2004 DOE Hydrogen Fuel Cell And Infrastructure Technologies Program

UTC Power

A United Technologies Company

Atmospheric Fuel Cell Power System for Transportation

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Philadelphia

Presentation Agenda

- Objective
- Technical Targets and Barriers
- Background/Approach
- Project Safety
- Program Schedule
- Technical Accomplishments/Progress
- Testing Progress
- Interactions and Collaborations
- Summary
- Future Challenges & Opportunities

Objective

To determine the feasibility of a on-board gasoline reforming 50 kW fuel cell power plant for commercial transportation applications based on the industry and DOE targets for commercialization.

Technical Targets and Barriers

Develop a 45% efficient reformer_based fuel cell power system for transportation operating on clean hydrocarbon or alcohol-based fuel that meets emissions standards, a start_up time of 30 seconds, and a projected manufactured cost of $45/kW by 2010 and $30/kW by 2015*.

- Transportation Fuel Processors Technical Barriers (3.4.4.2)*:

I. Start-up/Transient operation
J. Durability
K. Emissions
L. H2 Purification/CO clean-up
M. Integration/Efficiency
N. Cost

* Excerpts from: "Multi-Year Research, Development and Demonstration Plan, HFCIT, June 3, 2003"

Approach

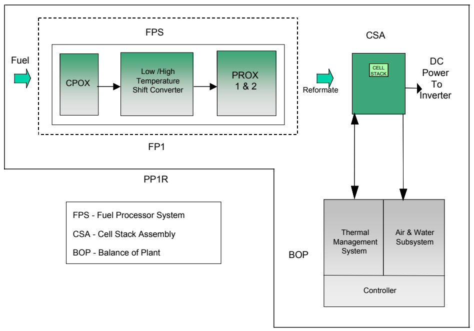
S400 Gasoline FCPP Phases

- Development in Two Phases **(FY02 - FY04)**
  - Integrated Gasoline Fuel Processor **(FY02 - FY03)**
    - Gasoline in, fuel cell-quality reformate out
    - Development Testing November 2002 – June 2003
    - Data shown here
  - Integrated Fuel Cell Power Plant **(FY03 - FY04)**
    - Assembly completed
    - Started testing in December 2003
    - ANL to conduct verification testing June 2004
    - Available data and projections shown here

Approach

Current S400 Development 2001-2004

System Concept 2001:



PPIR
2003-2004

FP1 testing completed
June 6, 2003

Program Steps

2001: Down-select optimum system

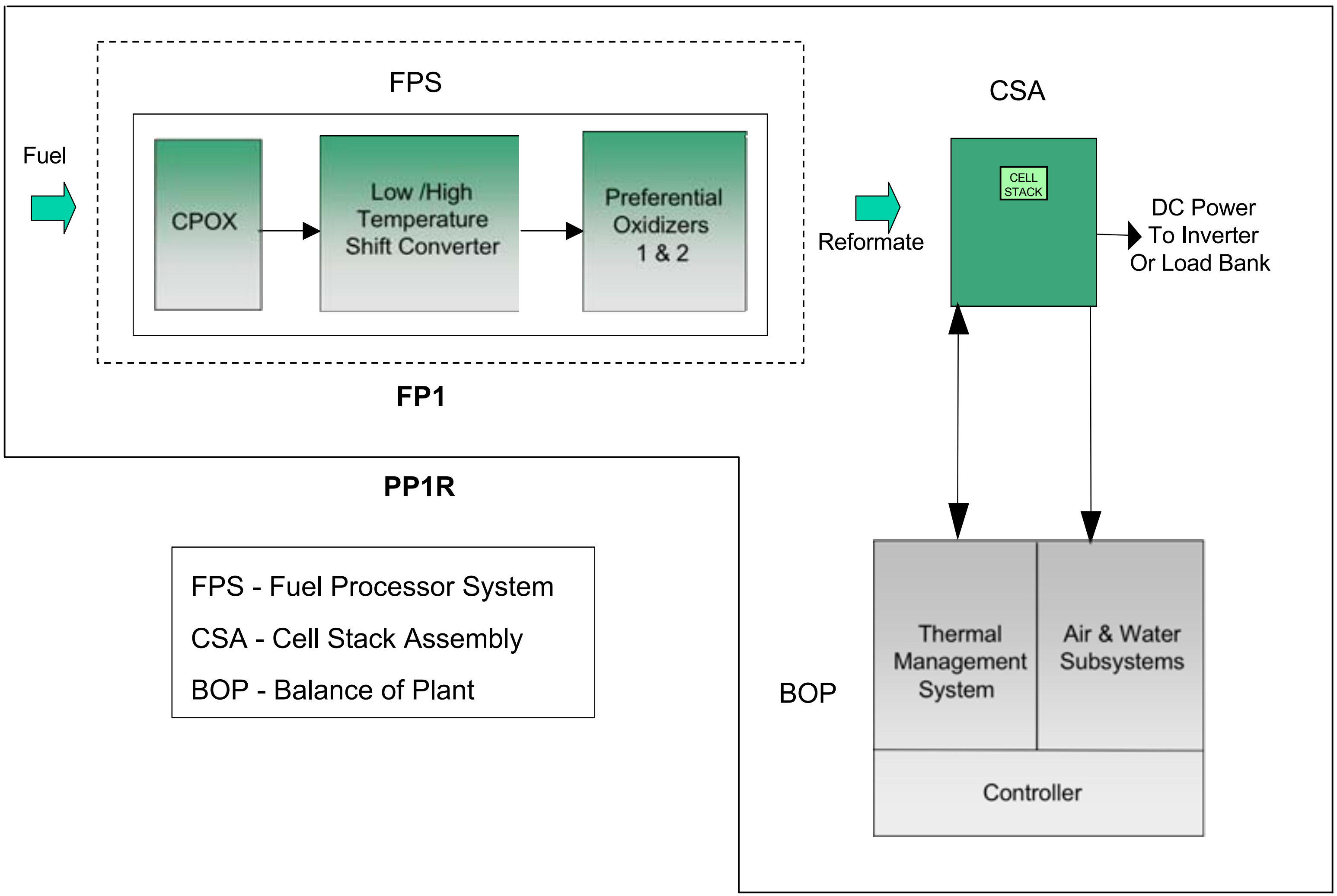
2002: Fuel Processor Focus: Start Time, Controllability & Volume

2003: Power Plant Focus: Start Time Controllability, Emissions & Efficiency

FPS → FP1
2002-2003

System Overview

Simple System Schematic



Project Safety

- Safety reviews of product and test equipment design, and of test processes
  - Codes and Standards, Hazard Analysis, FMEA, FTA, HAZOP
- Standards for Areas with Hazardous Fluids
  - Ventilation and Ventilation Monitoring
  - Gas detection and Fire Suppression
  - Selection of electrical components in potentially hazardous locations
- Out of Limits Conditions
  - Burner and reactor controls
  - Ground fault detection
  - High Temperatures and High Pressures

Project Safety – Safety Analyses

Potential Situations ↓ *Mitigation Approaches*

Hazard Analysis (HA)

Resultant Events ↑ *Failure Modes of Parts and Process*

Failure Mode and Effects Analysis (FMEA)

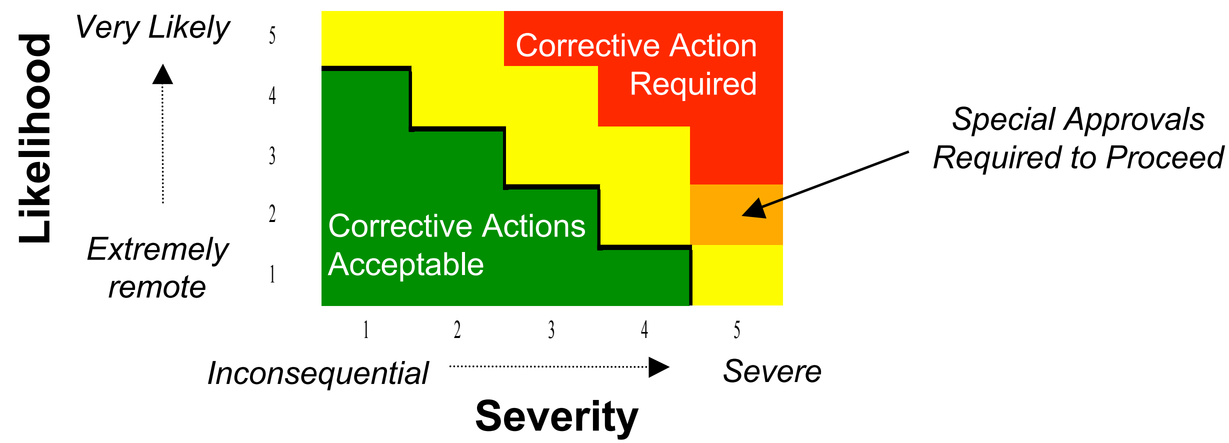
Events ↓ *Mitigation Approaches*

Fault Tree Analysis (FTA)

Procedures ↑ *Operation Approaches*

Reviewing Procedures for Hazardous Operation (HAZOP)

Analysis Risk Ranking



Project Safety – Management of Change

- UTC change process applied to product <u>& test equipment</u>
  - IPD team members review and approve
  - Safety Engineer involvement in IPD
  - Functional checkout of hardware/software changes
- Operating procedures under revision control
- Readiness reviews required for new equipment and chemicals, highlights:
  - Hazards analysis and FMEA
  - Equipment functional checkout
  - Identification of preventative maintenance
  - Procedures and Energy Control
  - PPE assessment, training and communication

Project Safety – Lessons Learned & Other Insights

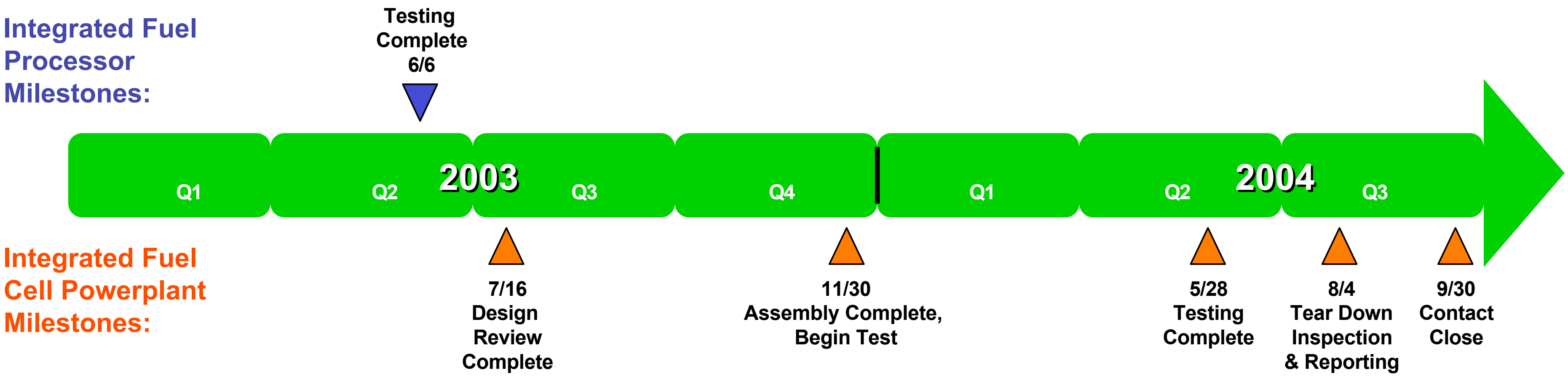
Two Lessons Learned Examples:

- **Gasoline Heater Control Failure**: Failed solid state relay used for primary control of heater, secondary relays were part of sequential control instead of being continuous. Corrective action: change to continuous and adding further over-temperature redundancy
- **Unintended Flow Path**: Failed active component creates unintended flow path, i.e. blower fails to start, other flows find unintended path. Corrective action: improved flow confirmation and backflow prevention

Other Insights:

- Perform more safety analysis early in project design to identify and resolve safety issues
- Off normal states used for engineering or diagnostic purposes can create challenges. Consideration of all operating states (start-up, shutdown, transitions and off-design) in safety analyses.

Program Schedule – Current Plan



Integrated Fuel Processor

Integrated Fuel Cell Powerplant

Accomplishments/Progress

Series 400 CPO-based FPS

- Benefits
  - No steam generator (smaller)
  - Fuel flexibility (Low sulfur gasoline, naphtha, diesel, F-T diesel, CNG, ethanol…)
  - Reformer durability on CA RFG II / III gasoline (desulfurization by UTC FC)
  - Faster start (lower mass) than ATR

- Start Time: 10 sec CPO ignition, ~5 min FPS
- Volume: 78L Packaged FPS
- Emissions: SULEV
- H_2 Production efficiency:
  ~75% FPS

Accomplishments/ Progress – iFPS Results

Summary of S400 FP1 Testing
Performance Data versus Targets

Data	Target	FP1 Test
• FPS Volume, liters	75	78
• Heat up time, s	165	171
• Number of start/stops	500	111
• Duration of operation (total hrs)	2000	232 hrs
– Longest single run, hrs		10 hrs
• Range of equivalent power, kWe	10-50	10-50
• LHV efficiency, % at rated	$\geq$75	69%
• LHV efficiency, % below rated	$\geq$70	69-72%

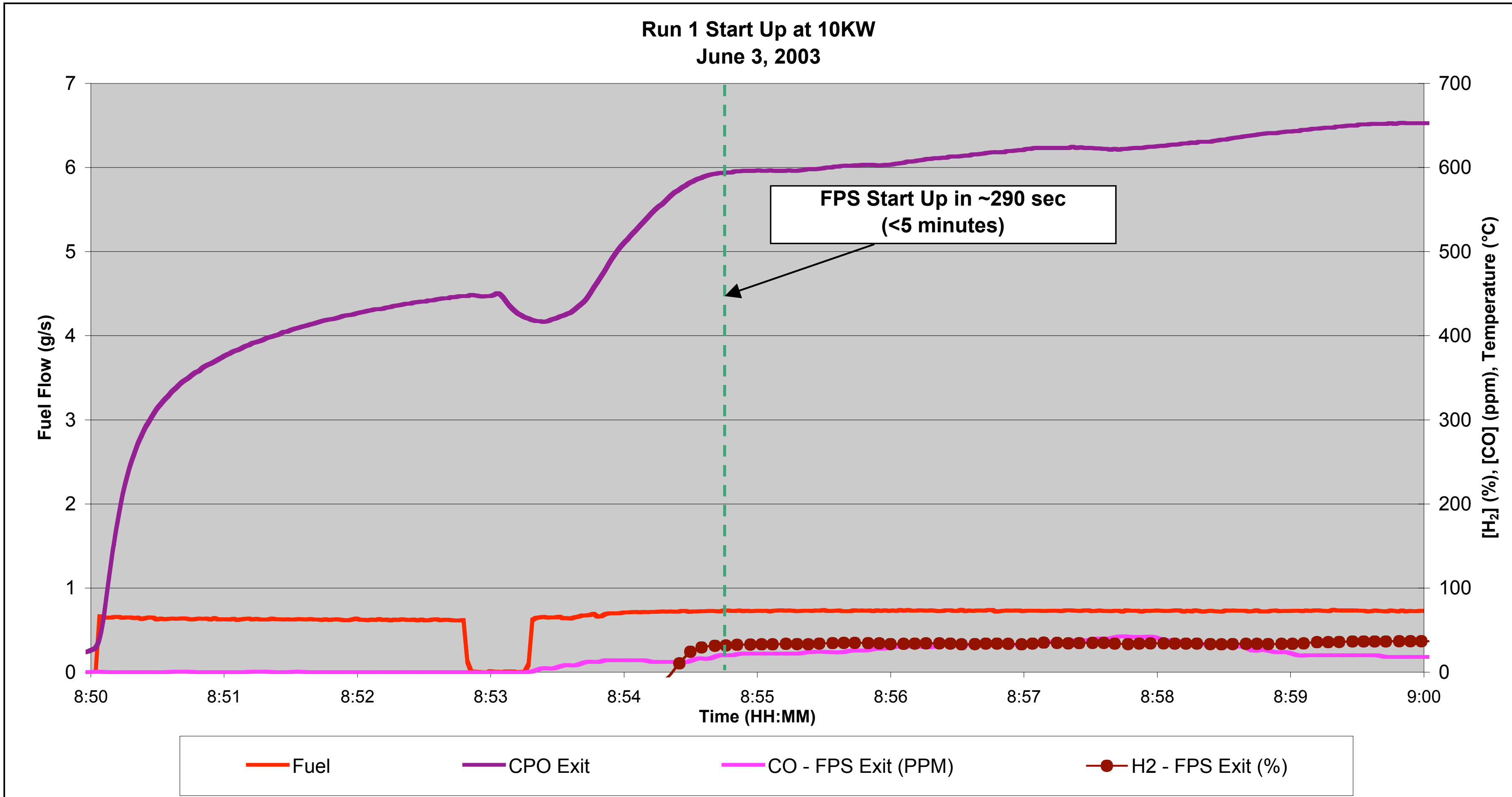
Accomplishments/ Progress – Powerplant Results

Summary of S400 PP1R Testing
Performance Data versus Targets

Data	Target	PP1R Test
• PP1R Volume, liters	570	582
• PP1R Mass, kg	455	690
• Start Time (to 10kW Power), min	15	TBD
• Number of start/stops	500	TBD
• Duration of operation (total hrs)	1000	TBD
• Maximum Net Power, kW	25-50	TBD
• System Efficiency at 25% of rated (12.5kW)	$\geq$35	TBD
• Ambient Operating Temperature	4 - 40°C	TBD

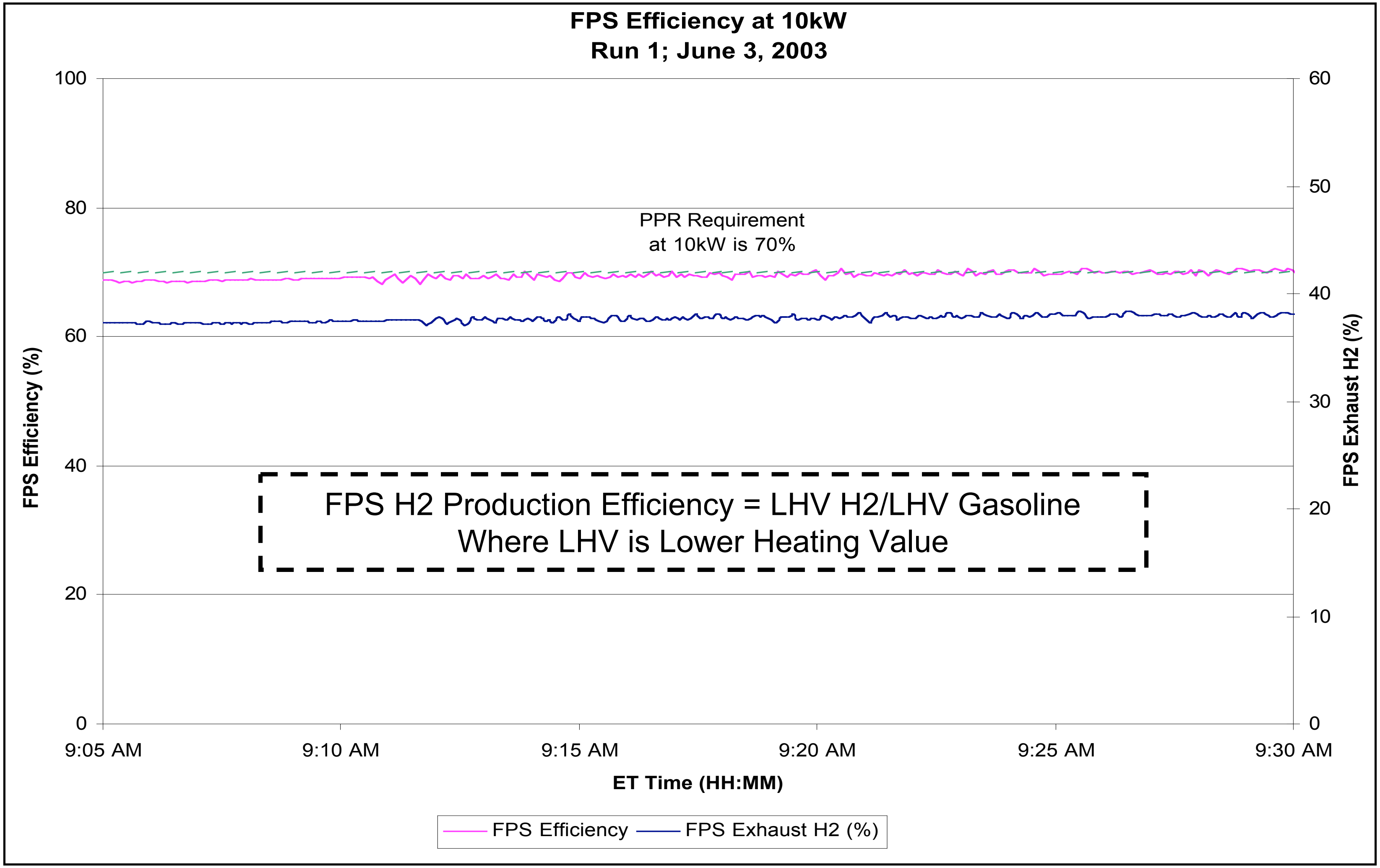
FP1 Test Results: Start Time

- Start time <5 minutes. Based on stability, H_2 and CO Concentrations



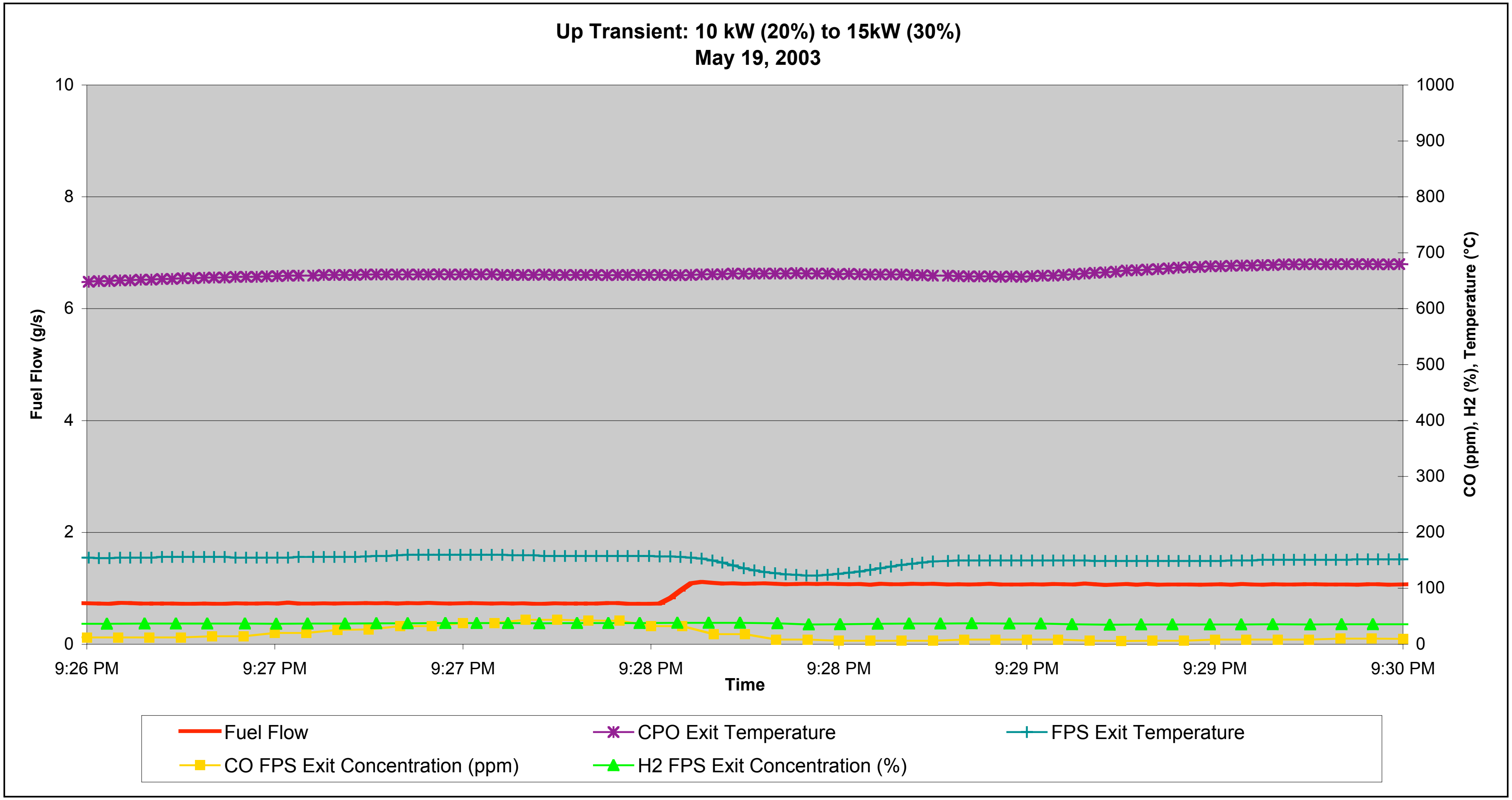
FP1 Test Results: FPS H_2 Production Efficiency

- H_2 Production Efficiency at 10kWe is ~70%



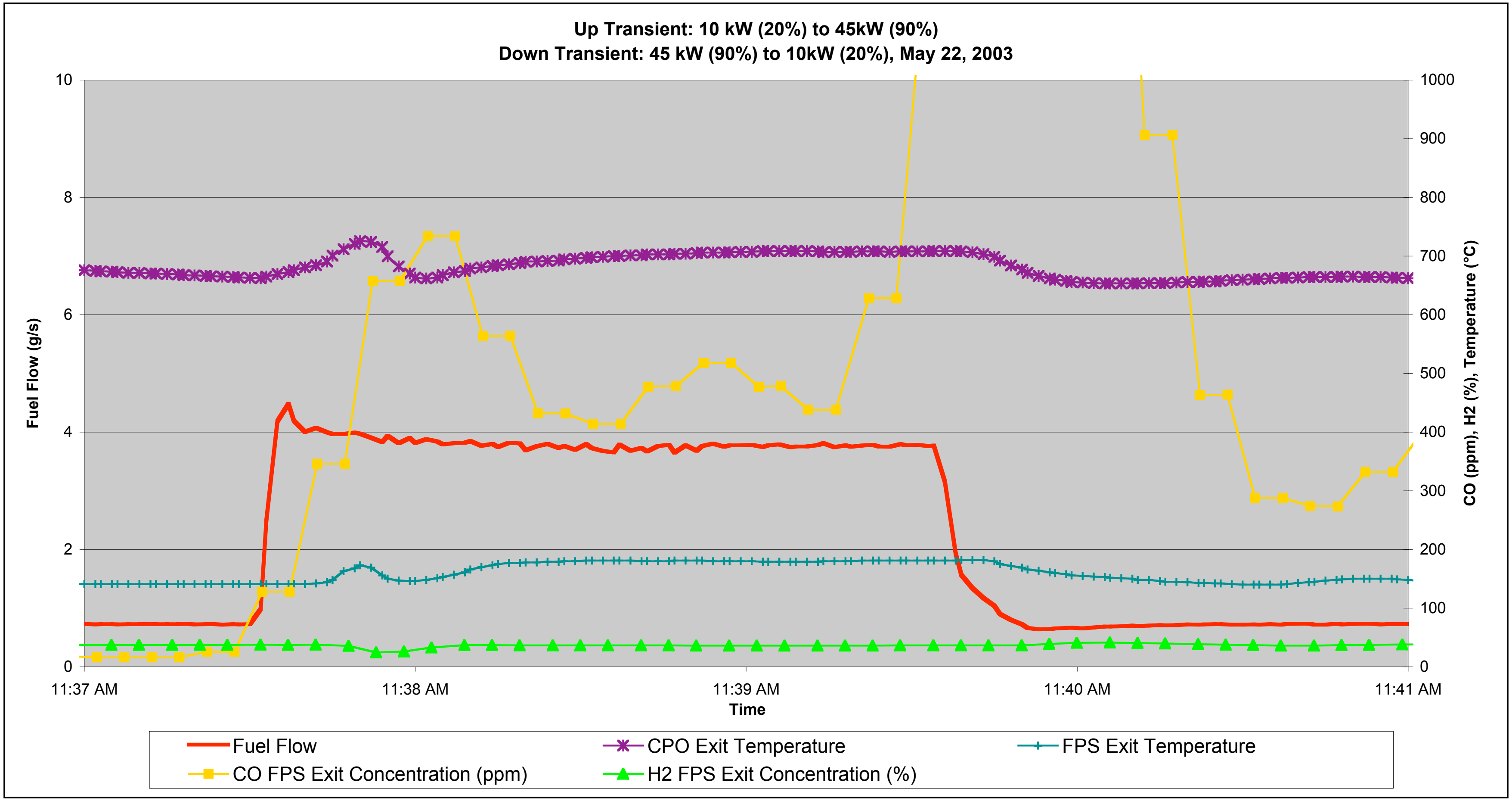
FP1 Test Results: Small Transient Performance

3.5 kW/s small transient. All stable, CO levels as desired



FP1 Test Status: Large Transient Performance

3.5 kW/s large transient. All stable, except CO levels high



FP1 Test Status: SULEV Emissions

- Power plant emissions design goal was to be equal to or less than the 2004 Super Ultra Low Emissions Vehicle (SULEV) standards for vehicles <8500lbs, for CO, NOx and NMHC.

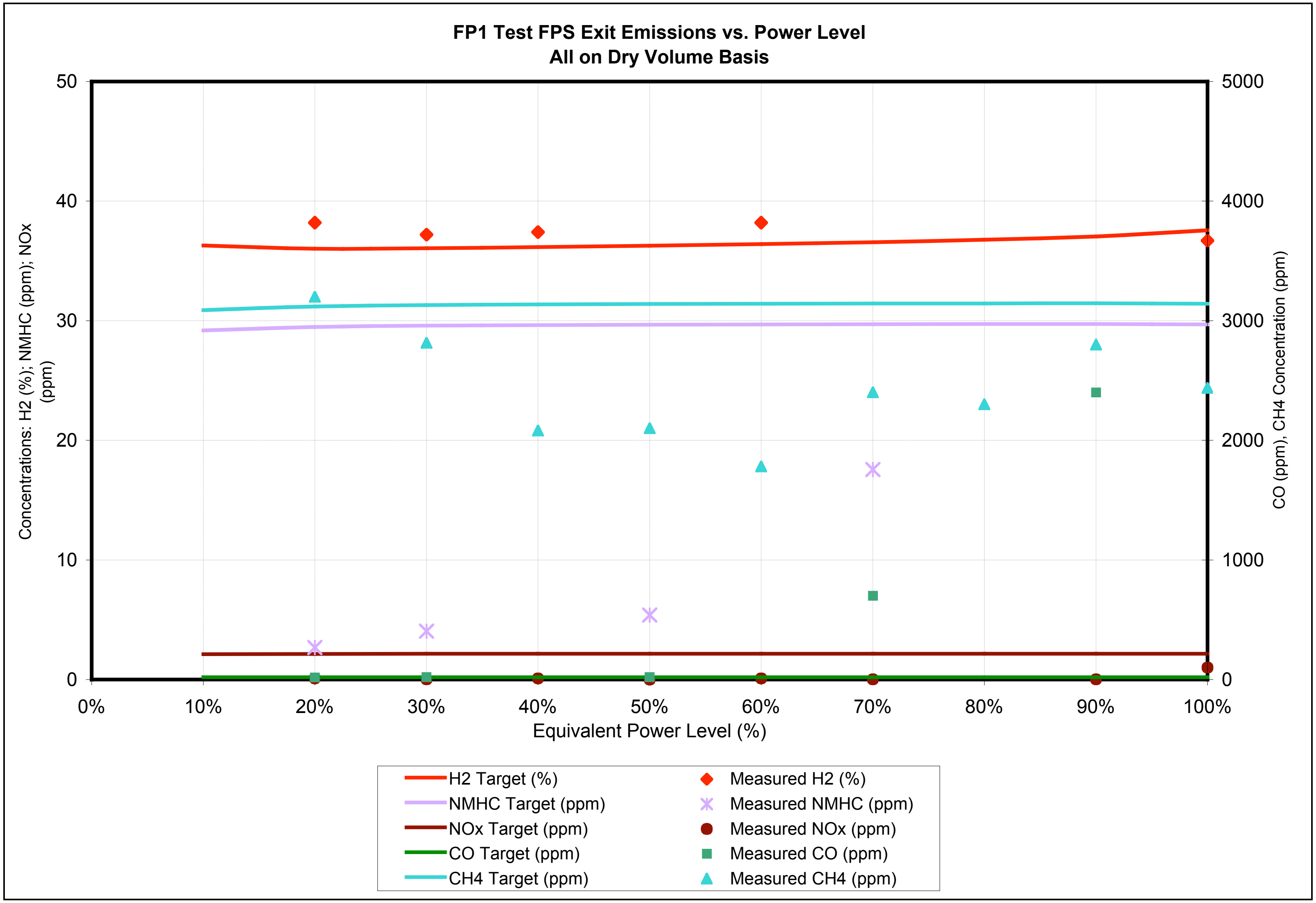
- The SULEV emission limits are specified in terms of g/mile. The emissions for FP1/PP1R were apportioned as total mass amounts for start up, and as concentrations during on-load based on the SULEV limits and the LA4-CH driving mode.

- A methane target of 700 ppm at the powerplant exhaust (3100ppm at FPS exit) and a NMHC target of 1ppm at the FPS exit were additional goals.

- The CSA limit for CO is 20ppm, which is lower than SULEV. The 20ppm target was used herein.

Steady State Goal	*Result*
NOx ≤ 2.1ppm (dry volume)	< 1ppm at all power levels
CO ≤ 20ppm (dry volume)	≤ 20ppm at power levels below 30 kW
CH4 ≤ 3100ppm (dry volume)	< 3100ppm at all power levels
NMHC ≤ 30ppm (dry volume)	≤ 30ppm at all power levels except 50 kW
Aromatics ≤ 1ppm (dry volume)	Average ~ 2ppm; Range: 0.1 to 10ppm

FP1 Test Results: FPS Exit Emissions and H2



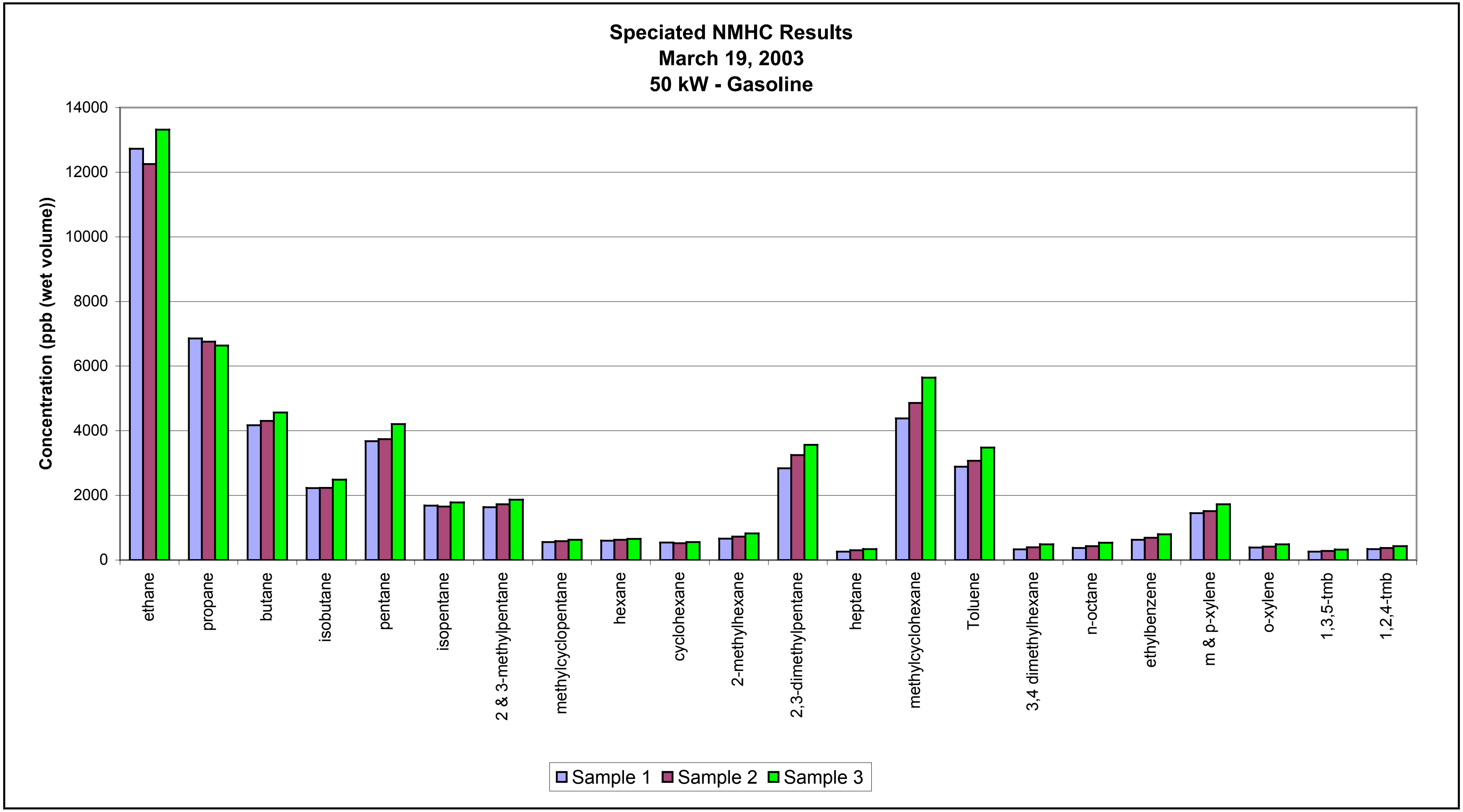
FP1 Test Status: Speciated Hydrocarbon Emissions

- In addition to the emissions testing was done to determine the unreacted non methane hydrocarbons (NMHCs) in the FPS exhaust.

- The total amount of NMHCs in the exhaust is very low

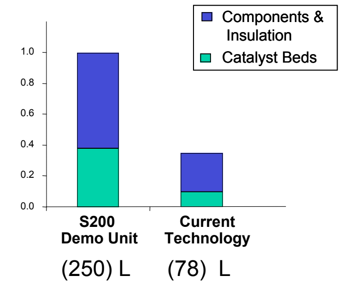
- Data is shown for three samples at 50 kW equivalent FPS operation. Data from 50 kW was used since the most species were measurable.

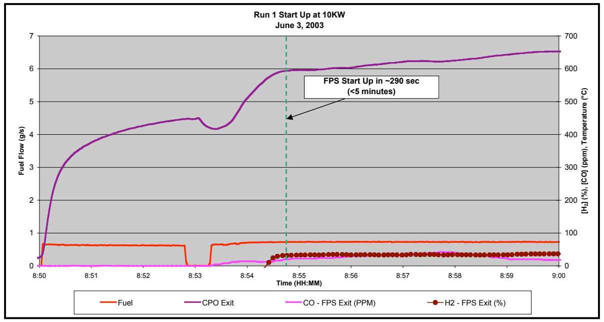
Test Results: NMHC Speciation at FPS Exit (~CSA inlet)



Summary/Future

- Significant progress made from S200 to S400
  - Weight
  - Volume
  - Start time
  - FPS Technology
  - CSA Technology



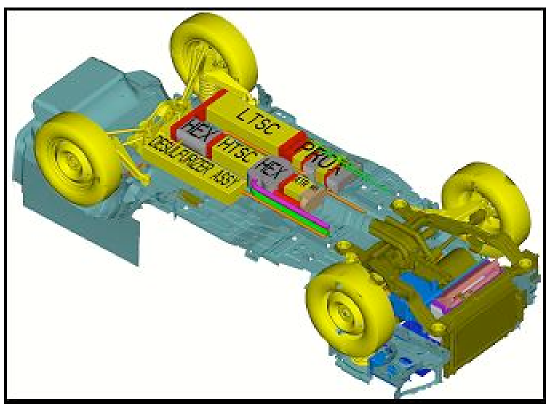


- Program ends in FY 04, remaining testing will be completed followed by complete teardown and analysis.

Future Challenges

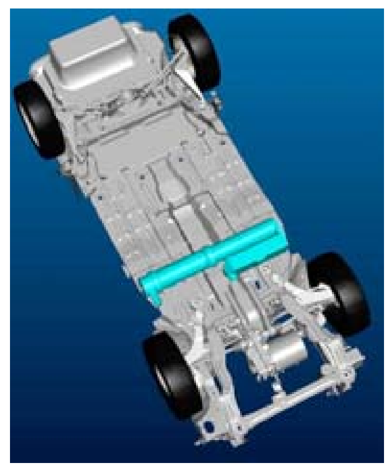
Gasoline reformer fuel cell power plants

ATR

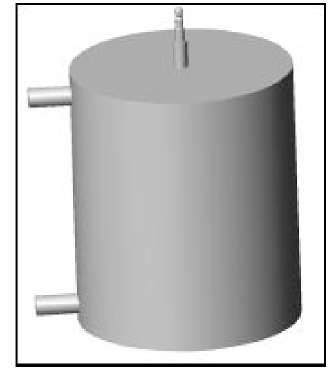


- **250 L**
- **45 min start**

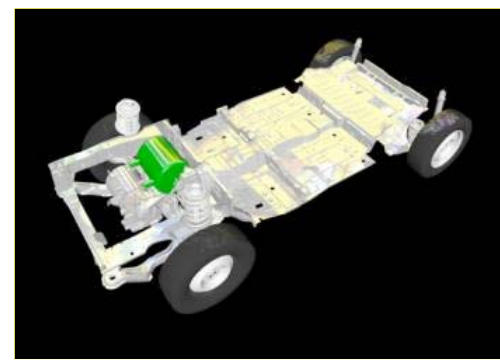
Current FPS



- **78 L**
- **<10 min start**



Next generation FPS



Goal

- **35 L**
- **< 30 sec start**

Future Opportunities

FPS Technology Advancement

- Focus on Fuel Processor System (FPS) technology to:
  - Improved catalyst
  - Reduce start time
  - Evaluate membrane separation technology
  - Evaluate PSA technology
  - Reduce weight and volume
  - Improved controllability
- Focus on smaller applications, 5 kW APU size demonstrations and development