Sensor Development for PEM Fuel Cell Systems
DOE Cooperative Agreement DE-FC36-02AL67615
Annual Program Review

Honeywell International
Sensing and Controls
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May 2004

Program Objectives

A 38-month research and development program leading to the creation of physical sensors suitable for monitoring and controlling a polymer electrolyte membrane (PEM) fuel cell-based power plant, including the fuel reformer, fuel cell stack, and thermal management system.

Task 1 – Sensor Requirements – October 2003 to September 2003 (Completed)

This task will define the requirements of each of the physical sensors. The preliminary sensor requirements will be evaluated against the requirements created from the customer interviews. A broad market survey will validate the requirements and provide the inputs to the design task.

Task 2 – Sensor Development – October 2003 to October 2004

This task will be an initial development of the Physical Sensors to demonstrate their ability to meet the necessary requirements in a laboratory environment. Several subtasks are identified to meet this objective.

Task 3 – Prototype Sensor Build and Test – November 2004 to June 2005

The proposed Physical Sensors developed in Task 2 shall be manufactured into operating prototypes suitable for third-party fuel cell system testing and evaluation. This includes all necessary design, fabrication, and rework necessary to meet the requirements set forth in Task 1.

Task 4 – Field Testing – July 2005 to October 2005

It is Honeywell's position that the proposed sensors will gain technical and/or cost advantage by combining their functionality into an overall system architecture and testing them in their intended fuel cell system environment. The purpose of this task is to test and demonstrate the sensors on operating fuel cells and reformers at third-party facilities.

Financial Overview

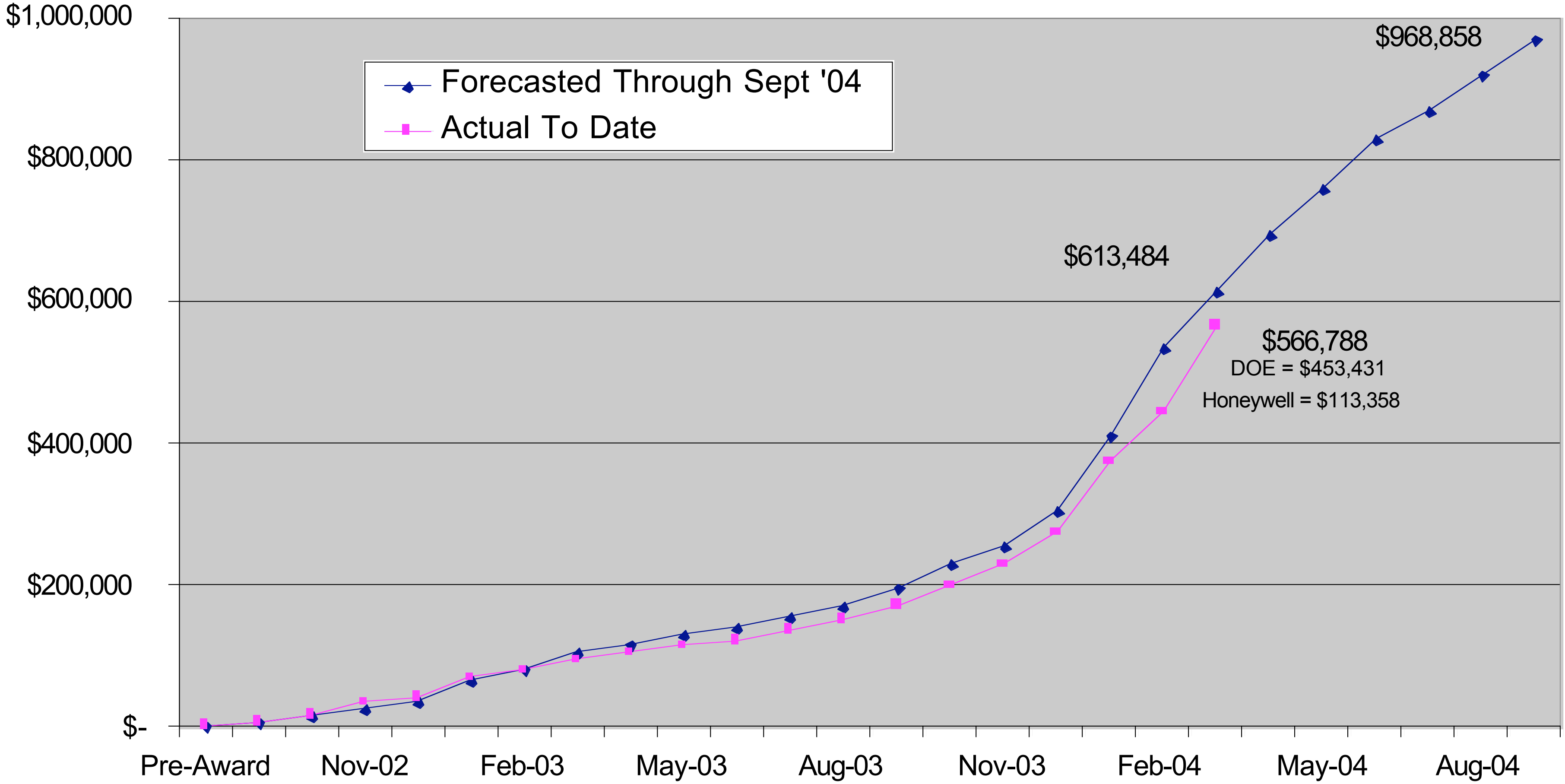
Honeywell

DE-FC36-02AL67615 Project Costs

Total Project Funding ($1.9M)

DOE 80% = $1,521,524

Honeywell 20% = $380,381



Specification Comparison

Honeywell

	DOE Technical Plan 6/3/03	Honeywell (VOC)
Humidity		
Rh Range	20 – 100%	0 to 100%
Temperature Range	30 – 110C	-40 to 90C
Accuracy	1%	0to80% Rh–4% / 80to100%Rh–2%
Flow		
Flow Range	30 to 300 SLPM	0 to 400 SLPM / 0 to 4,000 SLPM
Temperature Range	80C	-40 to 90C
Pressure		
Pressure Range	0 to 1 psi Diff/0 to 10 psi Diff	0 to 6 psi Diff/1 to 30 psi Abs
Temperature Range	30 to 100C	-40 to 125C
Response Time	<1 second	<0.1 second
Accuracy	1% FS	3% FS
Temperature		
Temperature Range	-40 to 150C	-40 to 150C
Response Time	>1 seconds	<2 seconds
Accuracy	1.5%	1%

Humidity Barriers and Targets

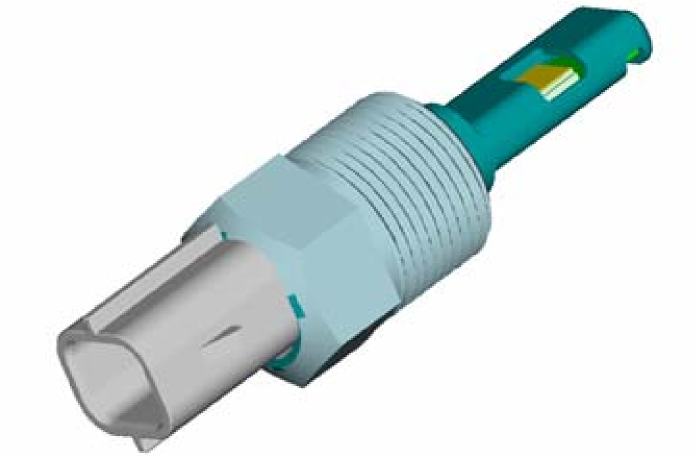
Honeywell

General Barriers

- Robust to high humidity and high temperature
- Exposure to DI and Hydrogen media
- Automotive grade
- Cost
- Overall package size
- Overall package weight

Probe Tip - 0.5”

Probe Length – 3.5”



Technical Barriers

- *Recovery from a condensing environment
- *Accuracy at high temp and high humidity w/ minimal drift

Targets

- 75C, 100% Rh (environment)
- 0 to 80% Rh – 4% / 80 to 100% Rh – 2%
- 30 second recovery time to 62.3% of Actual

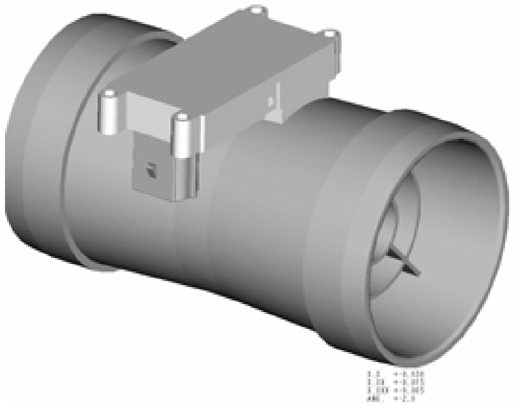
Flow Barriers and Targets

Honeywell

General Barriers

- Robust to high humidity and high temperature
- Exposure to DI and Hydrogen media
- Automotive grade
- Cost (4,000 SLPM)
- Overall package size

4000SLPM
Diameter – 2.5”
Length – 4.5”

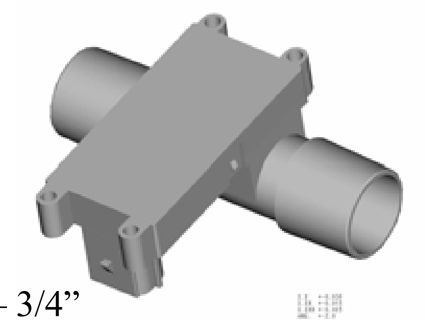


Technical Barriers

- Existing flow sensors cannot operate in condensing environments
- Flow sensors today are not robust to media with particulate matter

Targets

- 75C, 100% Rh (environment)
- 30 second recovery time to 62.3% of Actual
- Input Voltage 10V to 25V (Field Test)



400SLPM
Diameter – 3/4”
Length – 3.25”

Pressure Barriers and Targets

Honeywell

General Barriers

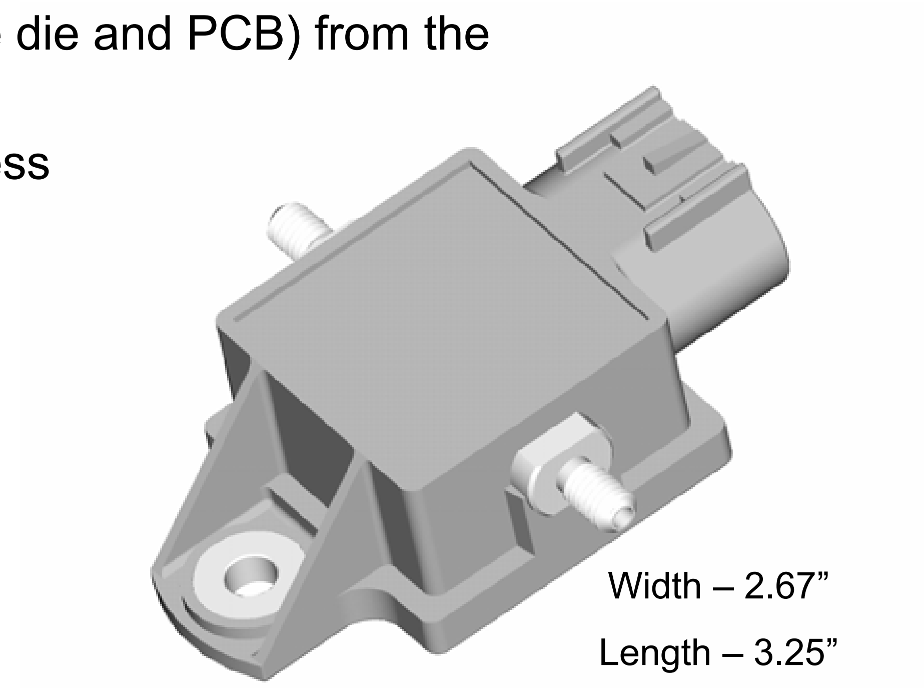
- Cost
- Overall package size
- Overall package weight

Technical Barriers

- Protection of the electronics (sense die and PCB) from the media
- Packaging strategy resistant to stress

Targets

- 75C, 100% Rh (environment)
- -40 to 125C
- 3% accuracy FS



Temperature Barriers and Targets

General Barriers

- Exposure to DI and Hydrogen media
- Automotive grade
- Cost

Technical Barriers

- Time Responsiveness

Targets

- <2 second response time

Probe Diameter - .25”

Probe Length – 2.5”

Technical Approach

Honeywell

Look at the fuel cell system and establish the requirements for each physical sensor. Deploy existing technologies and develop packaging strategies to minimize sensor cost. Prototype sensors will be designed, fabricated, and tested in third party fuel cell systems.

Fuel Cell manufacturers now use Instrument-grade sensors to accommodate sensing requirements. Do to cost, size, and weight, instrument-grade sensors do not provide a long term sensing solution for Fuel Cell applications.

Humidity Sensor Capacitive humidity sense die on ceramic with an Application Specific Integrated Circuit (ASIC). The technology is packaged in a heated die chamber with a micro-filter and controlled to shift the Dew Point .	**Flow Sensor** Thermal mass flow micro anemometer (Wheatstone Bridge) on a smooth sensing surface utilizing backside interconnects with linear transfer function output. Diagnostics for failed known state.
Pressure Sensor Chemically etched Silicon sense dies (2) utilizing backside die sensing. Packaged to isolate the circuitry from the media. Diagnostics for failed known state.	**Temperature Sensor** Amplified Resistive Temperature Device (RTD) in a Stainless Steel probe with a signal conditioned output. Diagnostics for RTD open / short.

Technical Accomplishments

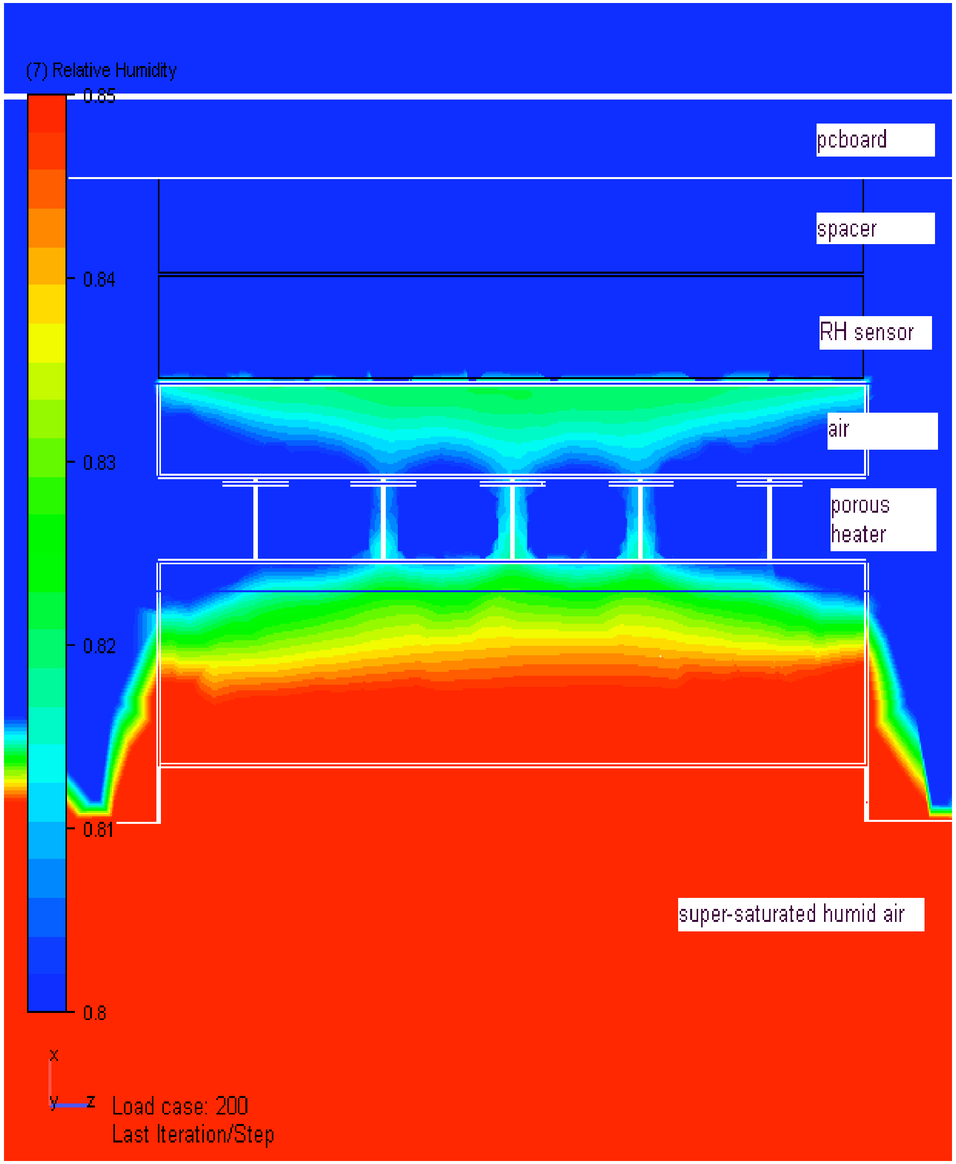
Honeywell

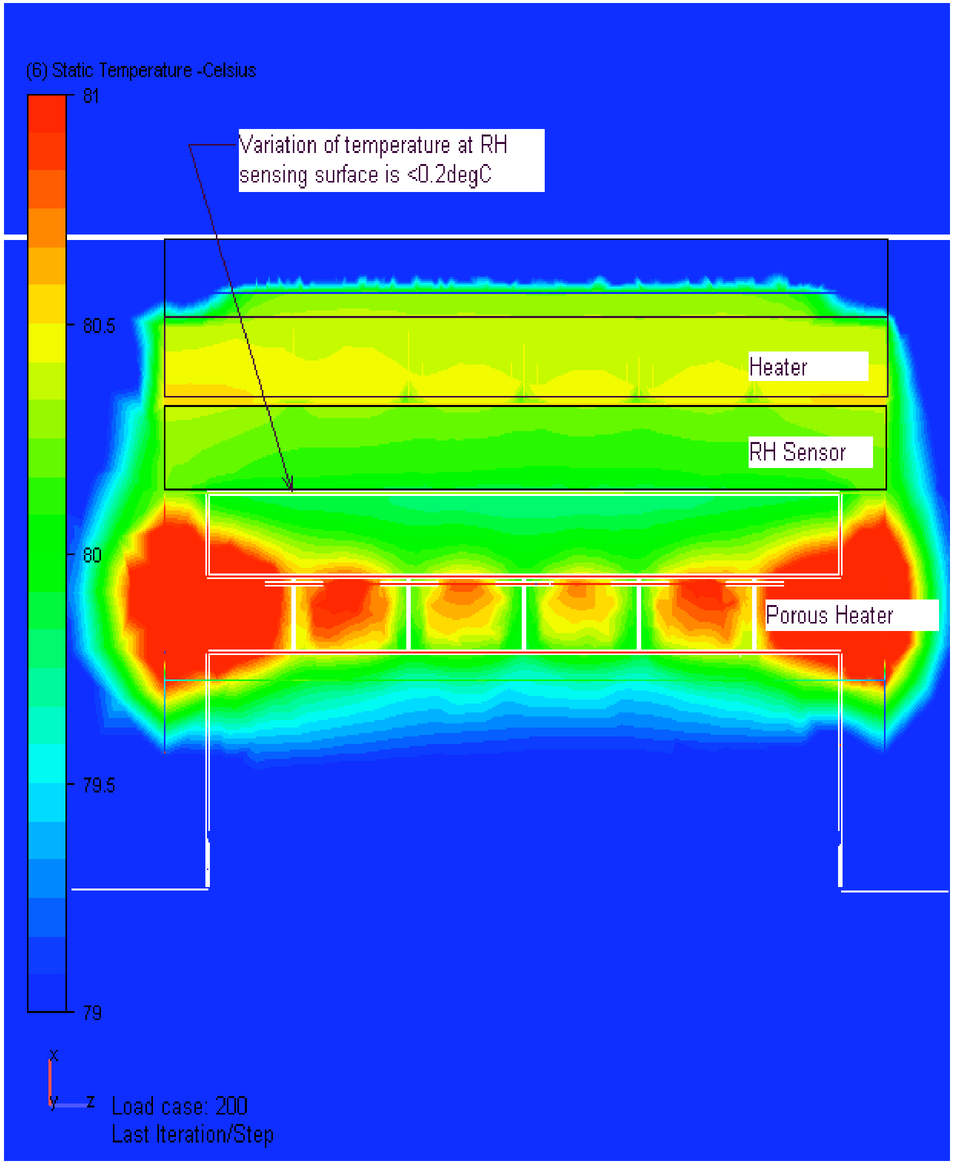
Humidity:

- Micro-filter research and performance testing in a condensing environment has been completed
- Initial condensation recovery tests, with the selected sensing technology, completed
- Selection of ASIC completed
- Bench top testing completed using chosen ASIC and “best of” humidity sense die
- Research of Rh alternative and emerging technologies complete
- Modeling has shown that temperature control at the sense die will allow a uniform dew point shift
- Material analysis and selection complete

Technical Accomplishments

Honeywell



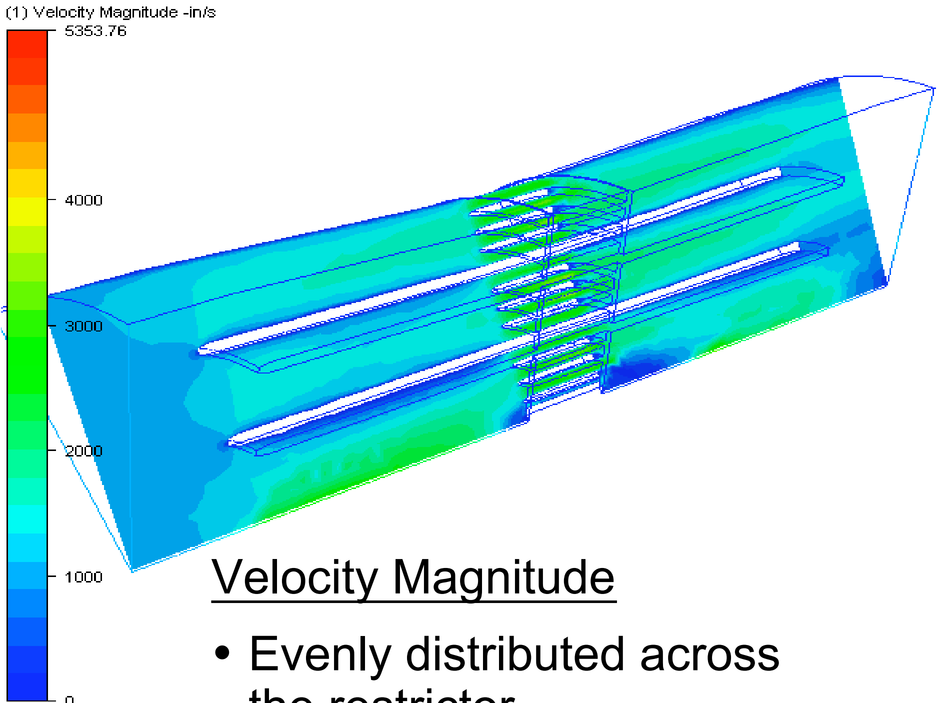


Technical Accomplishments

Honeywell

Flow

- Rugged glass sense die development with backside interconnects
- Package modeling completed for 400 SLPM and 4,000 SLPM
- Performance tested mechanical bypass sampling technology
- Material analysis and selection complete
- Test methodology for humidified flow defined

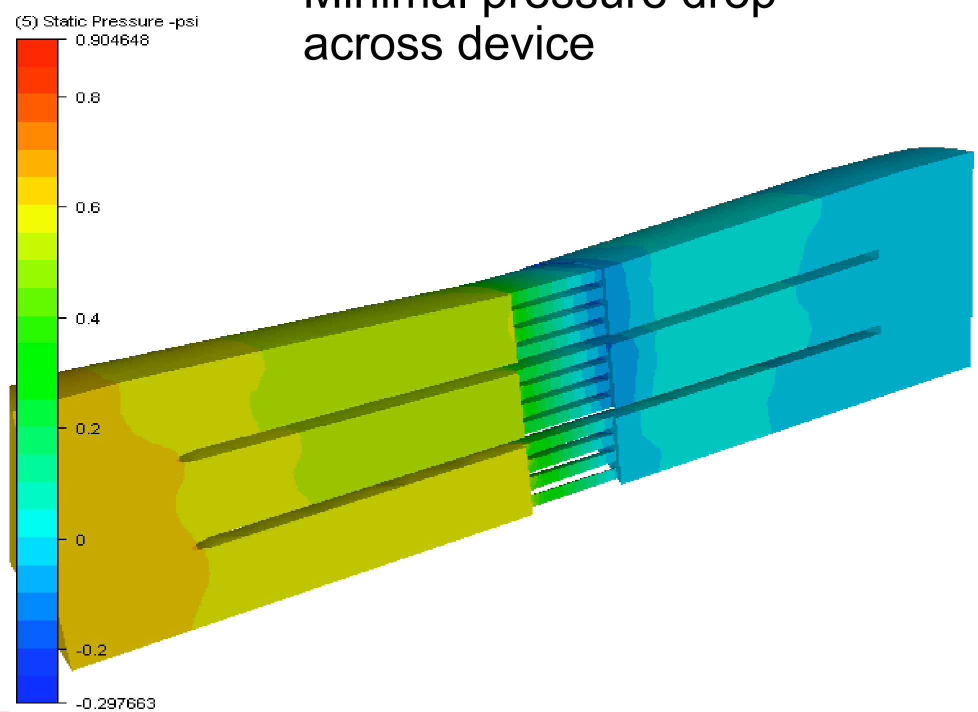


Static Pressure

- Even pressure drop across the restrictor
- Stability at point of bypass
- Minimal pressure drop across device

Velocity Magnitude

- Evenly distributed across the restrictor

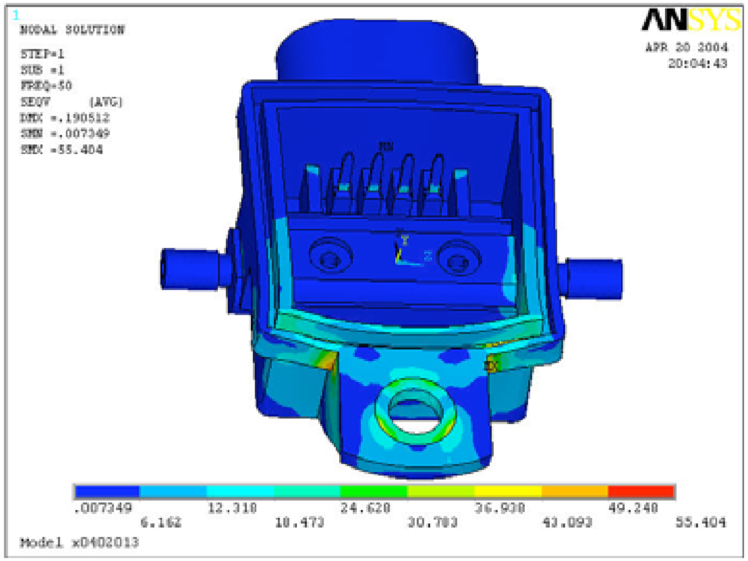


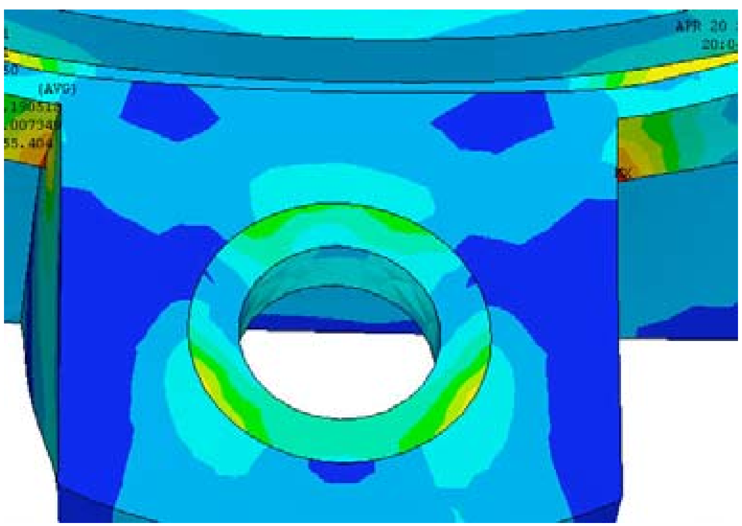
Technical Accomplishments

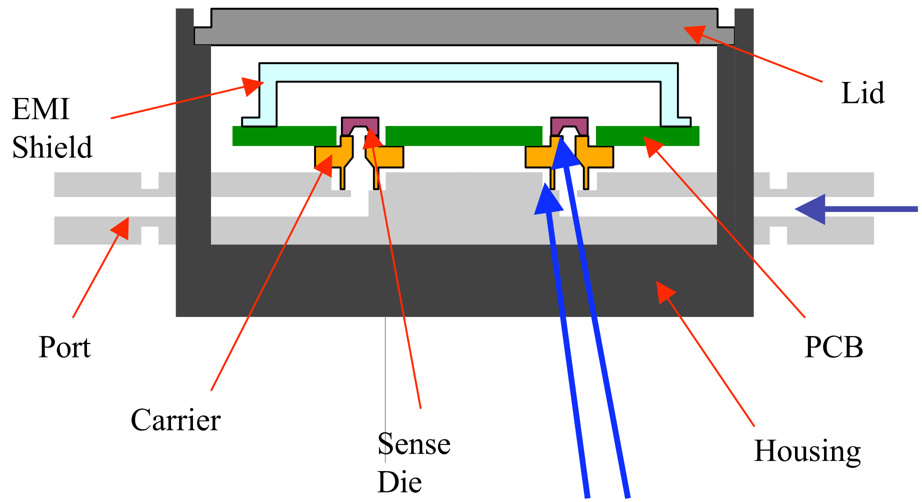
Honeywell

Pressure

- Concept validation testing has proven the design to be inert to Hydrogen gas
- Design robustness verified through exposure of electronics to Hydrogen gas (due care testing)
- Bond between Carrier and Stainless Steel port verified to maintain a seal across operating temperature range.
- Material analysis complete and selections made
- Package analysis and design complete







Sensing media is confined to inert surfaces by two key bond joints. Electronics are isolated from the sensing media by these joints and the silicon sense die.

Technical Accomplishments

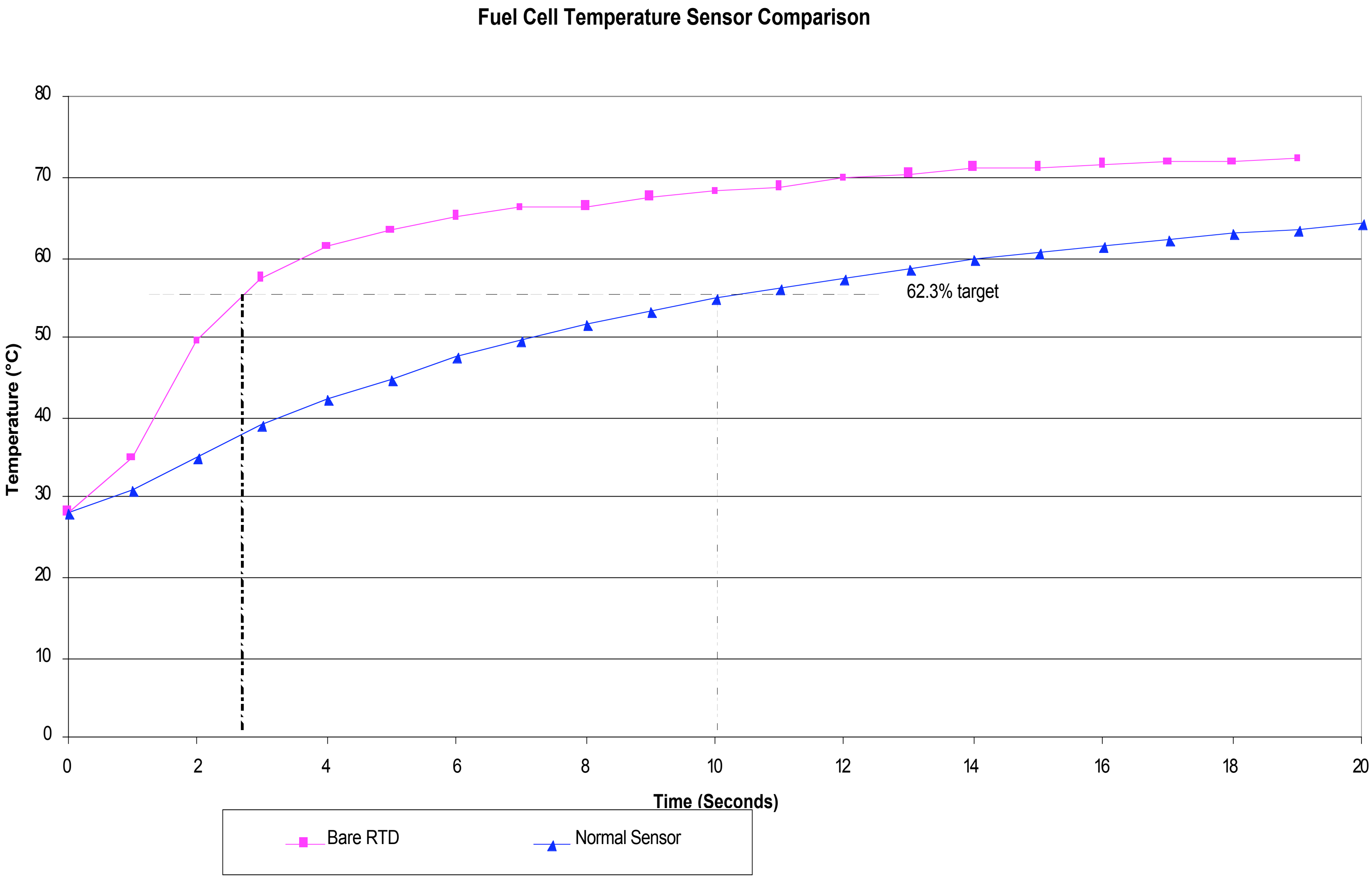
Honeywell

Temperature

- Material analysis and selection complete
- Time response modeling and initial empirical testing complete
- Initial circuit design and housing tested

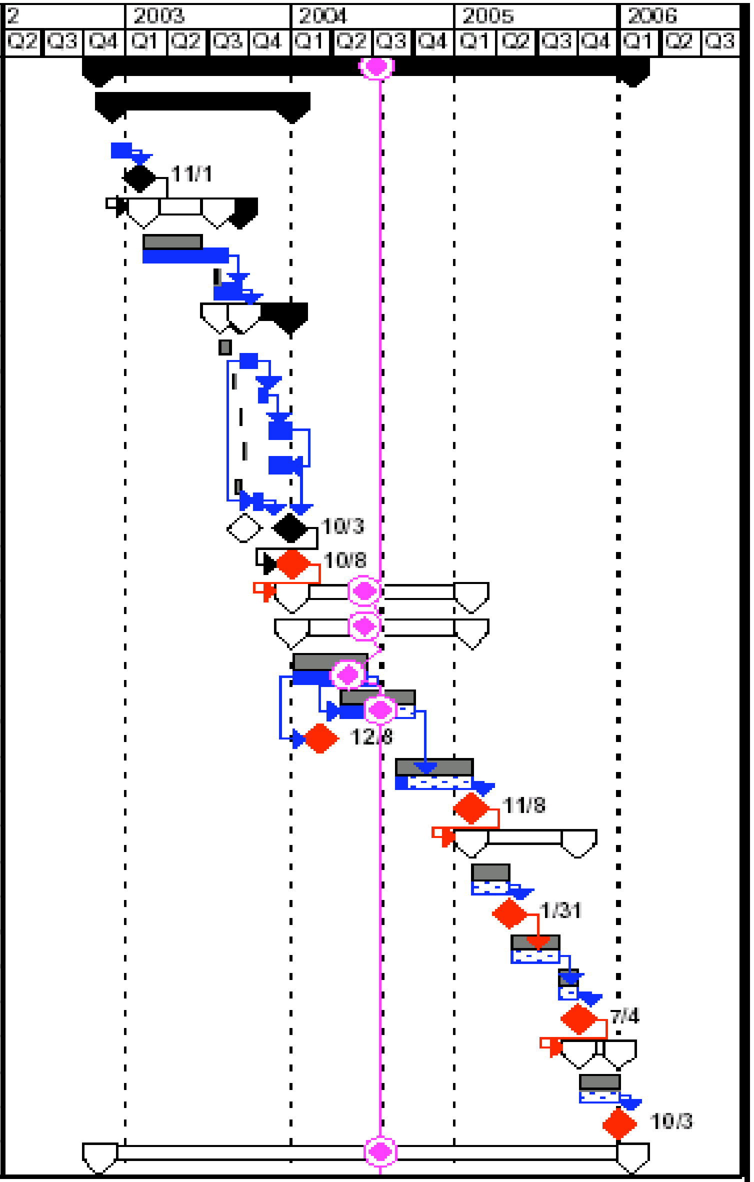
Technical Accomplishments

Honeywell



Project Timeline

WBS	Task Name	Start	Finish
1	DOE Fuel Cell Project #216905	Mon 8/5/02	Tue 11/1/05
1.1	Sensor Requirements	Mon 9/2/02	Wed 10/8/03
1.1.1	Preliminary Requirements Definition	Mon 9/2/02	Fri 10/11/02
MS-1.1	Preliminary Requirements Review	Fri 11/1/02	Fri 11/1/02
1.2	Update Requirements	Tue 11/12/02	Thu 6/12/03
1.2.1	Third Party Interviews	Tue 11/12/02	Thu 5/15/03
1.2.2	Evaluation of Third Party Requirements	Mon 4/14/03	Thu 6/12/03
1.3	Finalize Requirements	Fri 6/13/03	Tue 9/30/03
1.3.1	Determine sensor requirements from transcripts	Fri 6/13/03	Tue 7/22/03
1.3.2	Finalize Field Survey	Wed 7/23/03	Wed 8/13/03
1.3.3	Distribute Field Survey	Thu 8/14/03	Tue 9/30/03
1.3.4	Analyze Field Survey	Tue 8/19/03	Tue 9/30/03
1.4	Select Third Party Test Facilities	Fri 7/11/03	Thu 7/31/03
MS-1.2	Final Sensor Requirements Review	Fri 10/3/03	Fri 10/3/03
1.1.7	Finalized Requirements - DOE Approval to Close T	Wed 10/8/03	Wed 10/8/03
1.2	Sensor Development	Wed 10/8/03	Mon 11/8/04
1.2.1	Physical Sensors	Wed 10/8/03	Mon 11/8/04
1.2.1.1	Technology Concepts	Wed 10/8/03	Mon 3/22/04
1.2.1.2	Packaging Concepts	Tue 1/20/04	Mon 7/5/04
MS-2.1	Physical Sensors Test Plan Review	Mon 12/8/03	Mon 12/8/03
2.1.3	Preliminary Testing	Tue 5/25/04	Mon 11/8/04
MS-2.2	Physical Sensor Designed	Mon 11/8/04	Mon 11/8/04
1.3	Prototype Build & Test	Tue 11/9/04	Mon 7/4/05
1.3.1	Fabrication	Tue 11/9/04	Mon 1/31/05
MS-3.1	Physical Sensors Demonstration	Mon 1/31/05	Mon 1/31/05
3.2	Testing	Tue 2/1/05	Mon 5/23/05
3.3	Rework	Tue 5/24/05	Mon 7/4/05
MS-3.2	Proto Demo-Sensors for Test	Mon 7/4/05	Mon 7/4/05
1.4	Field Testing	Tue 7/5/05	Mon 10/3/05
1.4.1	Third Party Testing	Tue 7/5/05	Mon 10/3/05
1.4.2	Field Testing Complete	Mon 10/3/05	Mon 10/3/05
1.5	Program Management	Mon 8/5/02	Tue 11/1/05



Interactions and Collaborations

<u>Honeywell Advance Technology Laboratory;</u> Minneapolis, MN

- Rugged flow die development for glass and silicon
- Media evaporation modeling

<u>Micro Substrate Corporation;</u> Tempe, AZ

- Backside interconnect R & D

<u>United Technology Corporation;</u> Hartford, CT

- Utilize UTC as a “test bed”

<u>Douglas Nelson Ph.D., PE;</u> Professor Virginia Tech, Blacksburg, VA

- In house team training on Fuel Cell systems

<u>Exponent;</u> Boston, MA

- Fragility testing of glass substrate

<u>Field Testing:</u>

- Collaborative effort to define sensing specifications
- Ongoing effort to communicate development status
- Field test planning and execution

Response to 2003 Review

Voice of the customer exercise did not identify the need for a 4,000 SLPM flow sensor for automotive customers.

- Specifications for the 4,000 SLPM flow sensor are defined and sensor development is active.

Honeywell project timing is not coordinated with UTC

- UTC has communicated that their contract end date now coincides with Honeywell's.

Future Work

Honeywell

Humidity Sensor:

- Alpha II sensor design
- Package modeling
- Circuit design and debug
- Humidity research
  - Accuracy
  - Drift (Condensation)

Pressure Sensors:

- Complete Beta testing
- Circuit design and debug

Flow Sensors:

- Complete Alpha II testing
- Circuit design and debug
- Alpha II second level package build and initiate test
- Complete TTW research on Silicon substrate

Temperature Sensor:

- Alpha II sensor design
- Circuit design and debug
- Packaging modifications to improve response time

Safety

- Standard Operating Procedures are followed in consideration of design and testing
- Ongoing risk assessment tools are utilized throughout the development process
- Material analysis has been performed for all media wetted surface materials
- Hydrogen exposure testing remains an ongoing element of all test plans
- All sensors are low voltage U.L. Class 2 designs

*Sensors being developed are prototype field test designs. Additional work may be conducted at the end of the contract to complete full environmental, EMC, and agency approval testing.