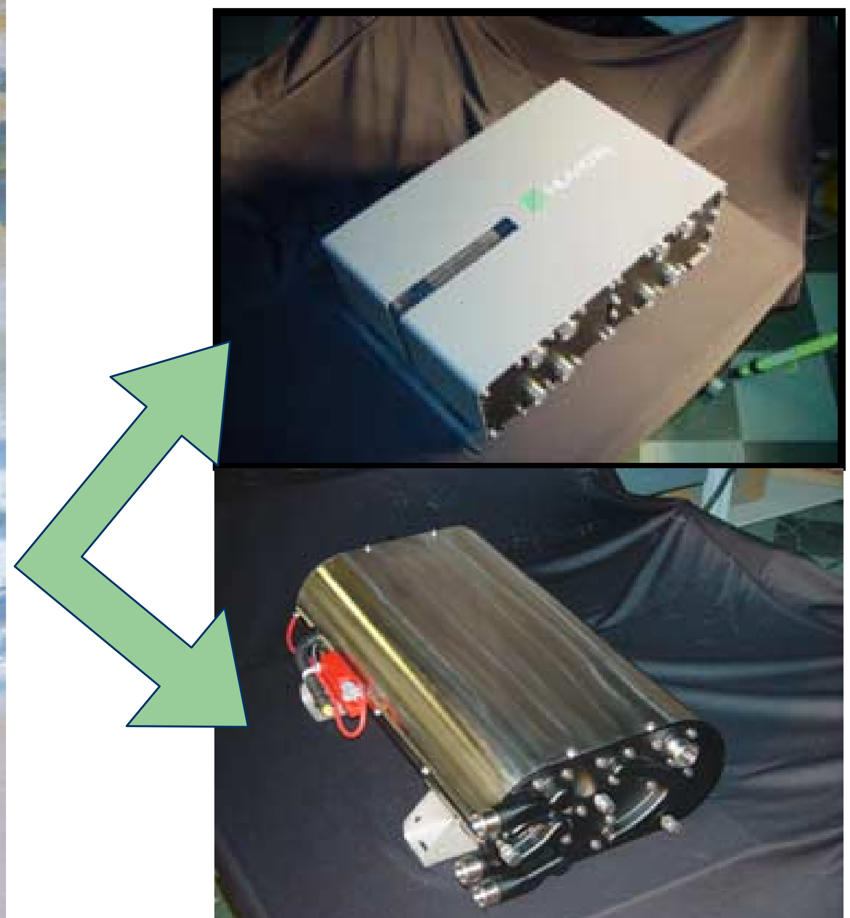
Environment | Transportation | Residential | Stationary | Premium Power

Commercial Automotive Fuel Processor Update

Automotive Product Vision

*Automotive quality **Products**, not laboratory prototypes!*

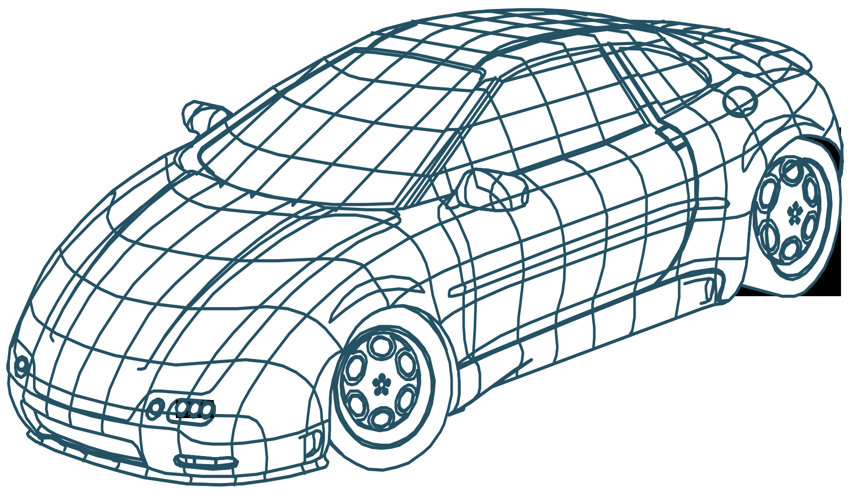




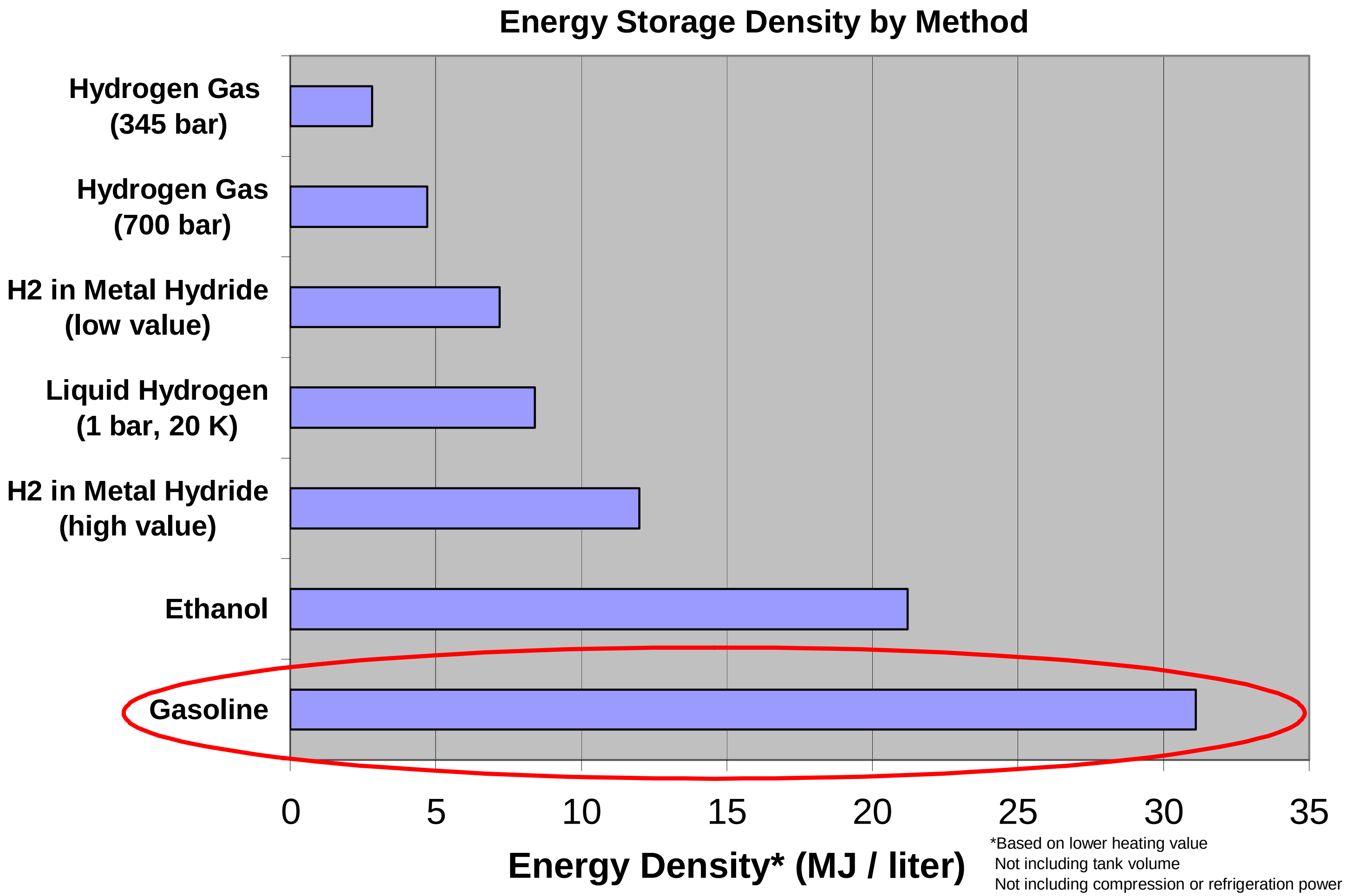
Automotive Technology Development Roadmap

Commercialization of fuel cell systems for automotive applications requires significant improvements in technology in the following areas

- **Efficiency**
- **Emissions**
- **Power Density**
- **Specific Power**
- **Start Up Time**
- **Transient Response**
- **Durability**
- **Packaging**
- **Cost**
- **System Integration**



Why explore onboard fuel processing?



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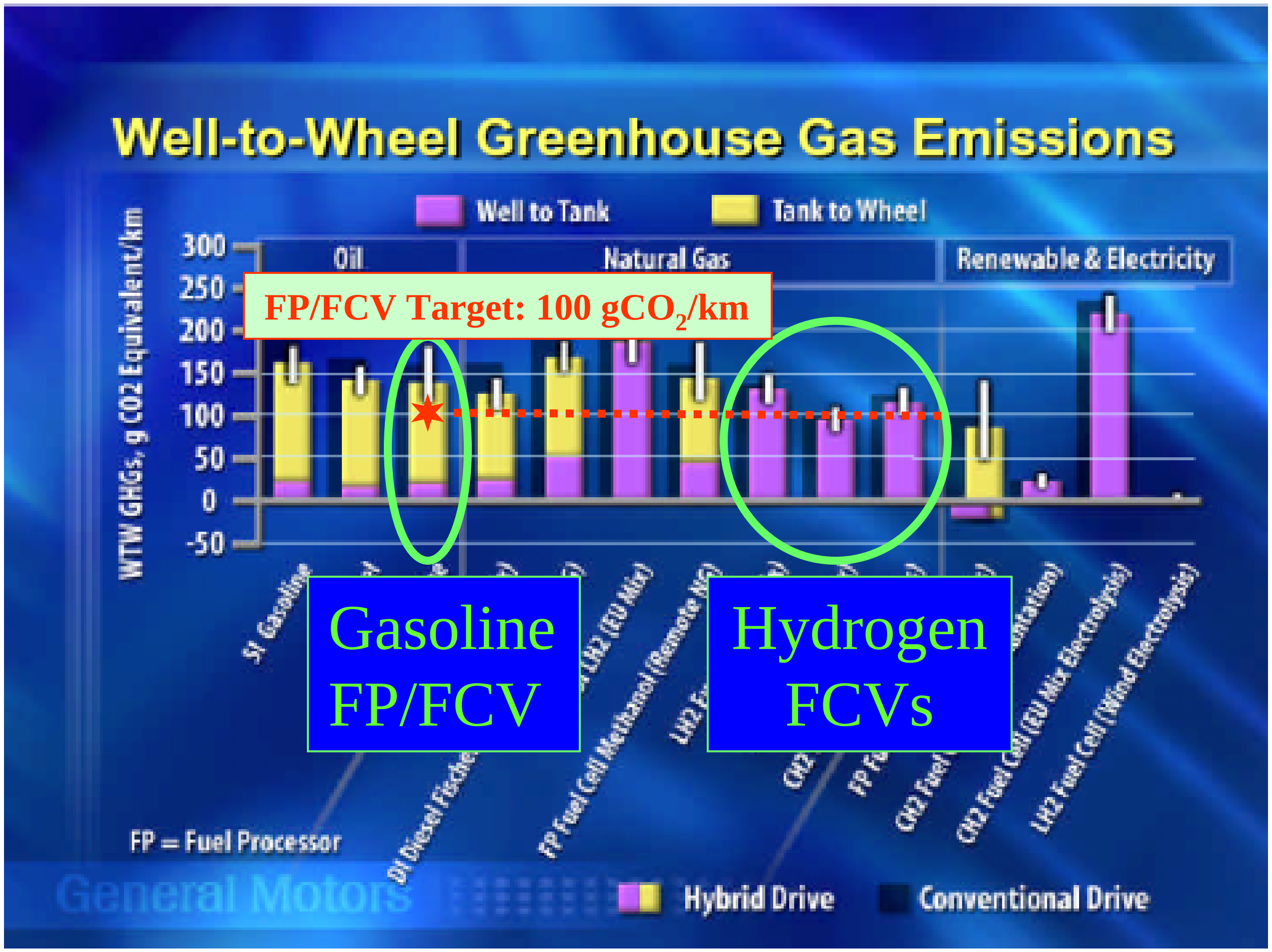


Gasoline FP/ FC Vehicle Targets are on-par with well-to-wheels CO2 from Pure H2 vehicles

Hydrogen Infrastructure costs could be avoided with gasoline FP/FCVs or managed across a longer timeframe while still allowing proliferation of fuel cell vehicles

Choudhury, Raj. *Well to Wells Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems. A European Study* Hart World Fuel Cells Conference. 2002

Renault strategy

Range

Customer acceptance

Security, Reliability

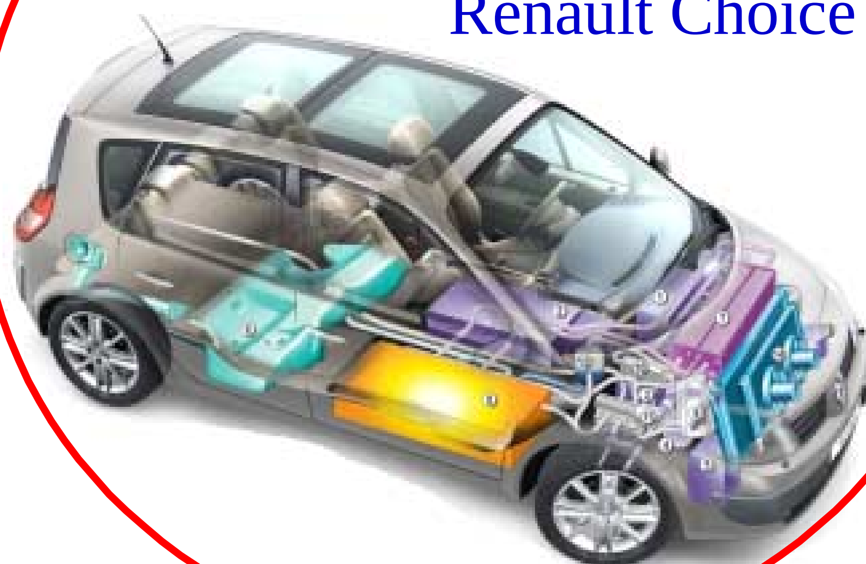
Cost of system, Cost of use

Performance

Infrastructure

Fuel Processor System

Renault Choice



Renault / Nuvera program

- Fuel Cell activities started in 1992
- Focused on a fuel-cell vehicle with a gasoline reforming system to be marketed after 2010.

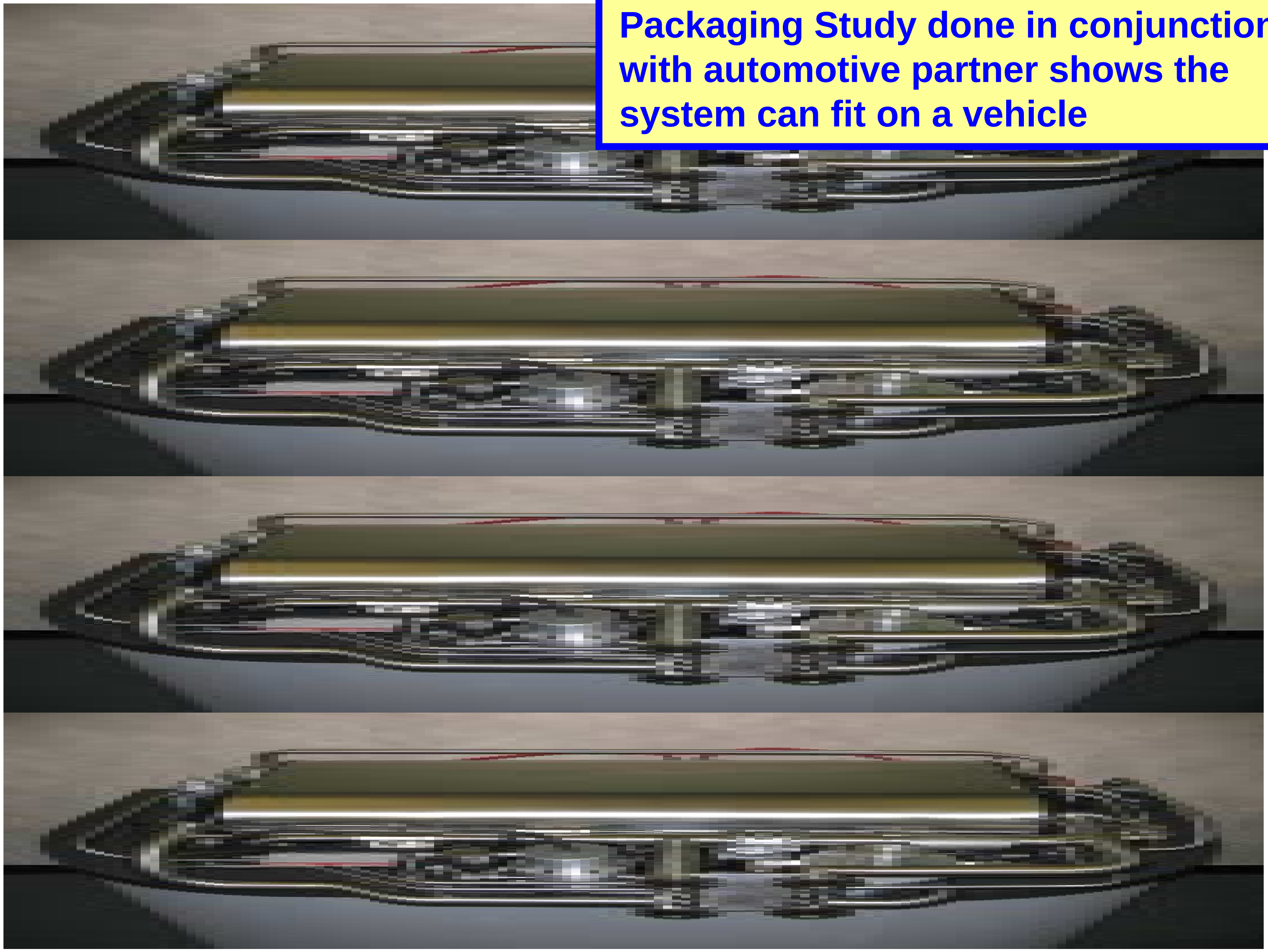
- Fuel processing and fuel cell expertise since 1992
- Focused on transportation and stationary systems

- Onboard Fuel Processor Project
- January 2002, until summer 2004
- Phase 1 : laboratory prototype system

  compactness, efficiency, and emissions
- Phase 2 : automotive prototype

  startup time, transient performance, fuel economy

Automotive Packaging Study



Packaging Study done in conjunction with automotive partner shows the system can fit on a vehicle

Conclusions

Nuvera has successfully demonstrated a fuel processor small enough and powerful enough for vehicle integration

Dramatic advancement of fuel processor technology

- ✓ 10x volume reduction
- ✓ Design for vehicle packaging

Proven operation

- ✓ Gasoline operation
- ✓ Power (33-200 kWth)
- ✓ Size (75 liters)
- ✓ CO (<100 ppm)
- ✓ Efficiency (81%)
- ✓ Pressure drop (0.5 bar)

Continuing work will build on the success so far

- ✓ Further fuel processor optimization
- ✓ More automotive controls
- ✓ Vehicle integration