Honeywell

Development of Thermal and Water Management System for PEM Fuel Cells

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ENGINES & AIR MANAGEMENT – TORRANCE , CA

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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

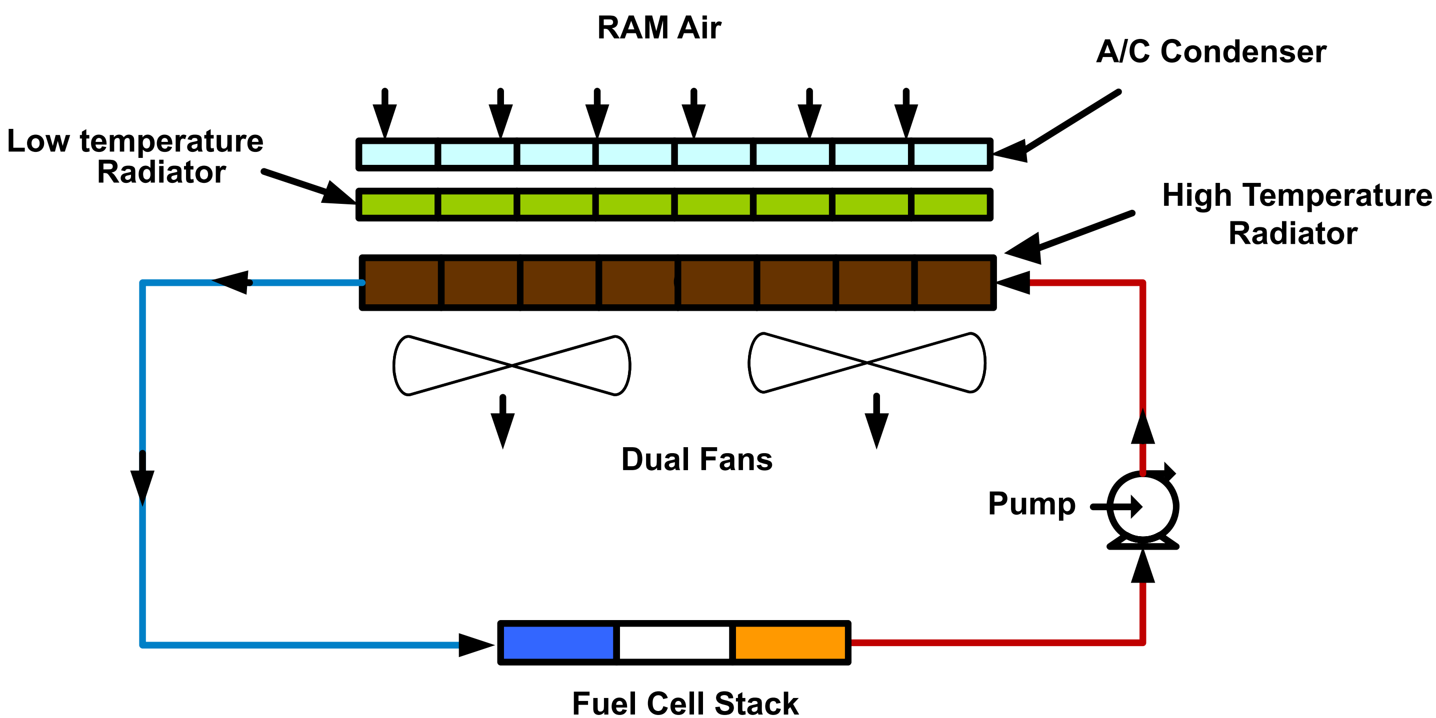
- The inlet air to the PEM fuel cell stack should have a minimum humidity of 60% (at 80 °C) to improve performance and increase stack life
- Two humidification systems were down-selected for the fuel cell application
  - Small-scale systems met the requirements
  - Full-scale units were built to validate 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

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

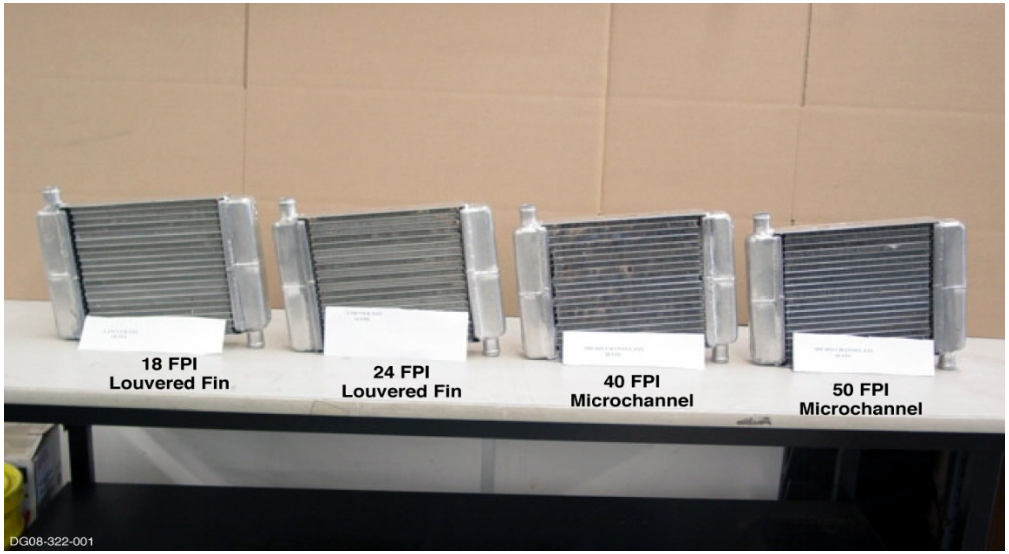
$$b = \frac{P_T - P_T^*}{P_{FCS}^*}$$

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

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
β_W	Effect of weight on FE	0.8
β_P	Effect of parasitic power on FE	0.1

Sub-scale Radiators Testing

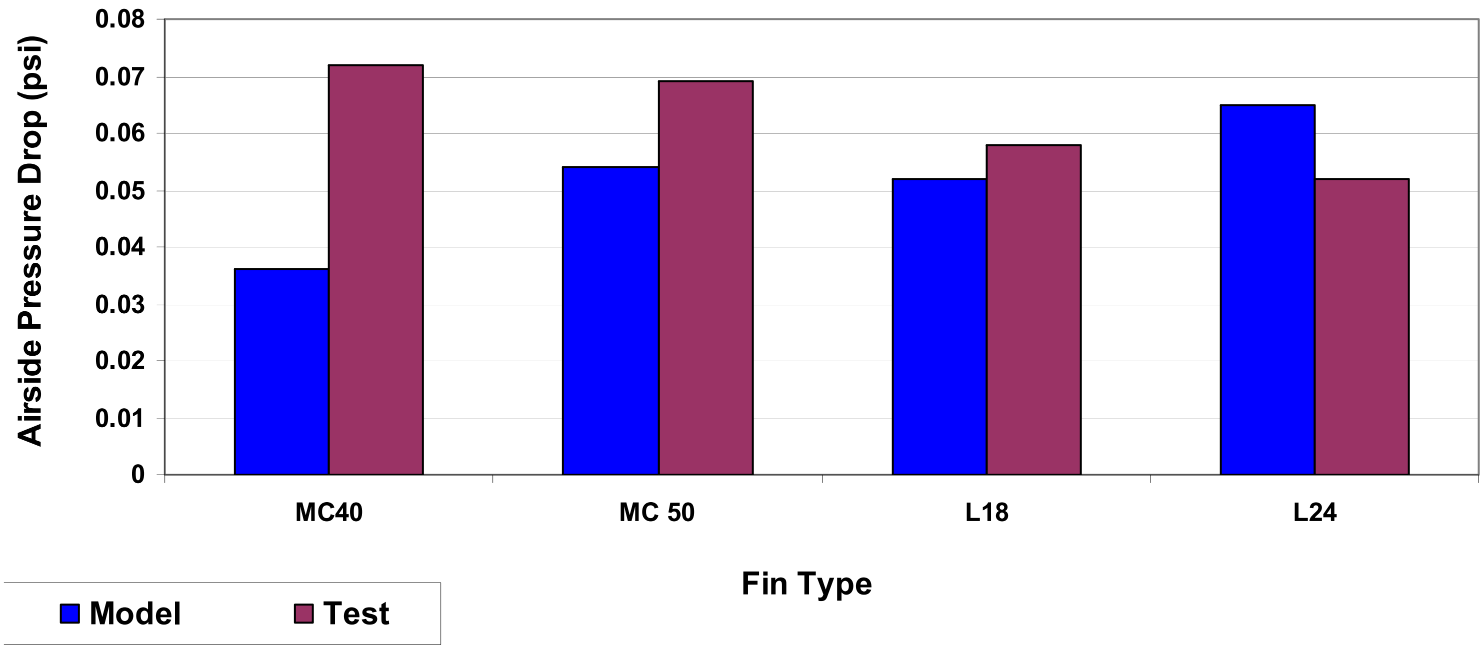
- Sub-scale (9″x 9″x 1.3″) radiators were built to validate:
  - Thermal performance
  - Manufacturability of microchannel fin radiators
- Updated full-scale radiator design/performance model
- Four fins were selected:
  - 18 fins/inch (fpi) Louver fins
  - 24 fpi Advance Louver
  - 40 fpi Microchannel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

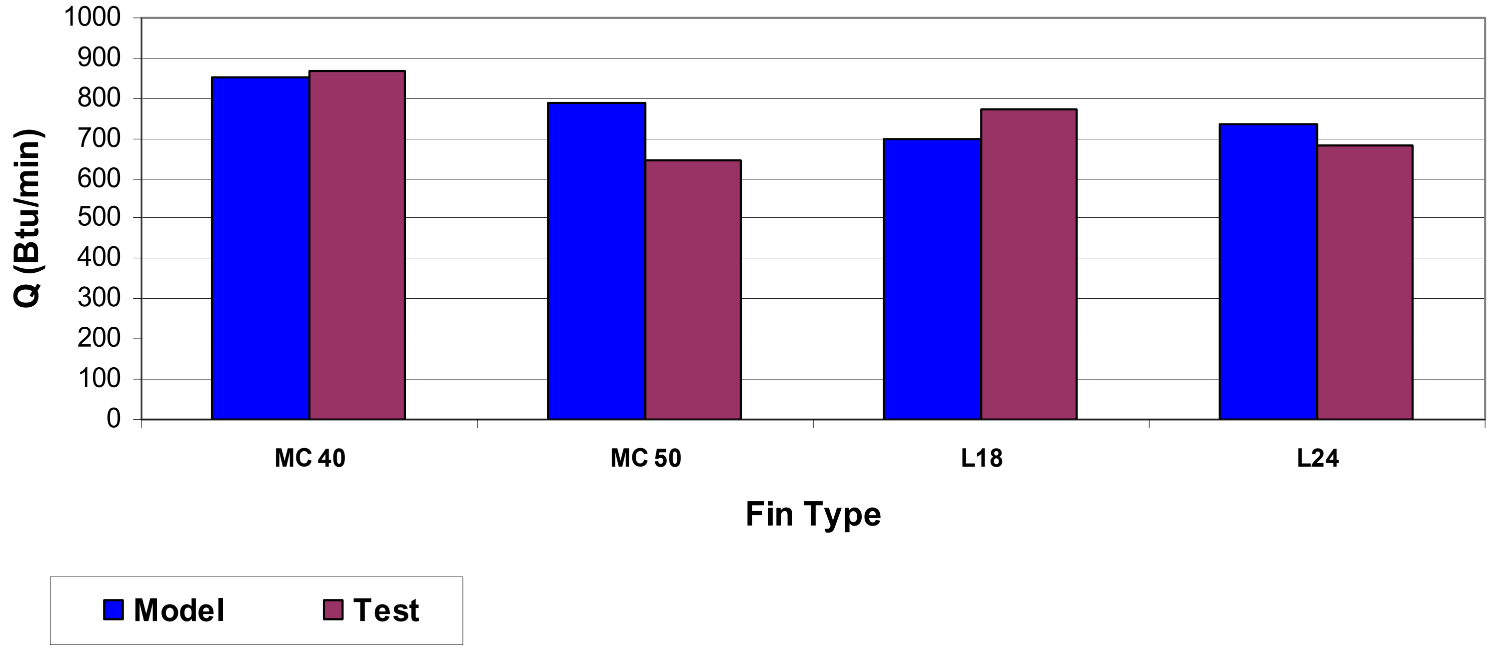


MC – Microchannel fins L – Louver fins

40 fpi MC presure drop test data being verified

Sub-scale Radiator Test Data & Model Prediction

Coolant flow of 19.4 gpm at 50 kW design condition



MC – Microchannel fins   L – Louver fins

Test data validated model predictions

Full-Scale Radiators

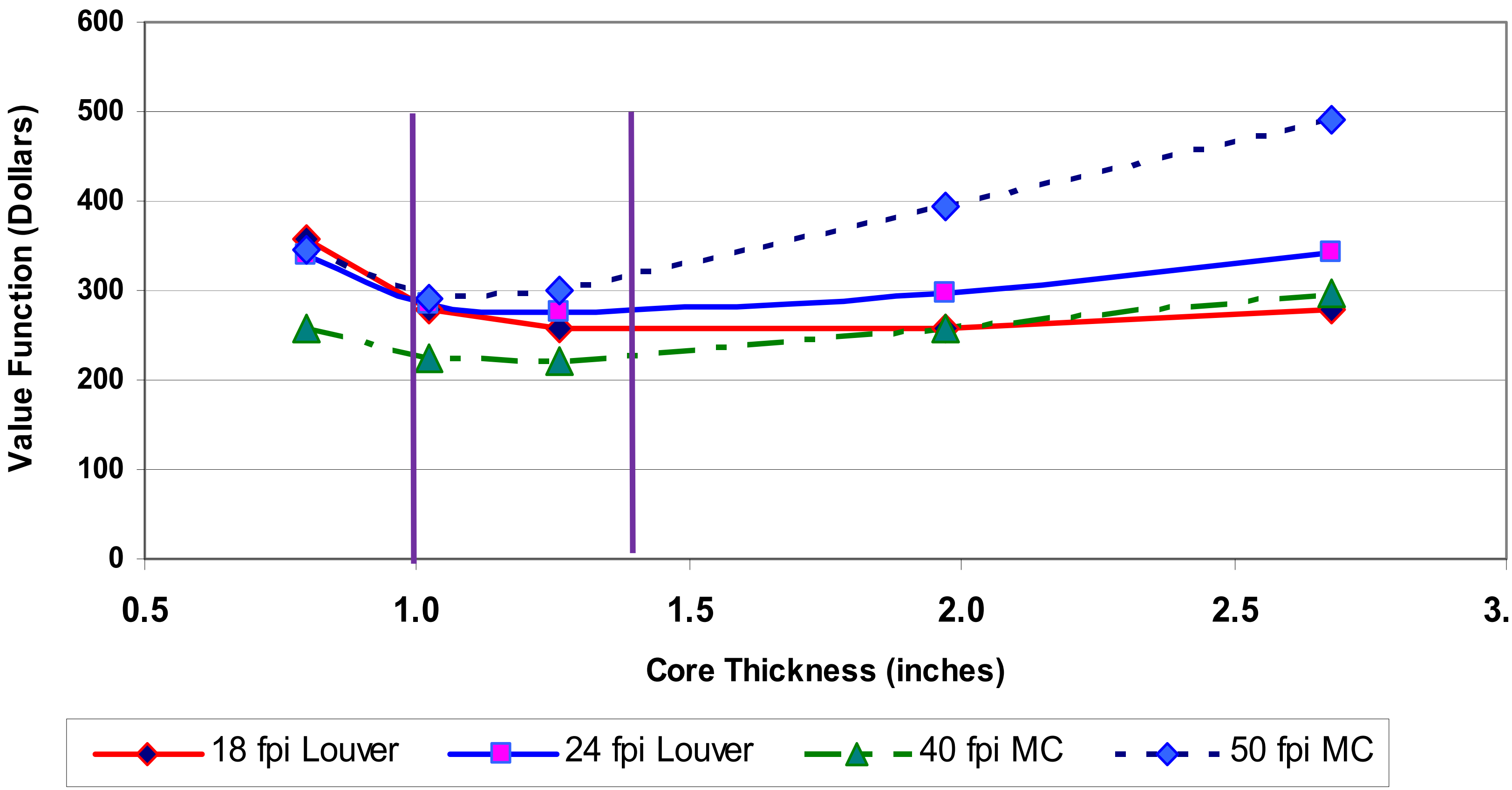
Size of the radiator 27.6″W, 17.7″H & 1.3″Depth
Estimated weight of full-scale louver and microchannel radiator (with plastic tanks) will be 10 and 13 lbs respectively

40 fins/in. Microchannel Fins

18 fins/in. Louver Fins

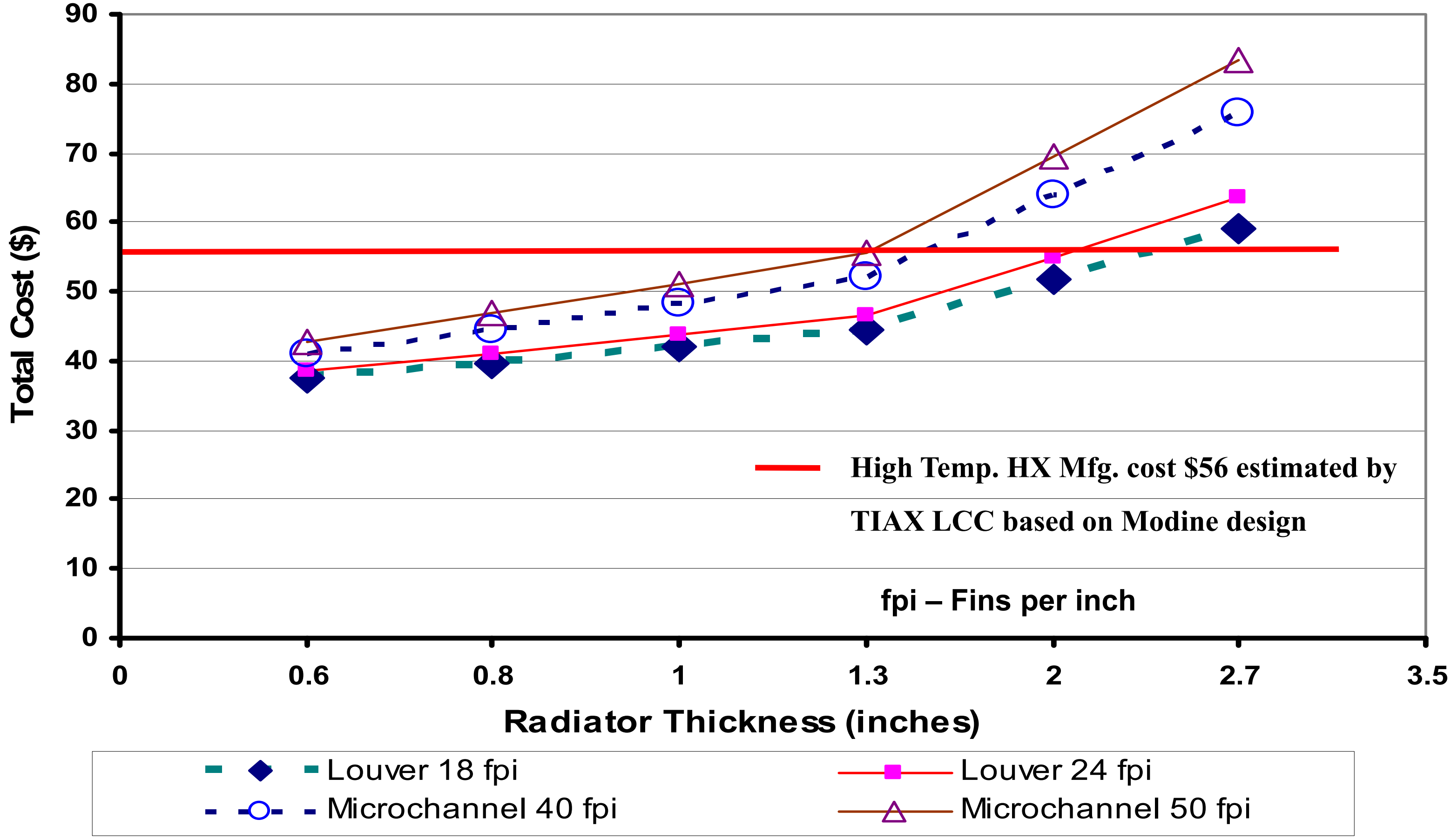
Full size microchannel radiators built successfully

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

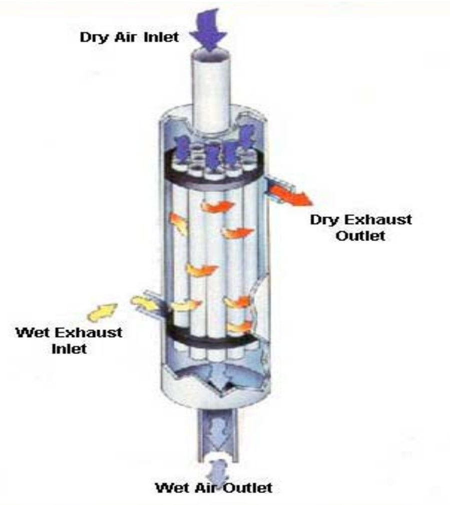
Humidification Devices

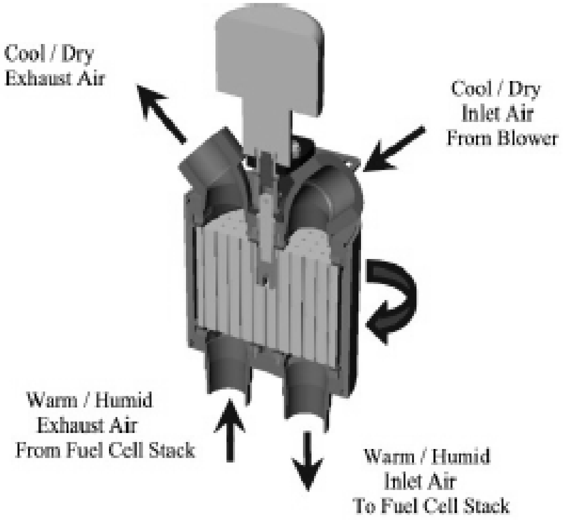
Membrane Module by Perma Pure

- 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

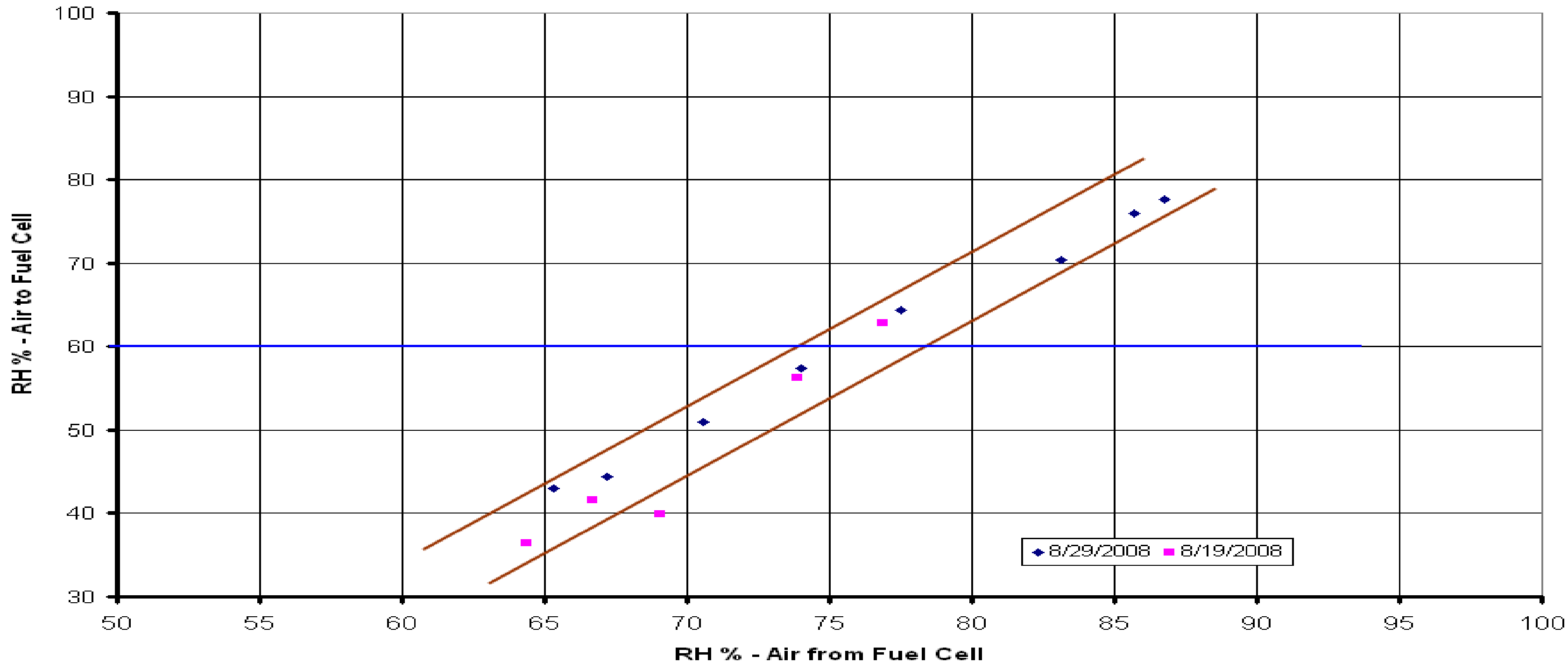




Half Scale Membrane Module Test Data

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

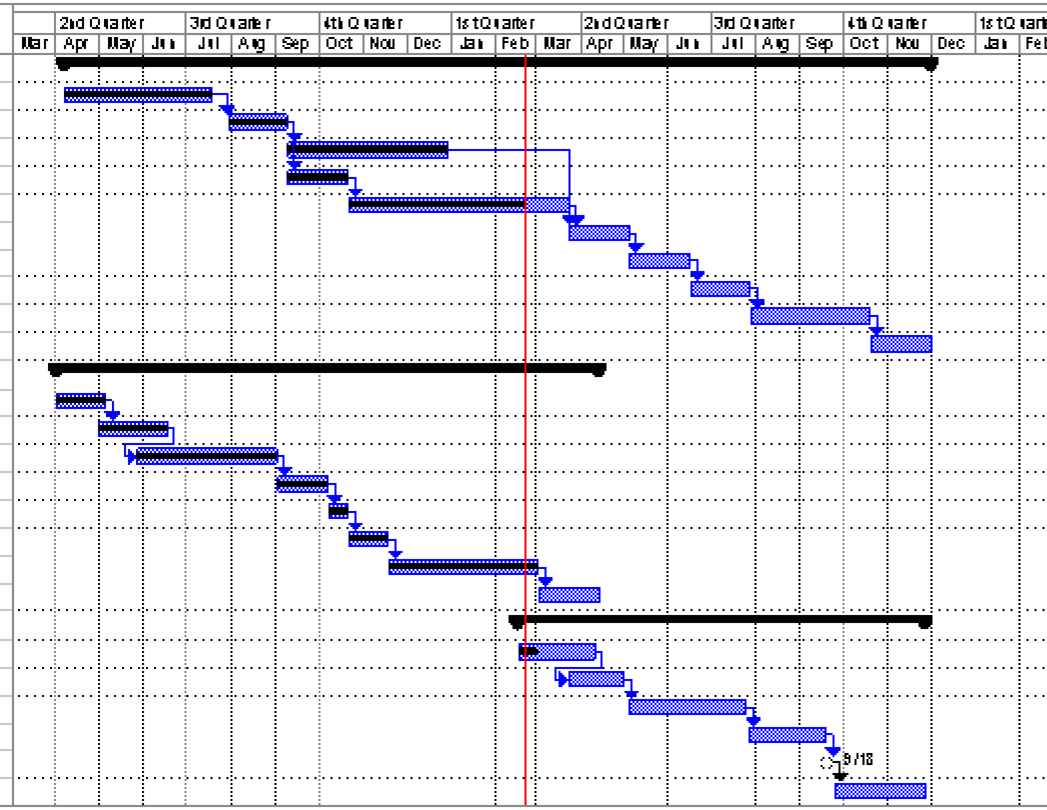
- **Argonne National Laboratory** — Federal Laboratory
  - Coordination of all technical activities including requirements definition, technical data interchange, and support to overall PEM Fuel Cell model development

- **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