Honeywell

# Development of Thermal and Water Management System for PEM Fuel Cells

Zia Mirza
Honeywell Aerospace
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Honeywell

# Honeywell Attendee

ENGINES & AIR MANAGEMENT – TORRANCE , CA

Zia Mirza
Program Manager
Development of Thermal and Water Management System for PEM Fuel Cells
Torrance, CA

Phone: 310-512-3374

E-mail: zia.mirza@honeywell.com

# Agenda

- Overview
- Objectives
- Approach
- Accomplishments and Test Results
- Schedule & Milestones
- Collaborations
- Proposed Future Work

# Overview

## Timeline

| | |
|---|---|
| Project start | FY03 |
| Program stopped | FY05/06 |
| Project end date | FY10 |
| 80% complete | |

## Budget

- Total project funding
  - DOE share - 3,250K
  - Honeywell - $812K
- DOE funding in FY08 - $500K
- DOE funding in FY09 - $500K

## Barriers

- Balance water production and consumption of PEM fuel cell by humidification systems
- Performance of select full-scale humidification system
- Thermal performance of advance radiators to meet fuel cell stack cooling requirements

## Partners

- US Department of Energy
- Argonne National Lab
- FreedomCAR Tech Team

# Objectives

- Improve PEM fuel cell performance and life by maintaining the humidity of inlet air stream at a high level (> 60%)
- Eliminate need for external water source by transferring water from stack exit air stream to inlet stream
  - Validate performance of full-scale humidification devices sized for 80 kW PEM fuel cell
    - Test Emprise enthalpy wheel
    - Test Perma Pure membrane module
  - Evaluate planer membrane humidification devices
  - Performance testing at sub-ambient conditions
- Design, build and test high-performance full-size radiators to meet the 80 kW fuel cell stack cooling requirements
  - Increase performance required to dissipate low-quality heat
  - Optimize the weight, size, and cost

# Approach

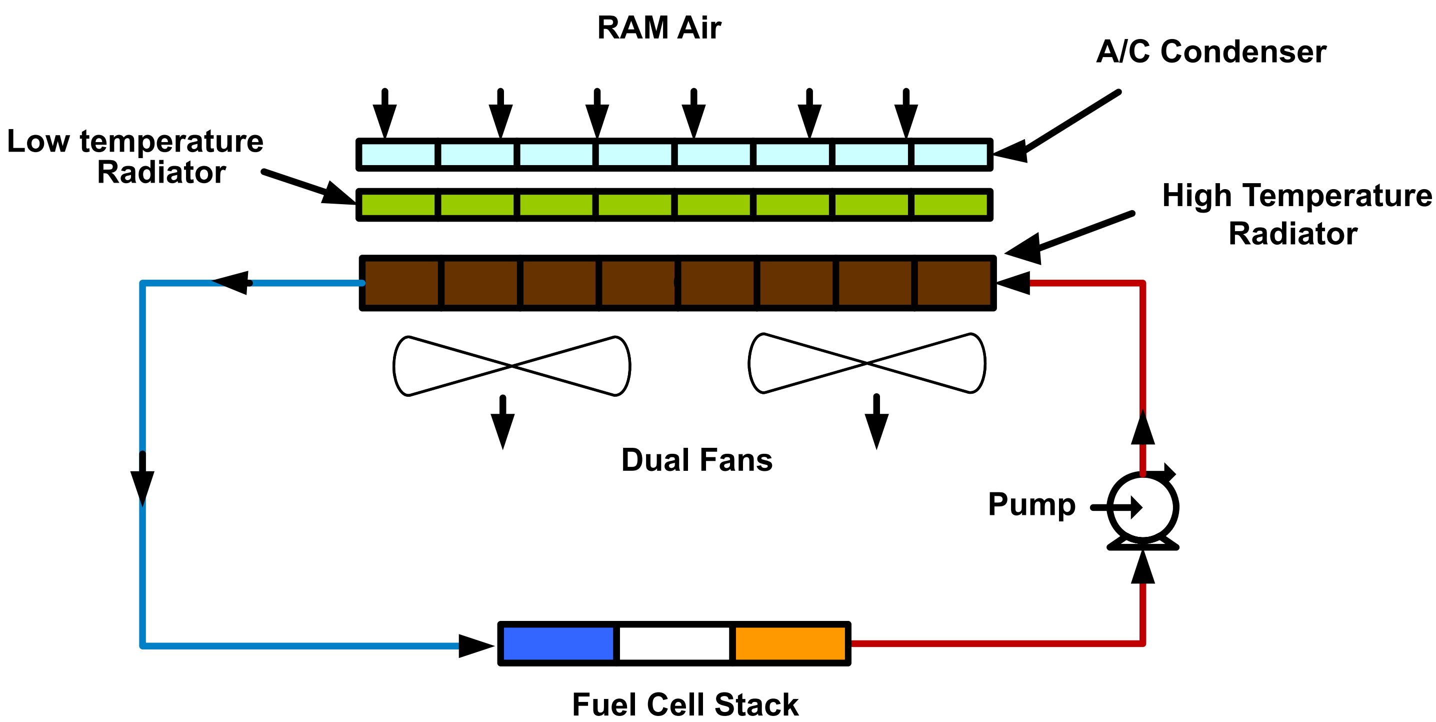
- The inlet air to the PEM fuel cell stack should have a minimum humidity of 60% (at 80 °C) to improve performance and increase stack life
- Two humidification systems were down-selected for the fuel cell application
  - Small-scale systems met the requirements
  - Full-scale units were built to validate the performance
    - Enthalpy Wheel (ceramic honeycomb) rotates while it adsorbs moisture from the fuel cell outlet air and transfers (de-sorbs) it to the inlet air
    - Nafion® membrane transfers moisture from one side of the air stream to the other side. The membrane has upper temperature limit which requires precooler in the inlet air stream
- Planer membrane-based humidification systems are being evaluated
- Value function was developed to compare radiators with different fin geometries
- Two designs were down-selected for full-scale radiator testing

# Accomplishments for FY08/09

- Fuel stack radiator requirements were established based on Argonne National Lab's PEM fuel cell automotive system model
- Value function was developed for evaluation of various configurations
- Four different fin configuration sub-scale radiators built and tested
- Validated full-scale performance model
- Lesson learned for brazing & assembly for microchannel radiators
- Designed and built full-scale radiators with optimized fin configurations
- Conducted testing of humidity device at low air flow rate
- Enthalpy wheel modified to reduce seal leakage
- Humidification test stand modification underway for higher air flow rate capability and improved measurement accuracy

# Thermal Management System Schematic

| | | | |
|---|---|---|---|
| High Temp. HX heat load | 50 kW | Radiator Area | 27.6 X17.7 inch |
| RAM air inlet temp. | 40°C | Max allowable depth | 2.8 inch |
| Radiator 20% larger than ICE radiators | | | |




***Requirements were established based on ANL model***

# Value Function for Radiator

$$VF = a(\frac{D}{FE^*})C_F + [bC_{FCS} - c(\frac{D}{FE^*})C_F] + C_T$$

(I) (II) (III) (IV)

I: Additional weight -> Lower fuel economy -> Higher fuel cost

II: Higher parasitic power -> Larger fuel cell system -> Higher initial cost

III: Larger stack -> Higher efficiency at part load -> Lower fuel cost

IV: Thermal management system initial cost

$$a = \beta_W (\frac{(W_T - W_T^*) + (P_T - P_T^*)/\hat{P}_{FCS}}{W_{GVW}})$$

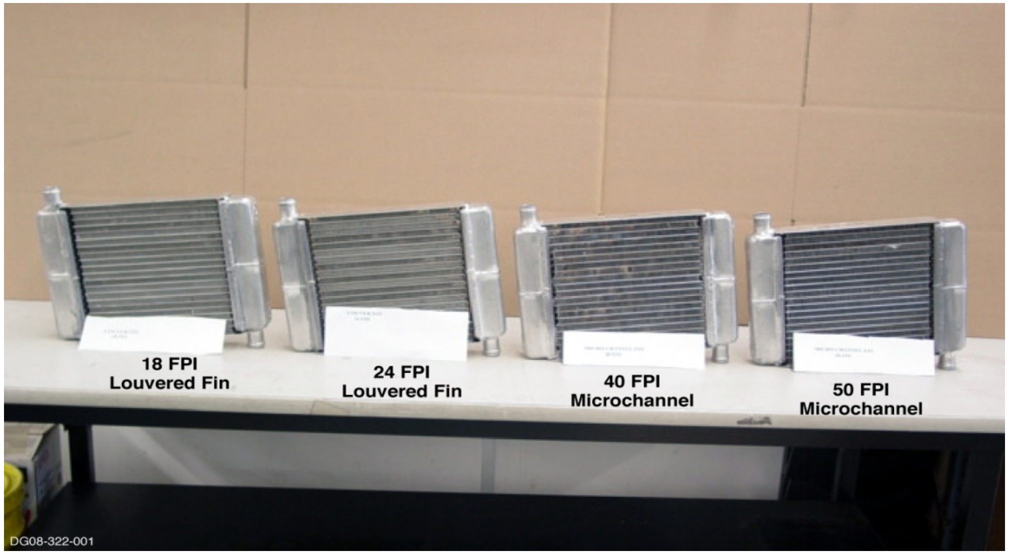
$$b = \frac{P_T - P_T^*}{P_{FCS}^*}$$

$$c = \beta_P (\frac{P_T - P_T^*}{P_{FCS}^*})$$

| Nomenclature Symbol | | Recommended Value |
|---|---|---|
| $C_F$ | Fuel cost | 3 $/kg |
| $C_{FCS}$ | FCS initial cost | 4800 $ |
| $C_T$ | TMS initial cost | |
| D | Driving Distance | 100,000 miles |
| $FE^*$ | Fuel economy | 60 miles/kg-$H_2$ |
| $P_T$ | TMS parasitic power | |
| $P^*_T$ | Reference TMS parasitic power | 1.5 kWe |
| $P^*_{FCS}$ | FCS power | 80 kWe |
| $W_T$ | TMS weight | |
| $W^*_T$ | Reference TMS weight | 40 kg |
| $W_{GVW}$ | Gross vehicle weight | 1920 kg |
| $\hat{P}_{FCS}$ | FCS specific power | 0.65 kWe/kg |
| $\beta_W$ | Effect of weight on FE | 0.8 |
| $\beta_P$ | Effect of parasitic power on FE | 0.1 |

# Sub-scale Radiators Testing

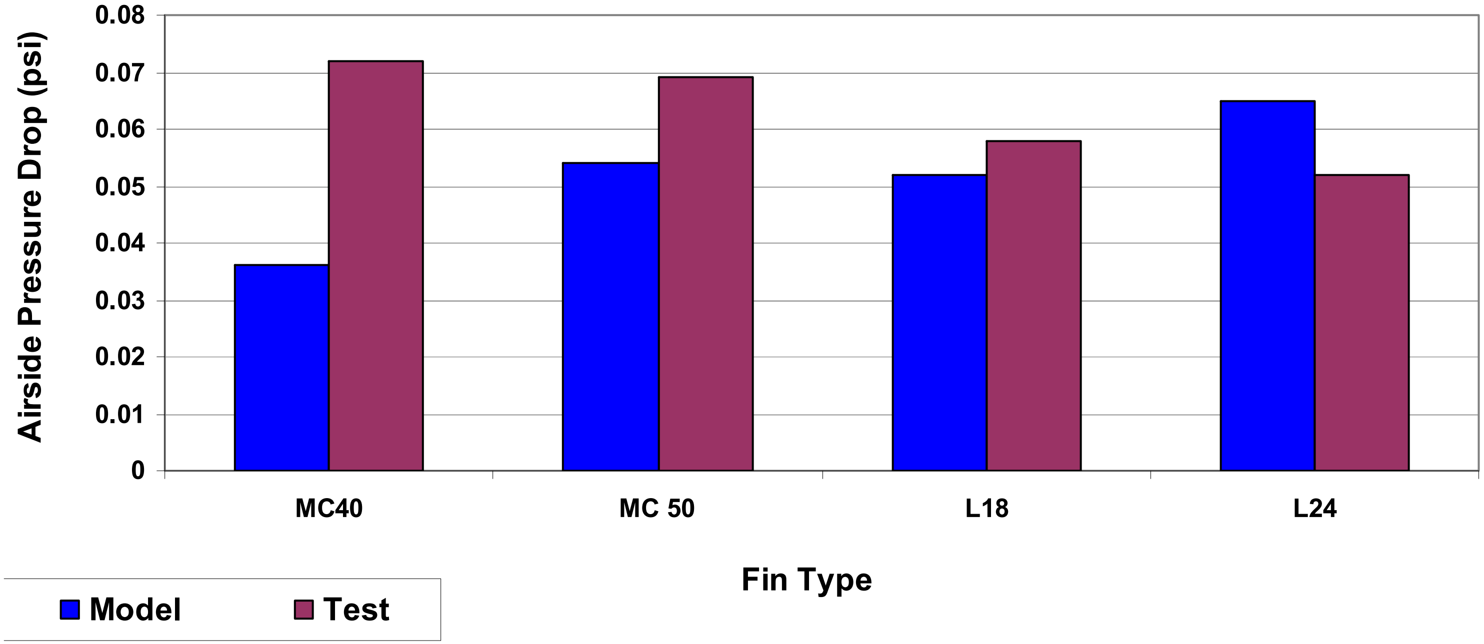
- Sub-scale (9″x 9″x 1.3″) radiators were built to validate:
  - Thermal performance
  - Manufacturability of microchannel fin radiators
- Updated full-scale radiator design/performance model
- Four fins were selected:
  - 18 fins/inch (fpi) Louver fins
  - 24 fpi Advance Louver
  - 40 fpi Microchannel fins
  - 50 fpi Microchannel




***Manufacturability with advance fins demonstrated***

# Sub-scale Radiator Test Data & Model Prediction

**Coolant flow of 19.4 gpm at 50 kW design condition**




**MC – Microchannel fins    L – Louver fins**

***40 fpi MC presure drop test data being verified***

# Sub-scale Radiator Test Data & Model Prediction

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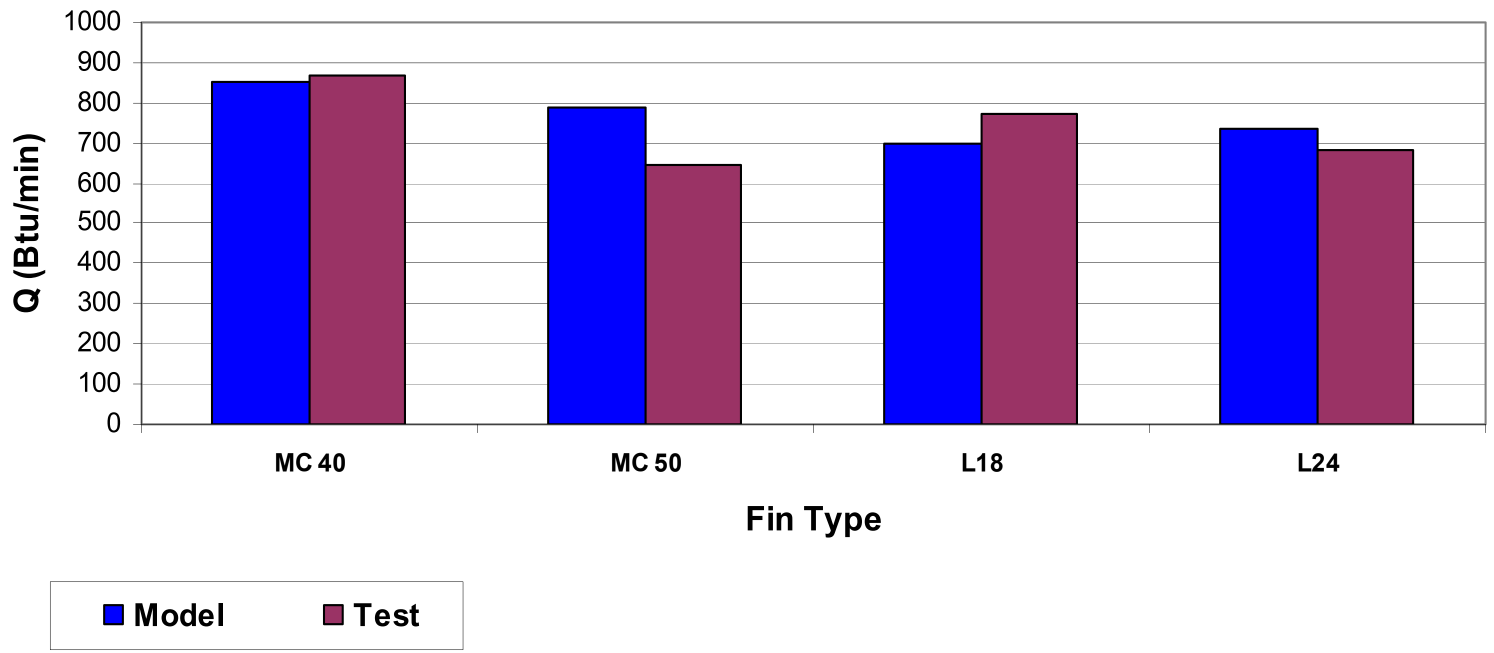



**MC – Microchannel fins    L – Louver fins**

***Test data validated model predictions***

# Full-Scale Radiators

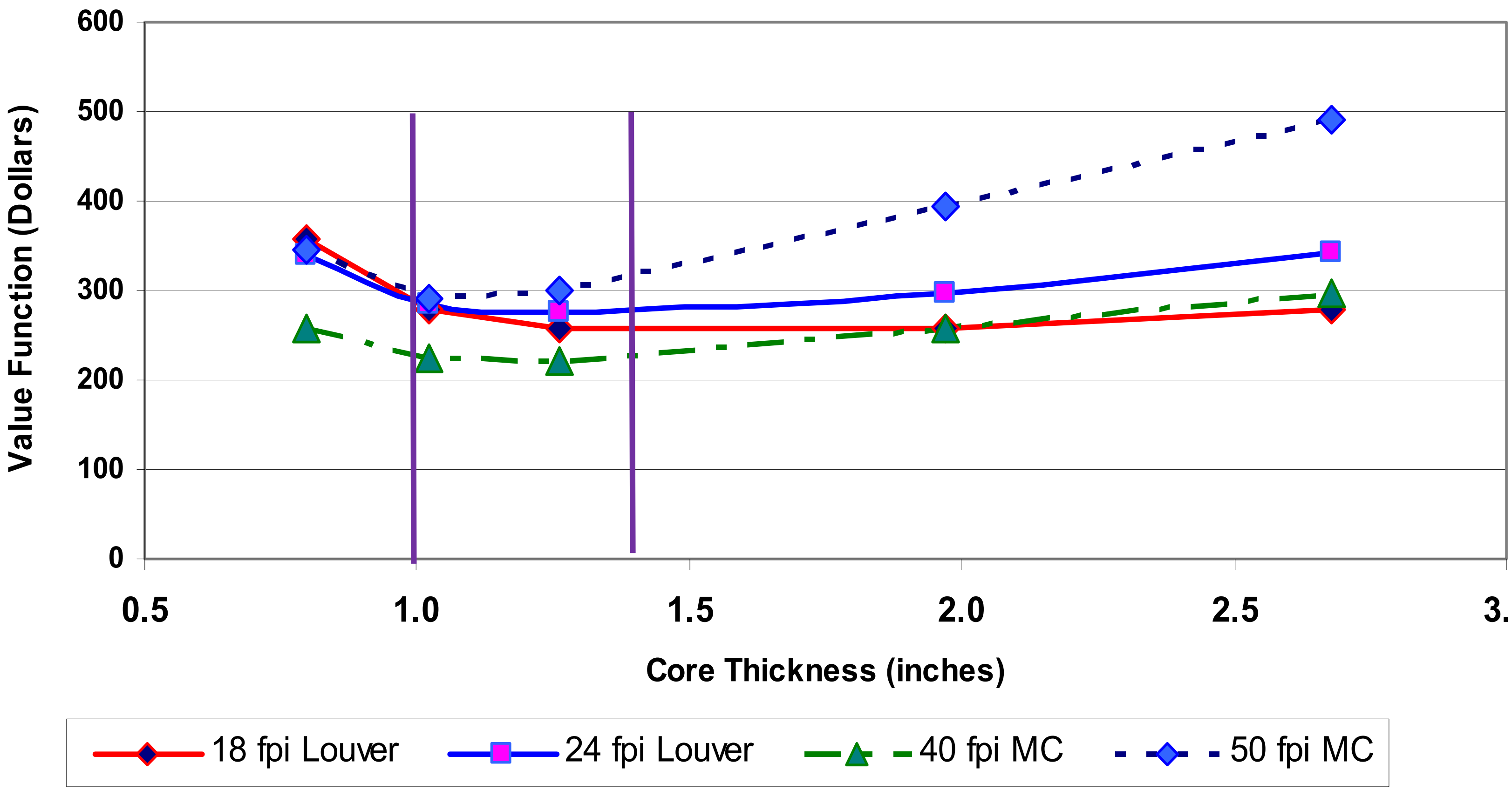
**Size of the radiator 27.6″W, 17.7″H & 1.3″Depth**
**Estimated weight of full-scale louver and microchannel radiator (with plastic tanks) will be 10 and 13 lbs respectively**

**40 fins/in. Microchannel Fins**

**18 fins/in. Louver Fins**

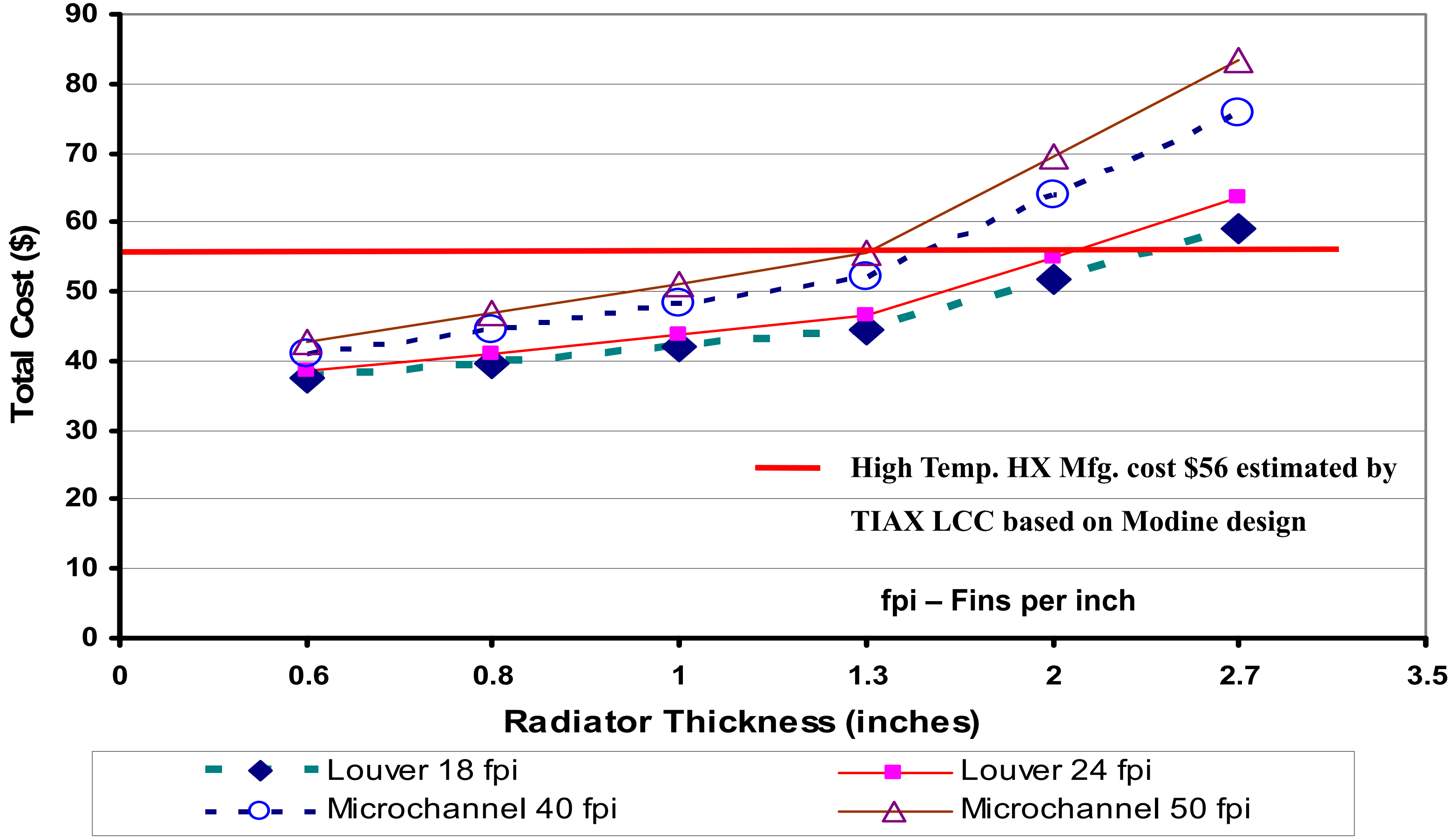
***Full size microchannel radiators built successfully***

# Value Comparison




***Optimum value with 18 Fins/in Louver & 40 fpi microchannel fins with core thickness of 1-1.4 in***

# Cost of Full-Scale Radiators




***Louver fins are lower cost and weight***

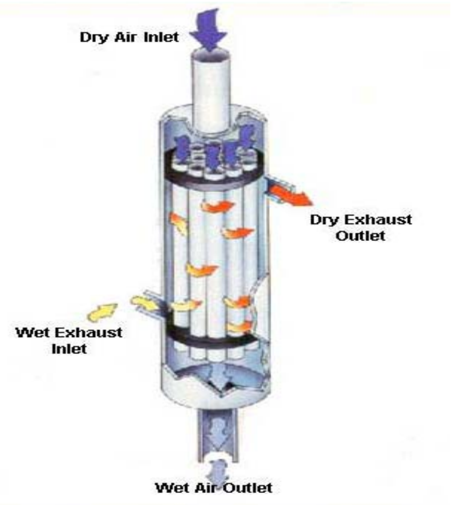
# Humidification Devices

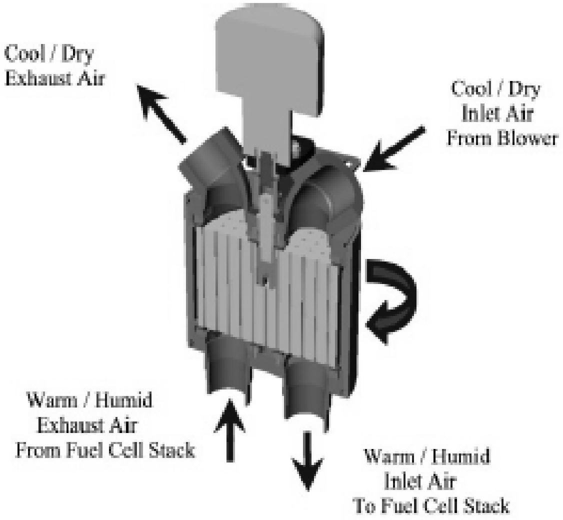
## Membrane Module by Perma Pure

- Membrane selectively allows water to pass through
- Performance sensitive to temp.
- 6” Ø, 10” length cartridge
- 7000 fibers 0.045” OD
- 11.13 $in^2$ Nafion

## Enthalpy Wheel By Emprise

- Water adsorbed and de-sorbed in a rotating wheel
- Power: < 100W
- Leakage < 1% process flow
- 8” Ø, 6” length wheel
- Vol: 17l cu in.; Wt: 17 kg

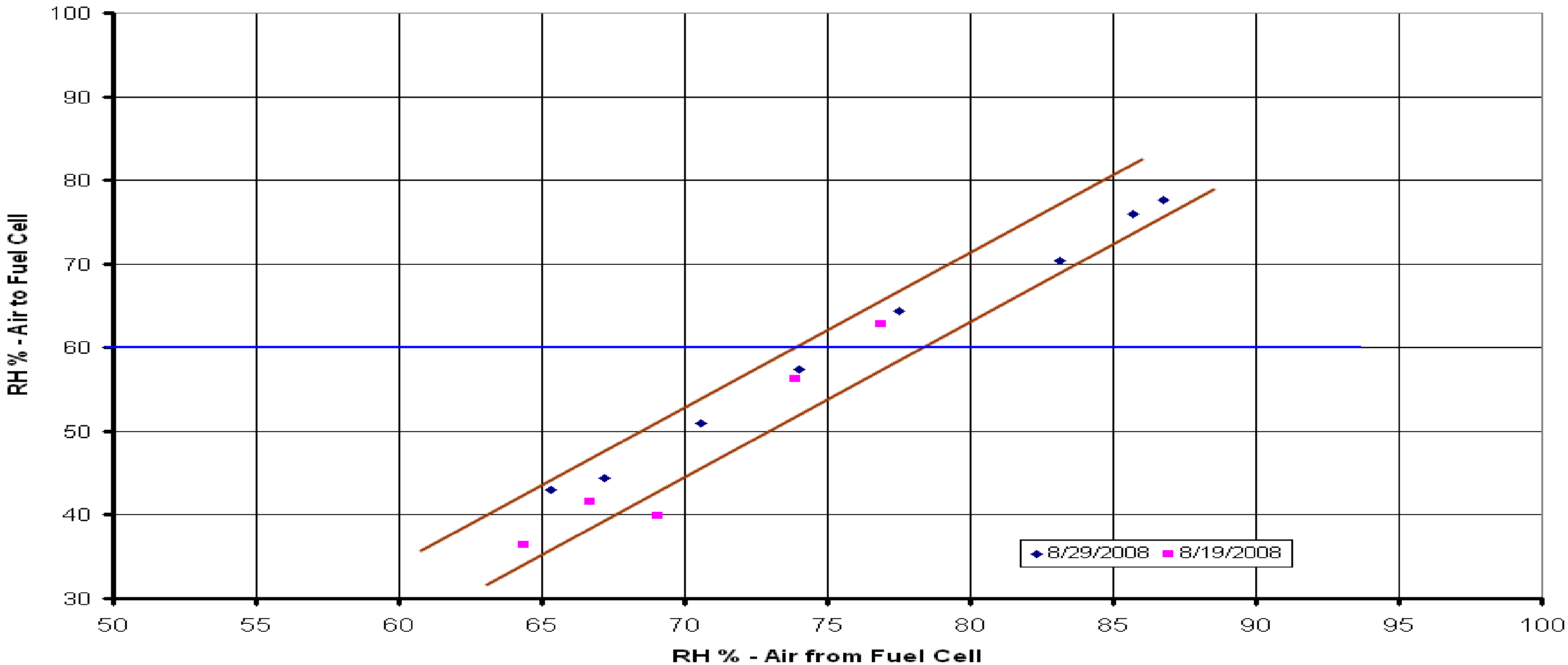


# Half Scale Membrane Module Test Data

Test operating temperature 70-80 °C
Fuel cell stack exit air will be 100% saturated

Air flow rate 1 lb/min.
Water mass balance within 10%




***Humidity of >75% in fuel exit air satisfies stack requirements***

# Collaborators

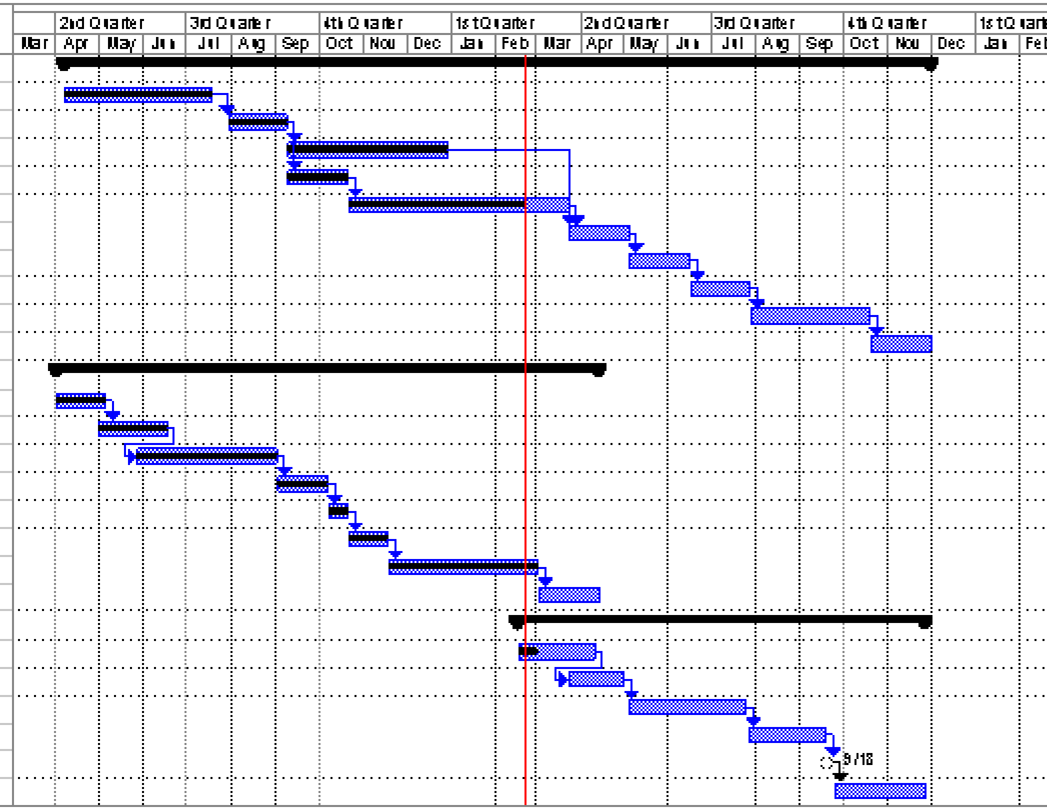
- Argonne National Laboratory — Federal Laboratory
  - Coordination of all technical activities including requirements definition, technical data interchange, and support to overall PEM Fuel Cell model development

- FreedomCAR Tech Team — US Council for Automotive Research
  - Participate in program reviews

- Emprise Corporation — Industry
  - Designed and built humidification test stand and Enthalpy Wheel. Active participant in improvement of test stand and enthalpy wheel design

# FY08/09 Schedule and Major Milestones

| ID | Task Name |
|---|---|
| 1 | **Water Management Program** |
| 2 | Test Stand Installation and Checkout |
| 3 | Enthalpy Wheel Testing |
| 4 | Modification of Enthalpy Wheel |
| 5 | Membrane Module Full Scale Testing at Low Flow |
| 6 | Modification of Test Stand |
| 7 | Enthalpy Wheel Testing |
| 8 | Full Scale Membran Module Testing |
| 9 | Memebrane Module Half Scale |
| 10 | Modify Test Stand for Sub-freezing temp. Testing |
| 11 | Testing of Select Humidification Device |
| 12 | **Thermal Management Program** |
| 13 | Requirements Definition |
| 14 | Design/test procedures for Sub-scale (SS) radiators |
| 15 | Fabrication of 4 SS radiators |
| 16 | Testing SS radiators |
| 17 | Performance Model Update |
| 18 | Design of Full-scale (FS) Radiators |
| 19 | Fabrication of FS Radiators |
| 20 | Testing of FS Radiator |
| 21 | **Design, Fab. and Testing of Planer Humidification Device** |
| 22 | Requirements definition |
| 23 | Survey plainer membrane suppliers |
| 24 | Evaluate the technology |
| 25 | Concept development |
| 26 | Concept /Technology Review |
| 27 | Define go-forward plan |




| | |
|---|---|
| **Thermal Management program kickoff** | **4/1/08** |
| **Fabrication and testing of Sub-scale radiators** | **10/6/08** |
| **Testing of full-scale radiators** | **4/13/09** |
| **Complete testing of humidification devices** | **7/27/09** |
| **Planer Membrane system evaluation complete** | **9/18/09** |

# Proposed Future Work

- Complete test stand modifications for higher air flow rate and improved humidity measurement accuracy
- Test modified Enthalpy wheel
- Test full and half scale Membrane Module
- Test full-scale radiators
- Evaluate planer membrane-based humidification devices for fuel cell application
- Test selected full-scale planer device to validate performance
- Test the selected humidification device at sub-ambient operating conditions