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2005
DOE Hydrogen Program Review

150 kW PEM Fuel Cell Power Plant Verification

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Project ID # FC46
Contract # DE-FC36-04GO14053

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Overview

Timeline

- Jan. 2, 2004 Start Date
- Dec. 31, 2009 End Date
- 20% Complete

Budget

- Total project funding
  - DOE share $11,617,821
  - Contractor share $10,165,096
- Funding FY04 $1,337,306
- Funding FY05 $1,562,694

Barriers

- **Components**
  - O. Stack Material & Manufacturing Cost
  - P. Durability
  - Q. Electrode Performance
  - R. Thermal & Water Management
- **Distributed Generation Systems**
  - E. Durability
  - F. Heat Utilization
  - G. Power Electronics

Partners

- United Technologies Research Center
- CT Light and Power
- EPRI
- Austin Energy
- New York Power Authority
- San Francisco Public Utilities Commission

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Objectives

- *The UTC Fuel Cells DOE Stationary Power Plant Program will resolve critical cell component, cell stack, and power plant reliability issues. Testing will be conducted in 20-cell stacks, and 150 kW power plants.*

1. Improve PEM CSA durability to achieve lifetimes >40,000 Hrs
2. Verify reliability of low cost PEM cell stack components
3. Verify the Design, Durability, and Reliability of Natural Gas Fueled PEM Power Plant
4. Complete a Fuel Cell Stationary Power Plant Market Assessment
5. Waste Heat Thermal Integration Assessment

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CSA Technology Approach

- Improve PEM CSA durability to achieve lifetimes > 40,000 hrs by:
  - Determine root cause and corrective action for high severity / frequent CSA failure modes
  - Develop a mathematical modeling to optimize inlet flow channel design for maximum humidification
  - Identify seal materials with chemical and mechanical stability in a fuel cell environment
  - Verify accelerated test conditions that demonstrate representative failure modes
  - Endurance verification of durability improvements

- Cost reduction of PEM CSA components by validating low-cost plate and UEA components
  - Performance in single cell tests and
  - Durability in 20-cell tests

CSA Technical Accomplishments

- Improved components and accelerated testing for CSA durability
  - Accelerated testing shows advanced reinforced membrane life-times of > 20-kh
  - Non-silicone materials for advanced designs down-selected
  - Seal accelerated testing suggests sealability maintained up to 40,000 Hrs
- Low cost component verification
  - Single cell performance verification of low cost plates and UEAs
- Endurance Testing
  - 11,500 hours on 20-cell stack with unreinforced membrane
  - 4,000+ hours on S900 20-cell stack

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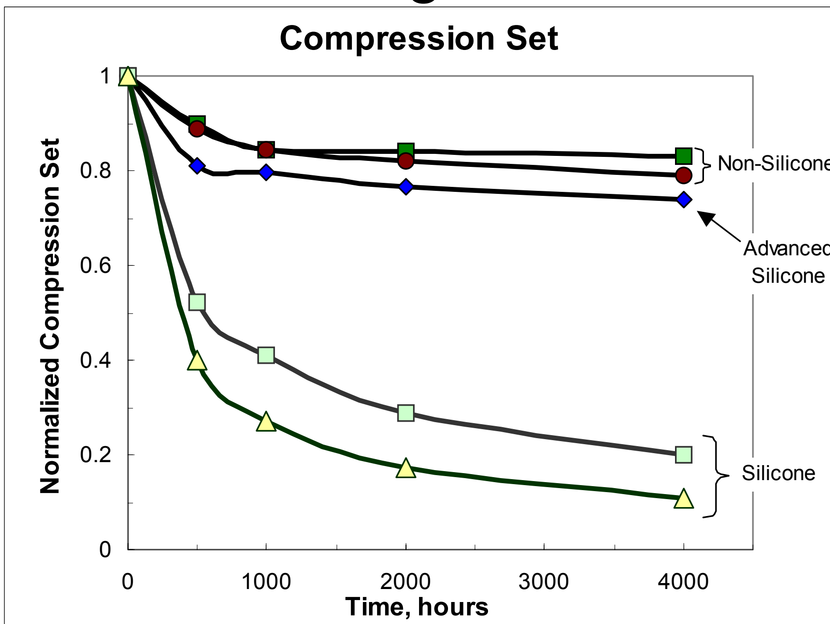
Seal Durability Accomplishment

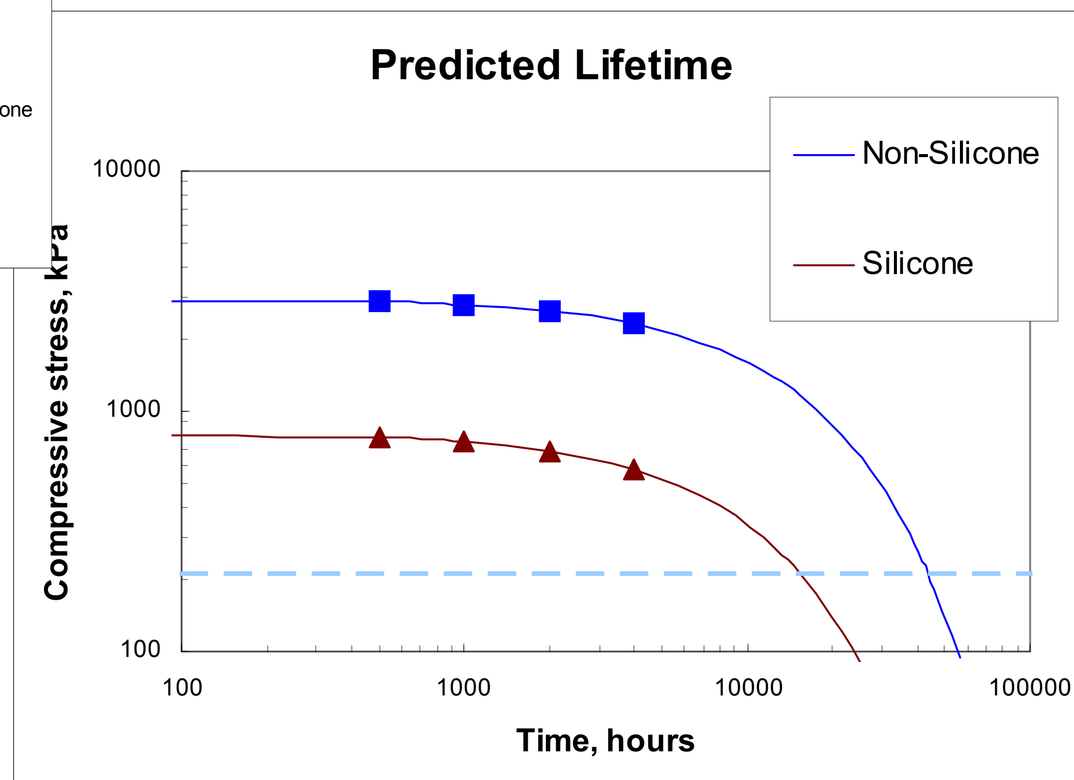
Interfacial gasket CSR



$$k = A\,exp\left(\frac{-E}{RT}\right)$$

Improved compression set resistance

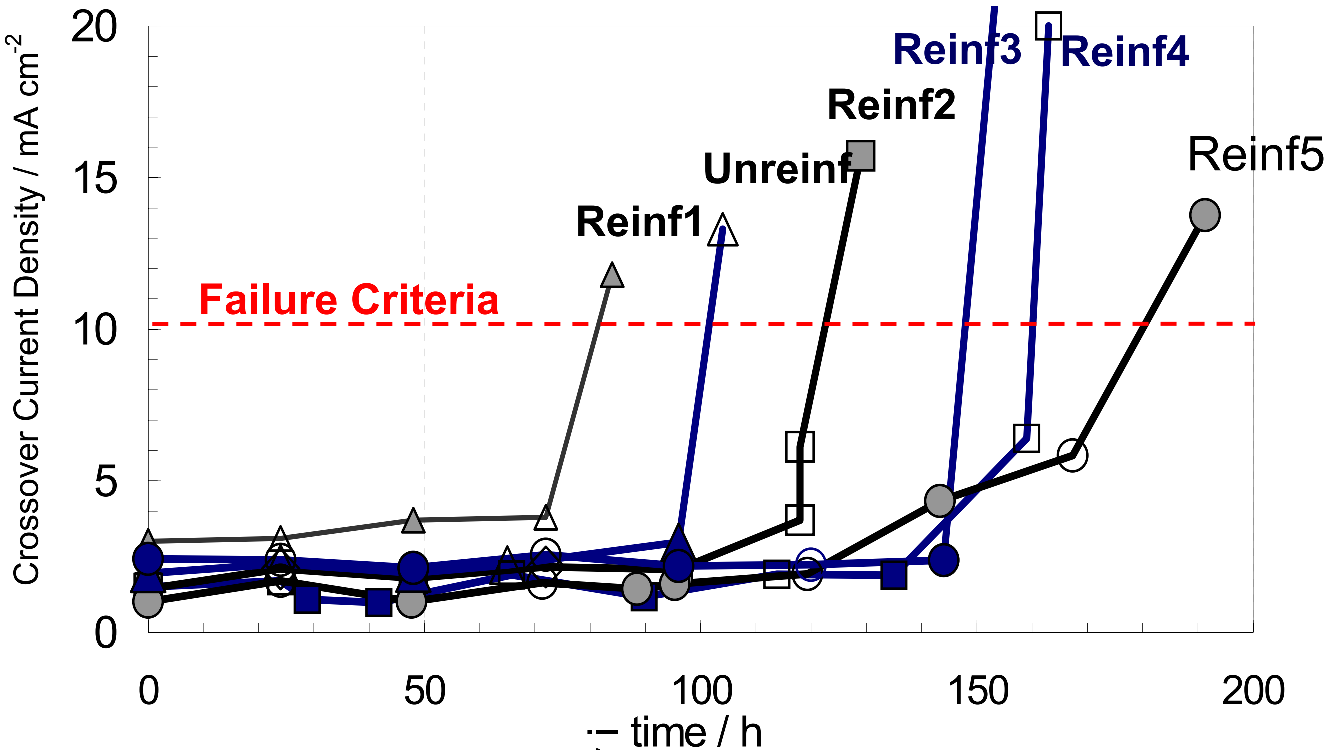
15,000 → 43,000 hours

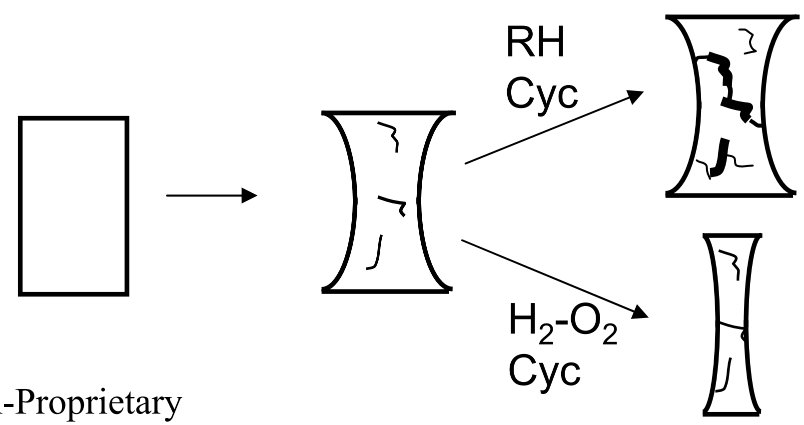


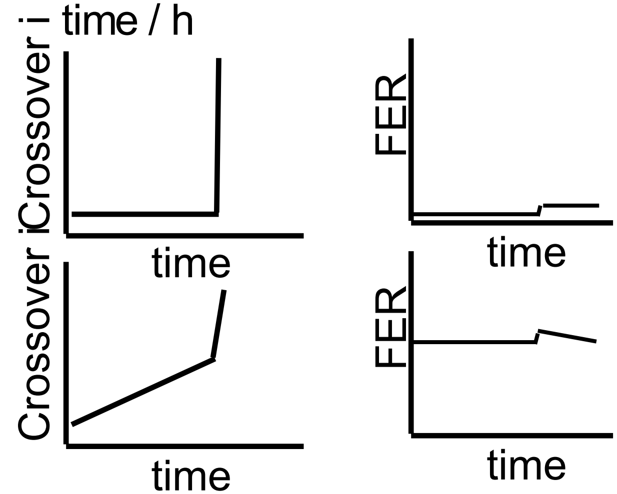
Membrane Durability Accomplishment

Cyclic accelerated testing

Reinf1	84~100 h
Reinf2	130 h
Reinf5	180 h
Unreinf	100 h
Reinf3	~160 h
Reinf4	~163 h



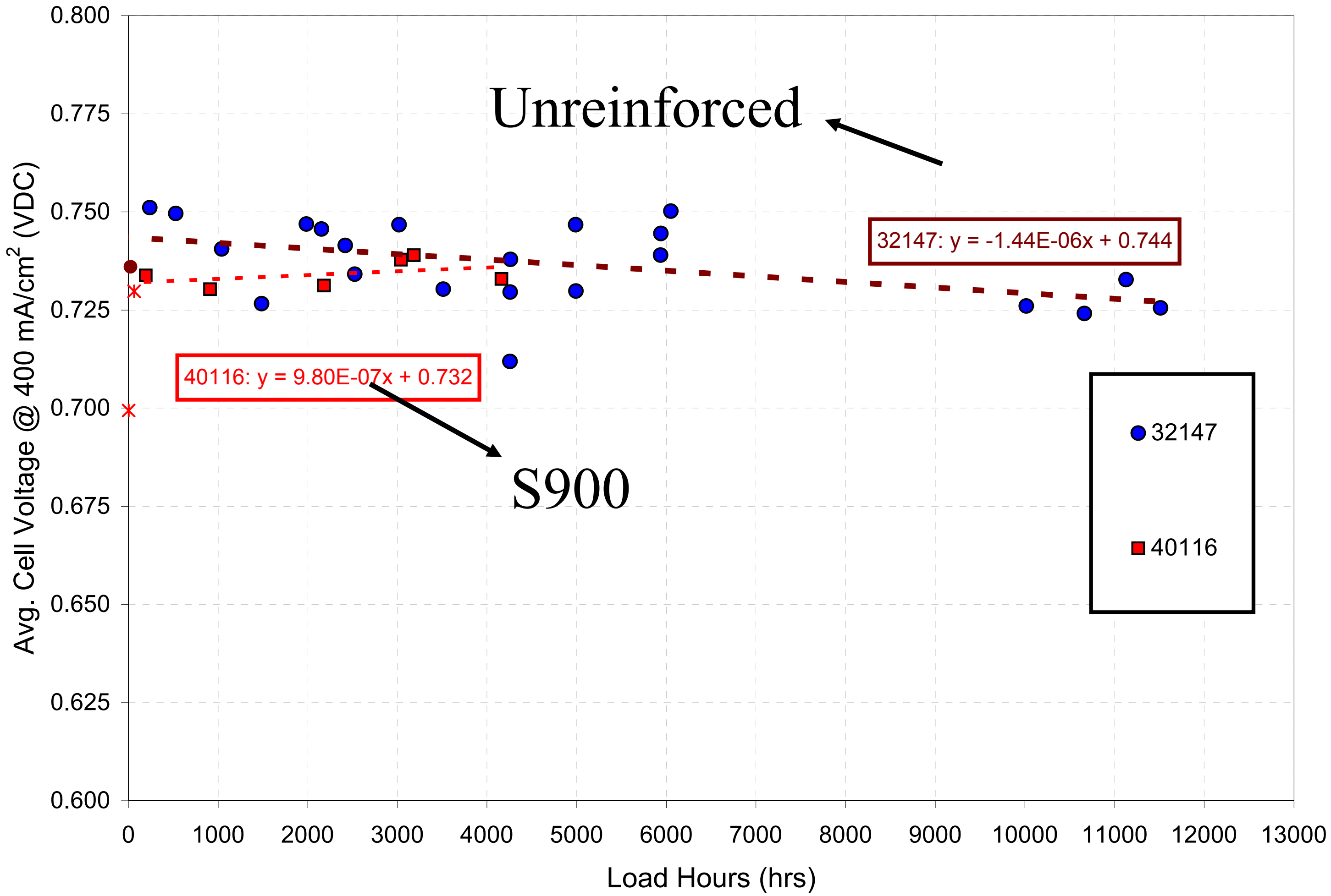




UTC Non-Proprietary

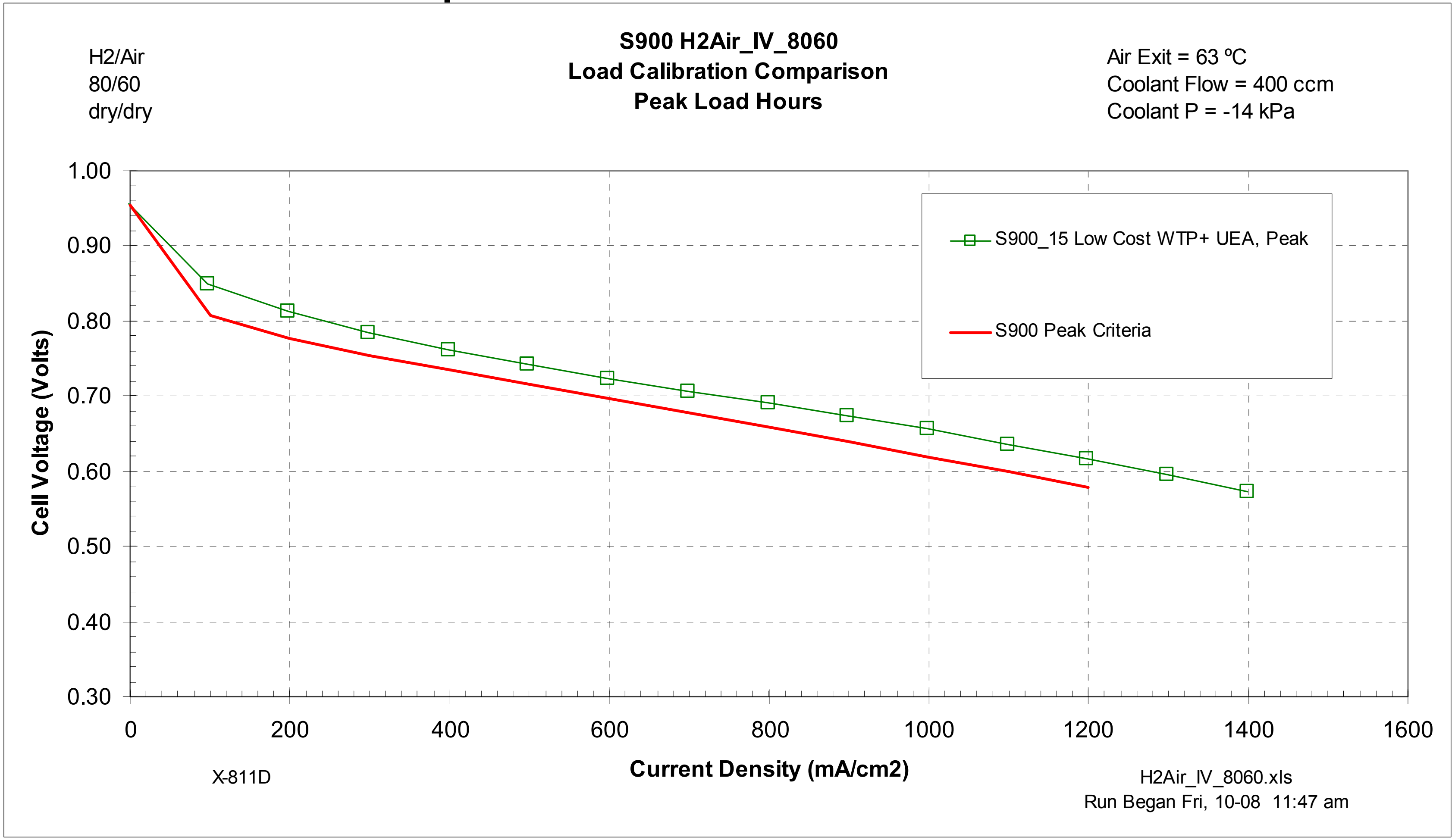
Endurance Demonstration Accomplishment

4.5-kh on S900 20-cell and 11.5-kh on N111 20-cell



CSA Cost Reduction Accomplishment

Performance comparison



Power Plant Approach

- Verify the specification, durability, and reliability of natural gas fueled PEM power plant
  - Operate PEM Beta Stationary power plant as a 150 kW baseline
  - Dynamic Controls Testing
  - Use Beta Test Article Results as a Baseline for Next Generation Verification Design
  - **Compete Improved Integrated System Design for Reliability**
  - Construct and Evaluate a PEM-150kW that incorporates significant Improvements in Power Plant Controls, **Fuel Processor Design**, Balance of Plant Components, and Grid Operation
- Complete a Fuel Cell Stationary Power Plant Market Assessment
  - Identify Market Segments, Drivers and Size
  - Identify Energy Credits and Incentives
  - Explore Domestic and International Opportunities
- Waste Heat Thermal Integration Assessment
  - Concepts,
  - Value Proposition Studies
  - Regional Needs Summary

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P/P Accomplishments

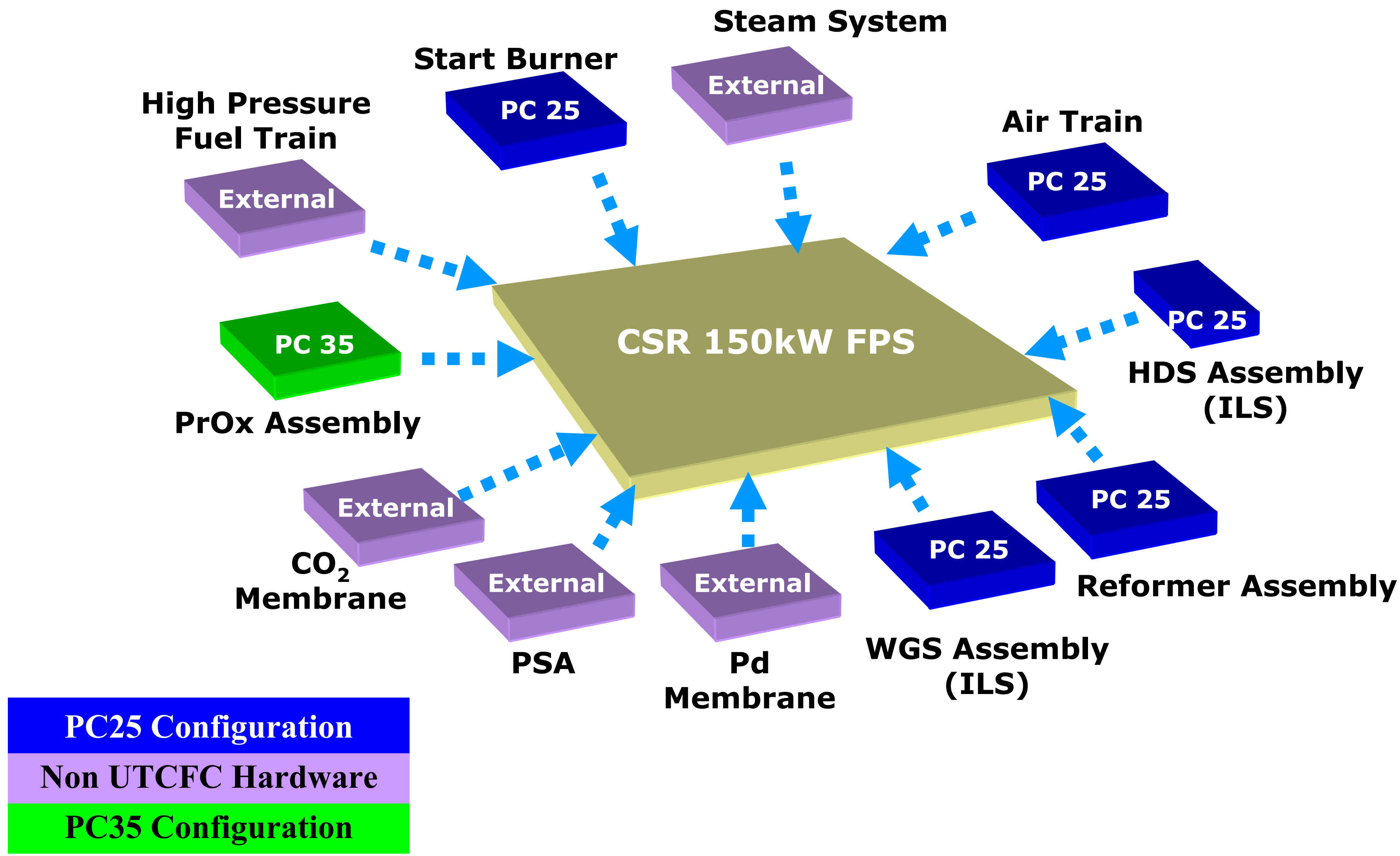
- Demonstration Testing of Beta Power Plant
  - Multiple daily runs: Typical 1 to 4 hour runs
  - Controls tuned for hands off automatic startup
  - Achieved maximum power of 139 kW DC / 117kW AC Net.
  - CO performance from FPS less than 10 ppm
  - FPS thermal management optimized
  - Debugged subsystems and BOP (balance of plant) components
  - P/P Start time reduced to 25 minutes
  - Cathode Humidification/Energy Recovery Device Verified

- Dynamic Tests Completed & Data Collected.
  - Tests conducted on 8 major loops: Power, Cathode air, CPO fuel & air flows, Prox air & thermal, Vaporizer water, CPO air blower
  - Tests conducted at 2 power levels: 40 kW and 75 kW.
  - Excitations used are step, sine-sweep and PRBS (pseudo random binary signal)
  - Dynamic data acquired at 10 Hz from the controller via CANalyzer

Power Plant FPS Approach

- Design and test a Fuel Processor System (FPS) capable of delivering high purity H_2 (> 90%) to a PEM fuel cell
- Design FPS to resolve critical component durability and cost issues using UTCFC experience
- Design validation will be accomplished via a full scale (150 kW) integrated FPS test

FPS Design Approach



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FPS Accomplishments

- 4 FPS design concepts were evaluated
- Reformer design based on Catalytic Steam Reforming (CSR)
- Examined the impact of reformate clean-up
    1. CO_2 Membrane (CO_2 Separation)
    2. Pd Alloy Membrane (H_2 Separation)
    3. Pressure Swing Adsorption (PSA)
    4. Preferential Oxidation (PROX)

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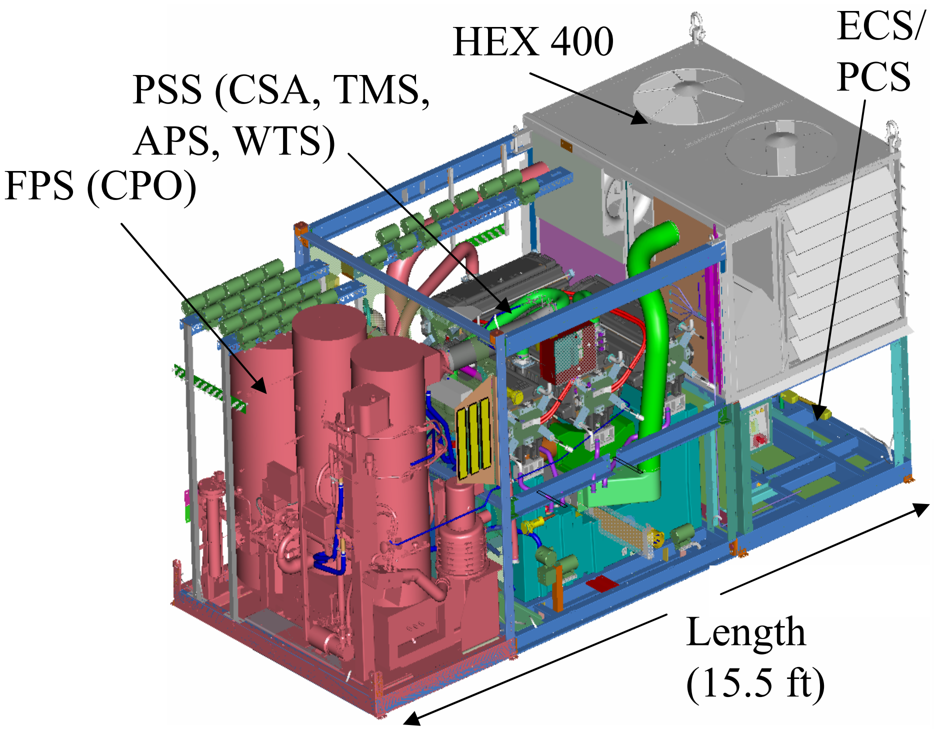
FPS Concept Options

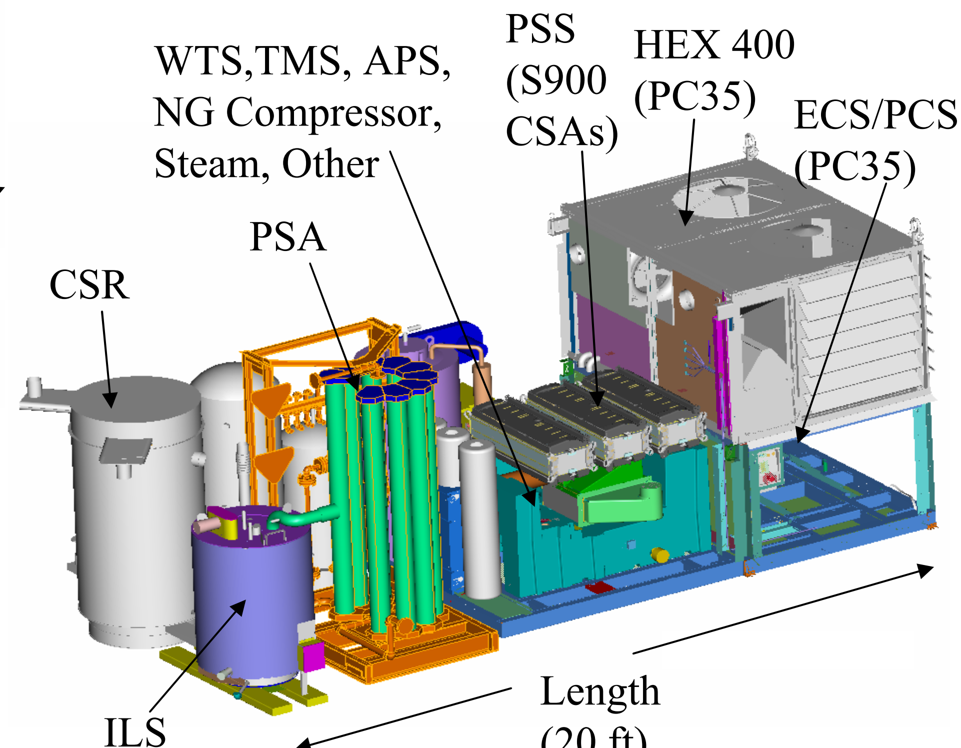
	Concept 1	Concept 2	Concept 3	Concept 4
FPS	**Reformer Type - CSR**			
Operating Pressure	**4 bar**	**6 bar**	**10 bar**	**1 bar**
CH_4 Conversion	**90%**	**85%**	**75%**	**90%**
Purification				
Method	**CO_2 Membrane**	**H_2 Membrane**	**PSA**	**NONE - PROX**
H_2 purity	**97% dry**	**>99%**	**>99.9%**	**78% dry**
CSA	CSA Type – S900			
Anode Recycle	No	Yes	Yes	No
Power Plant				
FPS Efficiency	**73.9%**	**62.2%**	**73.9%**	**73.8%**
Mech. Efficiency	**97.0%**	**95.5%**	**94.9%**	**98.7%**
CSA Efficiency	52%	52%	52%	**51%**
System Efficiency	**37.2%**	**30.8%**	**36.4%**	**37.0%**
Technical Risk	**Membrane**	**Membrane**	**Reformer**	**CSA - Reformate**

150 kW Conceptual Layout



PC35 Baseline Power Plant (2004)

CSR/PSA Concept (2006)



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Accomplishments

Fuel Cell Stationary Power Plant Market Assessment

Market Segments/ Drivers

Market Drivers	Commercial: Combined Heat & Power (CHP)	Commercial: Assured Power	Utility: • Power Supply • T & D Upgrade Avoidance	Industrial: • Conventional • Specialty (H2)	Government: • US Military bases • Municipal buildings	Government: • Municipal ADG • Landfills
Economic	• ~ 3 year payback • Energy Savings	Lost productivity costs (varies)	Up to 10 year payback	• ~3 - 5 year payback • Low Electric Rates	Longer paybacks possible	Longer paybacks possible
Technical	• Emissions / Noise • Heat Quality • Footprint	Reliability	• Large power requirements (1+MW) • High power density • Low Emissions	Multi MW needs	• Not always 24/7/365 • Emissions/ Noise • Heat Quality • Footprint	Require Gas Processing Unit
Regulatory / Other Factors	• Availability of Incentives /Subsidies • Utility Interconnection rules/tariffs		• State PUCs RPS Standards • Costs captured in regulated base • Grid Constraints			

(Segments / Applications: Commercial, Utility, Industrial, Government)

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Accomplishments

Fuel Cell Stationary Power Plant Market Assessment

- Domestic US Market
  - Direct Generation
  - Renewables (ADG)
  - On-Line Emergency Power
  - Assured Power
  - Micro-grid Power
  - Green Power / Cogeneration
- International Market Opportunities
  - **Germany**
    - Nuclear Power Phase out
    - Reduce CO2 Emissions Reduction levels by 25%
    - German Energy Agency Promoting (DENA) Renewable Fuels
    - CHP Incentives for Operators
  - **Korea**
    - Government Focus on Fuel Cells
    - Government Looking to Move to H2 Economy
  - **China**
    - Pollution-7 of 10 most polluted cities are in China
    - 10% of World Energy Consumption

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Accomplishments

Fuel Cell Power Plant Market Assessment

Identified Energy Credits and Incentives

CA	**SGIP – Level 1 Renewable** **SGIP - Non-Renewable**	$4.50 / W $2.50 / W	$900,000 $500,000
CA	**LADWP – Renewable Fuel** **LADWP – Non Renewable**	$2.20 – 2.40 / W $1.20 – 1.90 / W	$440,000 - $480,000 $240,000 – 380,000
CT	**CT Project 100**	10 Year contract for 5.5 cents/kwhr + wholesale pricing	Must be 1MW project
DE	**Green Energy Program Grant - Renewables**	Lesser of 50% cost or $250,000	
NJ	**Clean Energy Program - Renewables**	$360,000 - $855,000	Formula dependent on product size (100 kW – 1 MW)
NJ	**Renewable Energy Advanced Power Program**	20% of total construction cost	Minimum of 1MW in size. Undergoing revisions, new solicitation in summer 2005
MD	**Corporate Tax Credit – Both Renewable and non-Renewable**	30% of installed cost, max of $1.00 / W	$200,000 – credit carry forward for 10 years
MA	**Commercial, Industrial & Institutional Initiative (C31)**	$3.00 - $4.50 / W	$650,000 or 50% of construction cost.
OR	**Business Energy Tax Credit**	35% tax credit taken over 5 years	$350,000

Accomplishments

Power Plant Thermal Integration Study

Reviewed several thermal integration concepts, markets, regional aspects and evaluation methodologies to select **4 primary concepts, 5 markets and 8 regions for systematic evaluation** and identification of high value concepts

- CHP Markets Identified:
  - **Hospitals -** Chilling needs throughout the year and clean environment requirement
  - **Supermarkets -** Dehumidification needs
  - **Data Centers -** Requirements for reliable power and chilling needs
  - **Hotels -** Swimming pools would need dehumidification
  - **Labs/Clean rooms -** Reliable power and 24 hour conditioned air

- Regions Selected:
  - **San Francisco, Los Angeles, Chicago, Boston, New York City, Long Island, Miami Washington D.C.**
  - Density of Potential Customers
  - Spark Spread (Delta between Natural gas and Electrical costs)
  - Geographic Zones, Hot and Humid Areas
  - Areas with $ Incentives for CHP Applications

Project Future Work

- FY 2005
  - Continue to develop and demonstrate low cost, cell stack components with high durability and reliability
  - Design and manufacture of advanced seals
  - Performance verification of low cost plates and UEAs
  - Complete improved PEM stationary natural gas fueled power plant design based on Lessons Learned
  - Proceed with PSA system (Concept #3) as primary option unless further data from Concepts #1 and #4 suggest otherwise
    - Monitor technological progress as it relates to Concepts #1 and #4
    - Transition Concept #3 to the preliminary design phase
    - PSA purification technology
    - Complete Reformer development tasks
      - Noble metal catalysts
      - Modified tube structure
  - Finalize Thermal Integration study for the useful application of PEM power plant heat

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Project Future Work

- FY 2006 – 2009
  - Validate PEM stack components and power plant design concepts in Field Evaluation Power Plant on Grid
  - Begin quantified accelerated testing of advanced membranes to show 40,000 hr durability
  - Continue 20-cell stack demonstration of long life stacks (15,000 Hrs).
  - Stack testing under accelerated, aggressive conditions for lifetime estimation and robustness.
  - Validate PEM power plant performance on feeder systems located in three areas of the U.S: Austin, TX; Albany, NY; and San Francisco CA.
  - Develop predictive base for PEM power plants on various distribution feeders

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Backup Slides

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Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

Hydrogen leakage within the power plant fuel compartment leads to explosion.

1. Requires multiple failures
2. Multiple layers of protection
3. Very low probability of occurrence

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Hydrogen Safety

Our approach to deal with this hazard is based on CSA FC1, NFPA 496, and NEC:

1. Design equipment for pressure capability and leakage.
2. Actively monitor hydrogen flow to limit fuel leakage.
3. Ventilate the compartment to less than 25% LFL.
4. Monitor ventilation flow.
5. If necessary,
   - Monitor ventilation exhaust for combustibles
   - Fuel Compartment Fire Detection
   - Provide fail-safe isolation of hydrogen via multiple shutoffs and Normally-closed valves

Design Process for Safety

- **Safety reviews of product design and product operation**
  - Codes and Standards, Hazard Analysis, FMEA, HazOps
- **Layers of Protection Approach**
  - Passive, Active, Reactive Mitigations
  - Ventilation, Monitoring of Fuel Enclosure, Fuel Interlocks,
  - Selection of electrical components in Zone 2 areas
- **Engineering change process applied**
  - Cross functional team members review and approve
  - Functional verification of hardware/software changes
  - Operating procedures under revision control
  - Readiness reviews required for major changes, 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