2004 DOE Hydrogen & Fuel Cells Technologies Merit Review Presentation

150 kW PEM Fuel Cell Power Plant Verification

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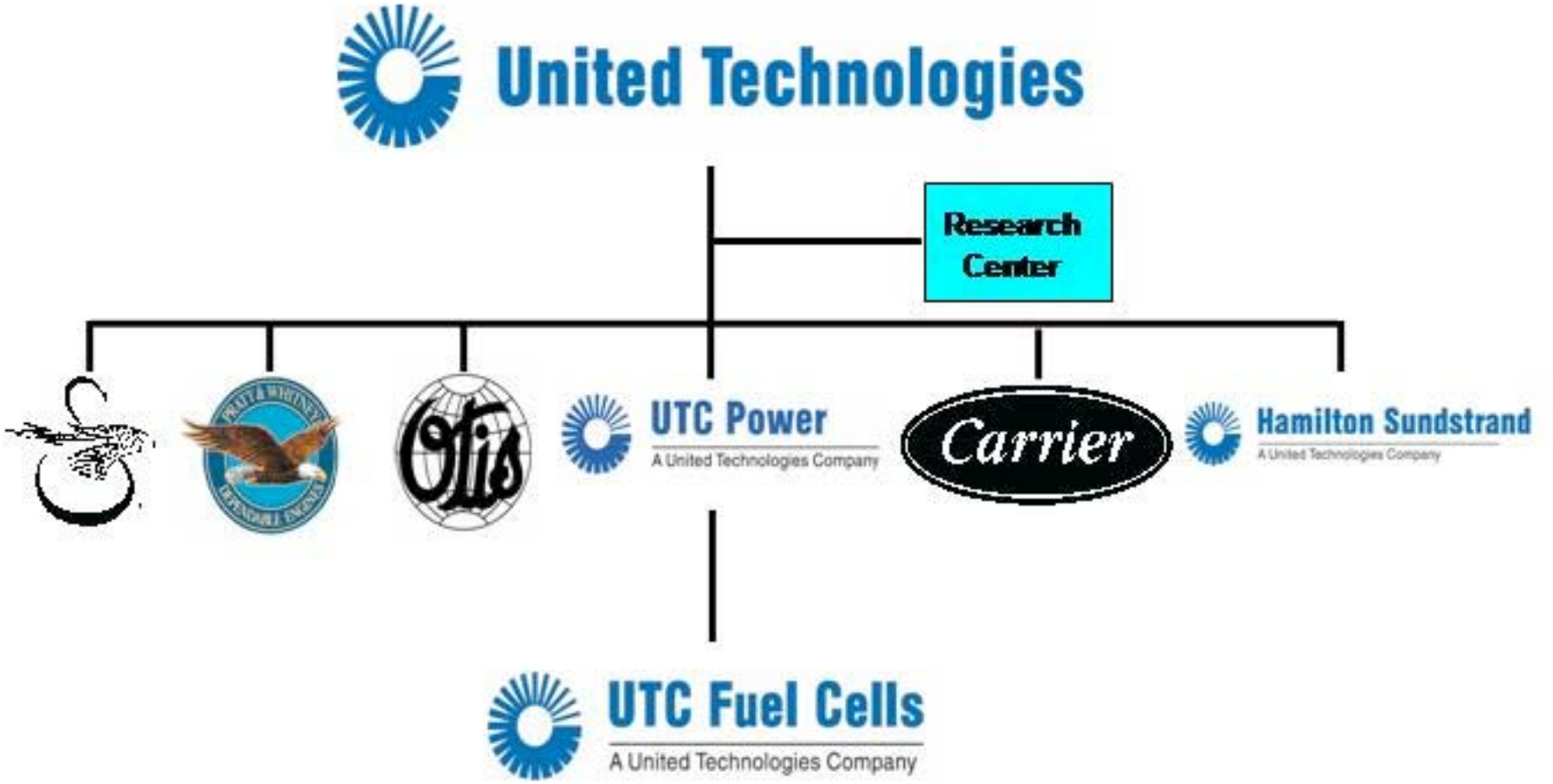
UTC Fuel Cells
A United Technologies Company

UTC Power
A United Technologies Company

UTC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Carrier
Hamilton Sundstrand
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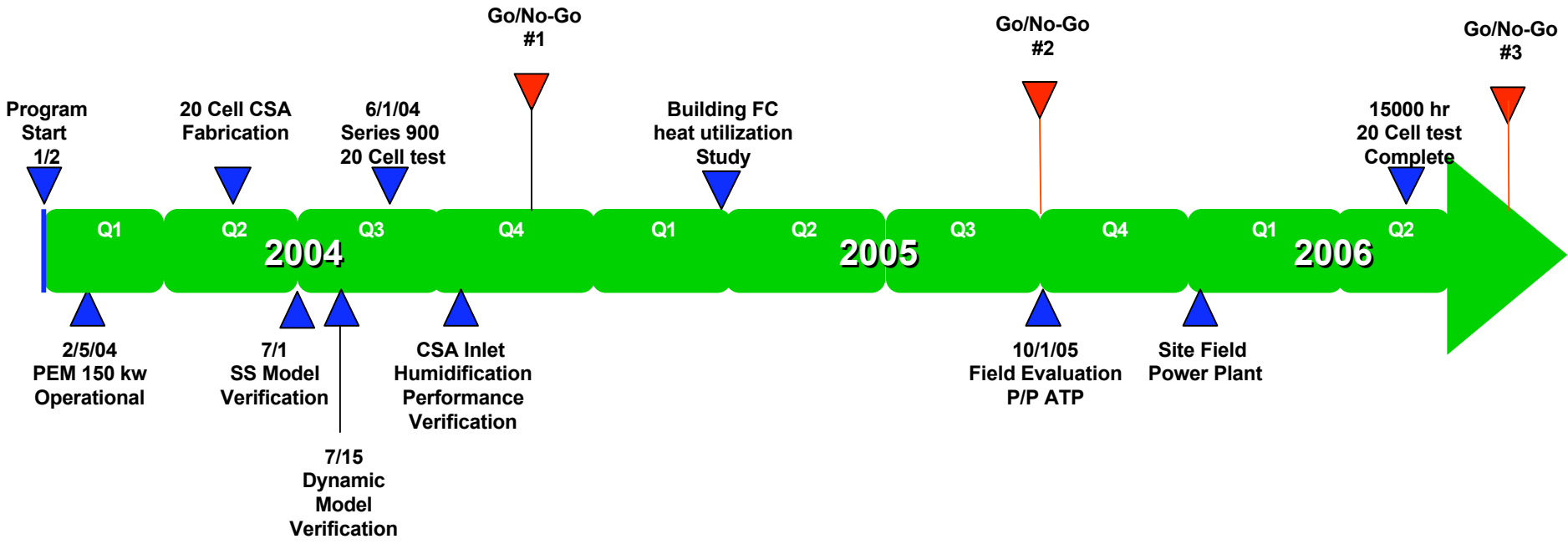
PROJECT OBJECTIVE

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.

This presentation does not contain any proprietary or confidential information.

DOE TOPIC 1 Project Schedule

Project Timeline



Project Budget

1st Go / No-Go →

2nd Go / No-Go →

3rd Go / No-Go →

FY	Total $	DOE Share $	Contractor Share $
04	3,188,266	1,753,546	1,434,720
05	4,402,607	2,421,433	1,981,174
06	4,091,142	2,245,281	1,845,861
07	7,194,483	3,744,352	3,450,131
08	2,383,197	1,191,598	1,191,599
09	523,222	261,611	261,611
Total	21,782,917	11,617,821	10,165,096

DOE Technical Targets

Integrated Stationary PEMFC Power Systems Operating on Natural Gas

Characteristics	Units	2003	2005	2010
Electrical Energy Efficiency	%	30	32	40
CHP Energy Efficiency	%	70	75	80
Cost	$/kWe	2500	1250	750
Transient Response	Msec	<3	<3	<3
Cold Start-up time to rated power @-20°C ambient @+20°C ambient	 min min	 <20 <10	 <15 <5	 <10 <2
Survivability (min and max ambient temperature)	°C	-25 +40	-30 +40	-35 +40
Durability @<10% rated power degradation	Hour	15,000	30,000	40,000
Noise	dB	<65 dBA@ 10 m	<60 dBA@ 10 m	<55 dBA@ 10 m
Emission Combined NOx,CO, Sox	g/1000 kWh	<8	<2	<1.5

Specially addressed in this contract

Not Specially addressed in this contract as deliverable, but part of UTCFC's internal efforts

Technical Barriers

- 150 kW PEM Fuel Cell Power Plant Verification
  - Components
    - O. Stack Material and Manufacturing Cost
    - P. Durability
    - Q. Electrode Performance
    - R. Thermal and Water Management
  - Distributed Generation Systems
    - E. Durability
    - F. Heat Utilization
    - G. Power Electronics

Reference: www.eere.energy.gov/hydrogenandfuelcells/mypp

Project Objectives

- Verify Reliability of low cost PEM cell stack components
  - Demonstrate reliability of cell stack components
    - 20 Cell Stack Development & Endurance Testing
- Improve the Durability of PEM CSA Technology
    - Improved Seals
    - Inlet humidification
- Verify the specification, durability, and reliability of natural gas fueled PEM power plant
    - Operate Beta-power plant as a 150 kW baseline
    - Field Evaluation 150 kW Power Plant
    - Demonstrate efficiency and reliability

Project Objectives

- Verify a power plant can be connected to a distribution feeder with no adverse interconnection effects
  - Field Evaluation Power Plant 150 kW
    - Operate on CL&P distribution feeder
    - Confirm no interconnection issues
    - EPRI will extend results to range of U.S. feeders by analysis
- Analytically confirm useful application of PEM power plant heat
  - Market assessment of PEM waste heat utilization
    - Compatibility of desiccant humidity control and PEM will be determined

Safety Aspects of Project

- 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
  - IPD 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

Safety Analyses

Potential Energies or Situations

Mitigation Approaches

Hazard Analysis (HA)

Resultant Events

Failure Modes of Parts and Process

Failure Mode and Effects Analysis (FMEA)

Events

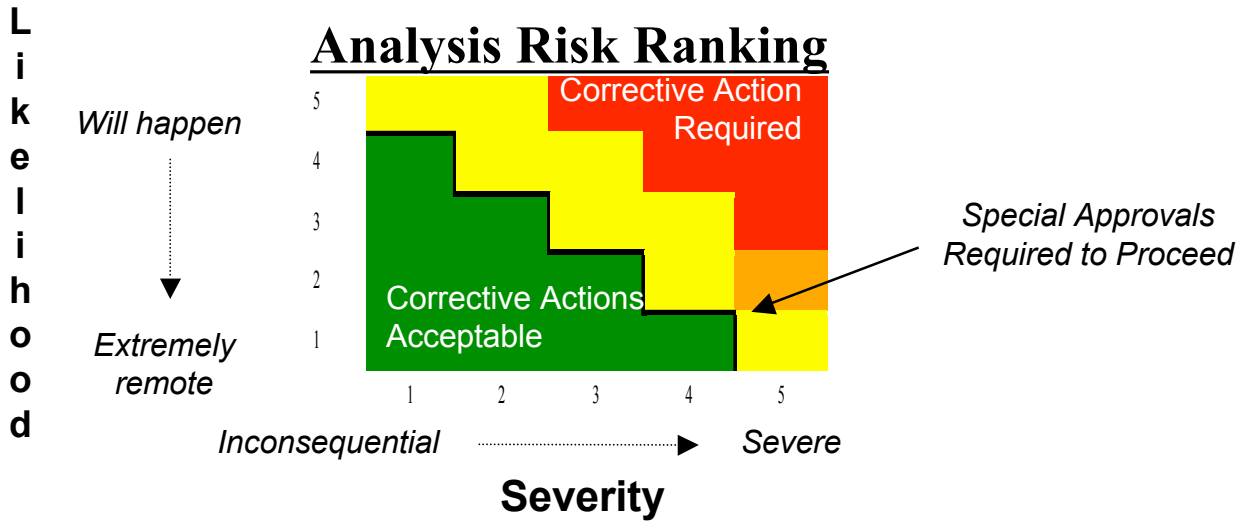
Mitigation Approaches

Fault Tree Analysis (FTA)

Operating Procedures

Failure Modes of Operations

Reviewing Procedures for Hazardous Operation (HAZOP)



Power Plant Testing

Objective

- Baseline PEM Beta 150KW Power Plant performance
  - Verify FPS start time and CO Levels
  - Tune controls for transient response
  - Calibrate Dynamic and SS model tools with actual data
  - Identify early reliability issues with BOP systems
  - Verify P/P start time
  - Optimize software for automatic startup and unattended operation

Power Plant Testing
Technical 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 operational

Power Plant Testing

Technical Accomplishments

	Requirement	Current
Maximum Power	150 KWAC	117 KWAC
Number of Start Stop Cycles	250 Cycles	97 Cycles
Run time	15,000 hrs	37 hrs
FPS Exit CO	<10 ppm (steady state) <100 ppm (large step change)	< 10 ppm <100 ppm (small step change)
Maximum Continuous Run	10 hrs @ max. power	5.75 hrs up to 103 KWAC

S900 Development Testing

Objective

- Demonstrate 15K hour durability on a S900 20 cell Cell Stack Assembly (CSA)
  - Procure hardware to support the 20 cell CSA
  - Document a test plan establishing test conditions and diagnostic requirements
  - Construct the 20 cell CSA

S900 CSA Development Testing Background

- S900 Cell plan form is designed for high durability
- S900 20 cell consists of:
    1. 20 UEA/WTP sets and seals
    2. Manifolds
    3. Axial load system
    4. Voltage pins and fittings for attachment to the test stand

S900 CSA Development Testing
Technical Accomplishments

- Test plan complete defining — April 2004
  - Flows, temperatures, power, utilizations and humidity
  - Diagnostics
  - Test stand interfaces
- Manifold & Axial Load system procured — March/April 2004
  - 4 manifolds
  - 2 End plates
  - Fittings
  - Material for WTP's

CSA Durability
Objectives

- Develop a mathematical modeling to optimize inlet flow channel design for maximum humidification
- Determine root cause and corrective action for high severity / frequent CSA failure modes
- Identify seal materials with chemical and mechanical stability in a fuel cell environment
- Verify accelerated test conditions that demonstrate representative failure modes

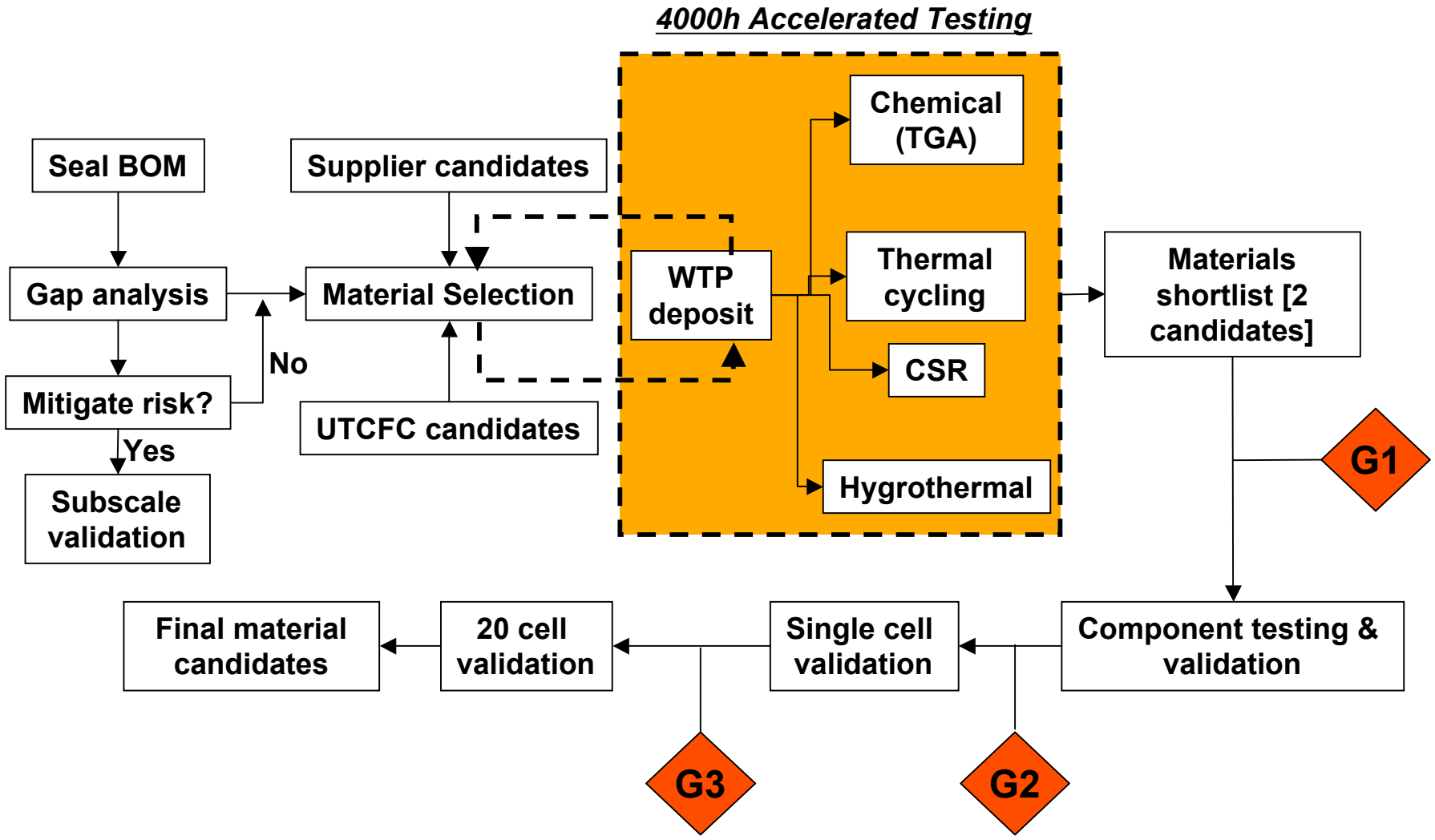
CSA Durability Approach

- Focus on mechanisms identified in root cause analysis and with high severity x occurrence in FMEA
- Understand failure modes thoroughly to verify accelerated testing protocols
- Demonstrate superior humidification approach to extend membrane lifetimes
- Identify sealing systems with chemical and mechanical stability

CSA Durability Accomplishments

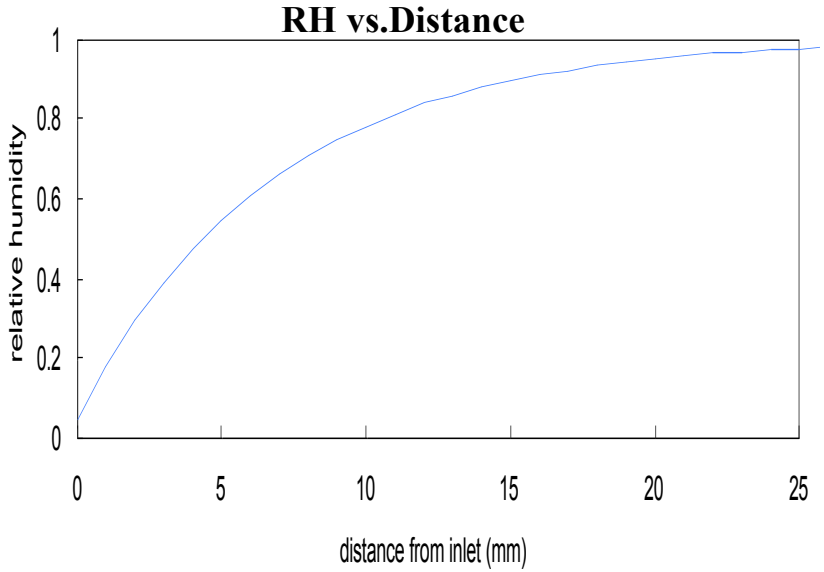
- 15 seal material candidates identified and screening in process
- Modeled inlet zone of new cell stack configuration
  - Predicted humidification levels provide uniformly liquid-equilibrated membrane over plan form

CSA Durability
Seal Material Qualification Approach

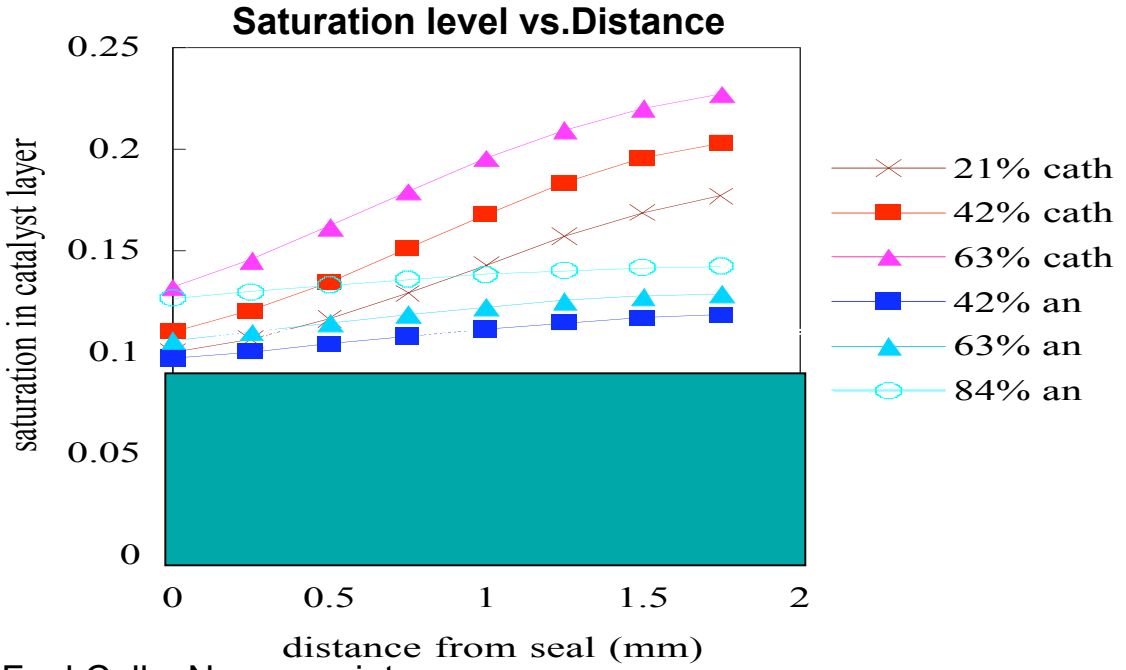


CSA Durability Technical Progress

- Membrane dry out region confined to < 5 mm in WTP system



- Grey zone indicates area at risk of membrane dry-out
  - New stack design shows entry region liquid equilibrated under worst case operating scenario



CSA Durability
Future Work

- Accelerated test protocols to be narrowed and verified
- Seal materials to be down selected in Q2 ’04
- Inlet humidification state to be verified experimentally

Interactions and Collaborations

- Subcontractors
  - United Technologies Research Center
  - Connecticut Light & Power
  - EPRI
  - Austin Energy
  - New York Power Authority (NYPA)
  - San Francisco Public Utilities Commission Hetch Hetchy
- Other Team Members
  - Connecticut Clean Energy Fund
  - Conservation and Load Management Fund (Northeast Utilities)

Project Future Work

- Remainder of FY-2004
  - Complete Beta-power plant testing and establish baseline performance for PEM power plant
  - Continue PEM cell low cost component reliability and performance program
  - Initiate and complete market analysis comparing natural gas fueled PEM to hydrogen fueled PEM for stationary applications

- FY 2005 - 2009
  - Develop and demonstrate low cost, cell stack components with high durability and reliability
  - Validate PEM stack components and power plant design concepts in Field Evaluation Power Plant on Grid
  - 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