DOE Hydrogen Program

Low-Cost Manufacturable Microchannel Systems for Passive PEM Water Management

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Project FC38

Battelle

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Overview

Timeline

- Start – February, 2007
- End – March, 2009
- 45% Complete

Budget

- $1000K Total funding
  - DOE share – 100%
  - Contractor share – 0%
- $300K FY07 funding
- $650K FY08 funding

Partners

- PNNL – PM & technology development
- ADMA – Manufacturing support
- ANL – System analysis support

Barriers

- 3.4 Fuel Cells Barriers
  - B. Cost:
  - E. System Thermal and Water Management
- Targets
  - 3.4.2 Automotive-Scale: 80 kW_e Integrated Transportation Fuel Cell Power Systems Operating on Direct Hydrogen

	Target	80 kW_e System	Water Mgmt Target %
Power Density	650 W_e/L	123 L	2–7%
Specific Power	650 W_e/kg	123 kg	2 - 9%
Cost	$30/$kW_e$	$2400	< 7%

Objective

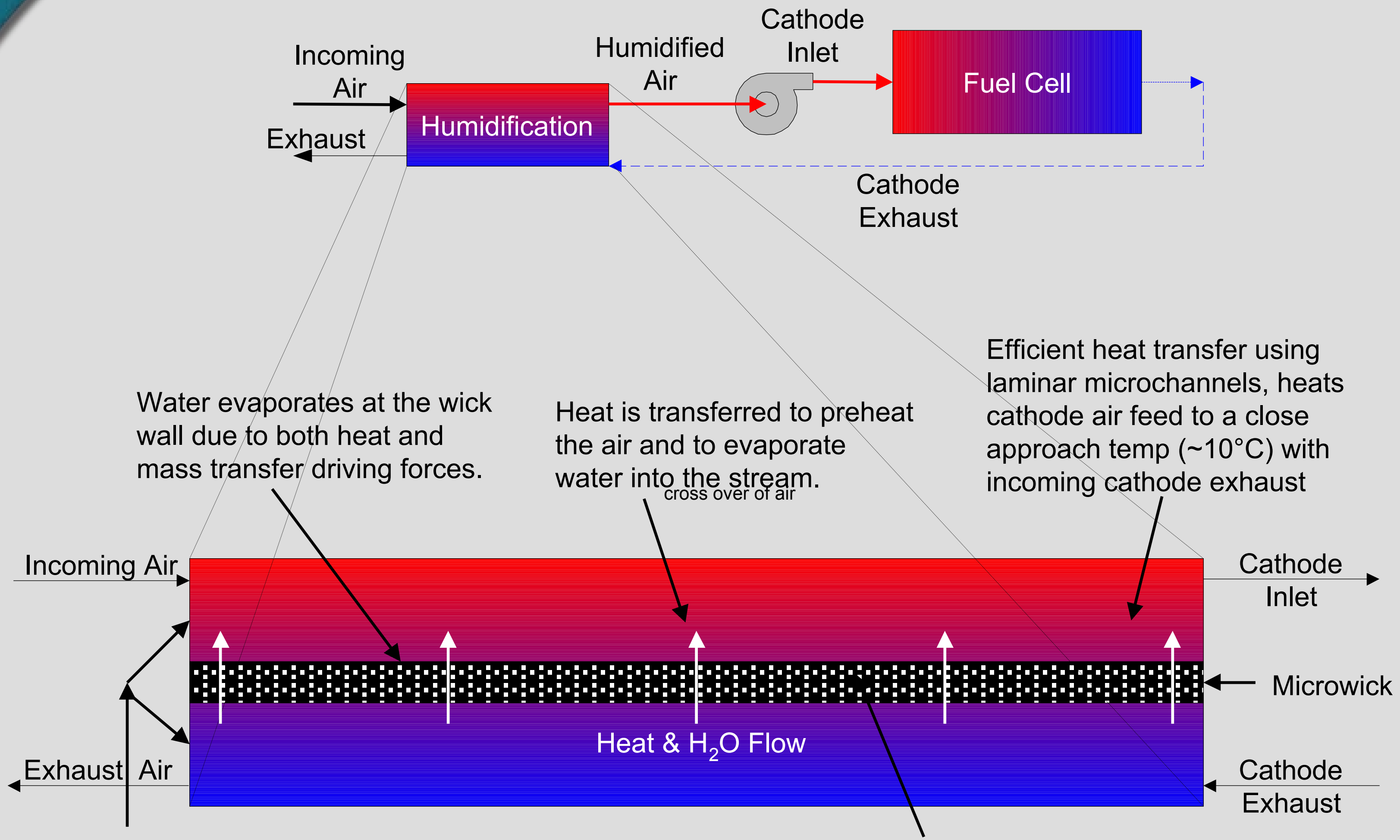
OVERALL

- Create a low cost, passive technology for water management in PEM systems

Milestones

Month/Year	Milestone	Status
April-08	Demonstrate a prototype humidifier device with processing capacity to support 1 kW_e fuel cell at a power density >8 kW_e/L and a specific power >6 kW_e/kg.	A 1 kW_e device has been designed and built at 22 kW_e/L power density and 4.2 kW_e/kg specific power. Testing in progress. Scale-up to 80 kW_e device projected at ~42 kW_e/L power density and ~10 kW_e/kg specific power.
May-07	Projected manufacturing cost <\$3/kW_e based on validated process	The primary cost driver for the device would be suitability of powder rolled and annealed sheet. Current results indicate the powder rolled sheet will work and therefore cost projections will be met.

Approach



Water evaporates at the wick wall due to both heat and mass transfer driving forces.

Heat is transferred to preheat the air and to evaporate water into the stream.

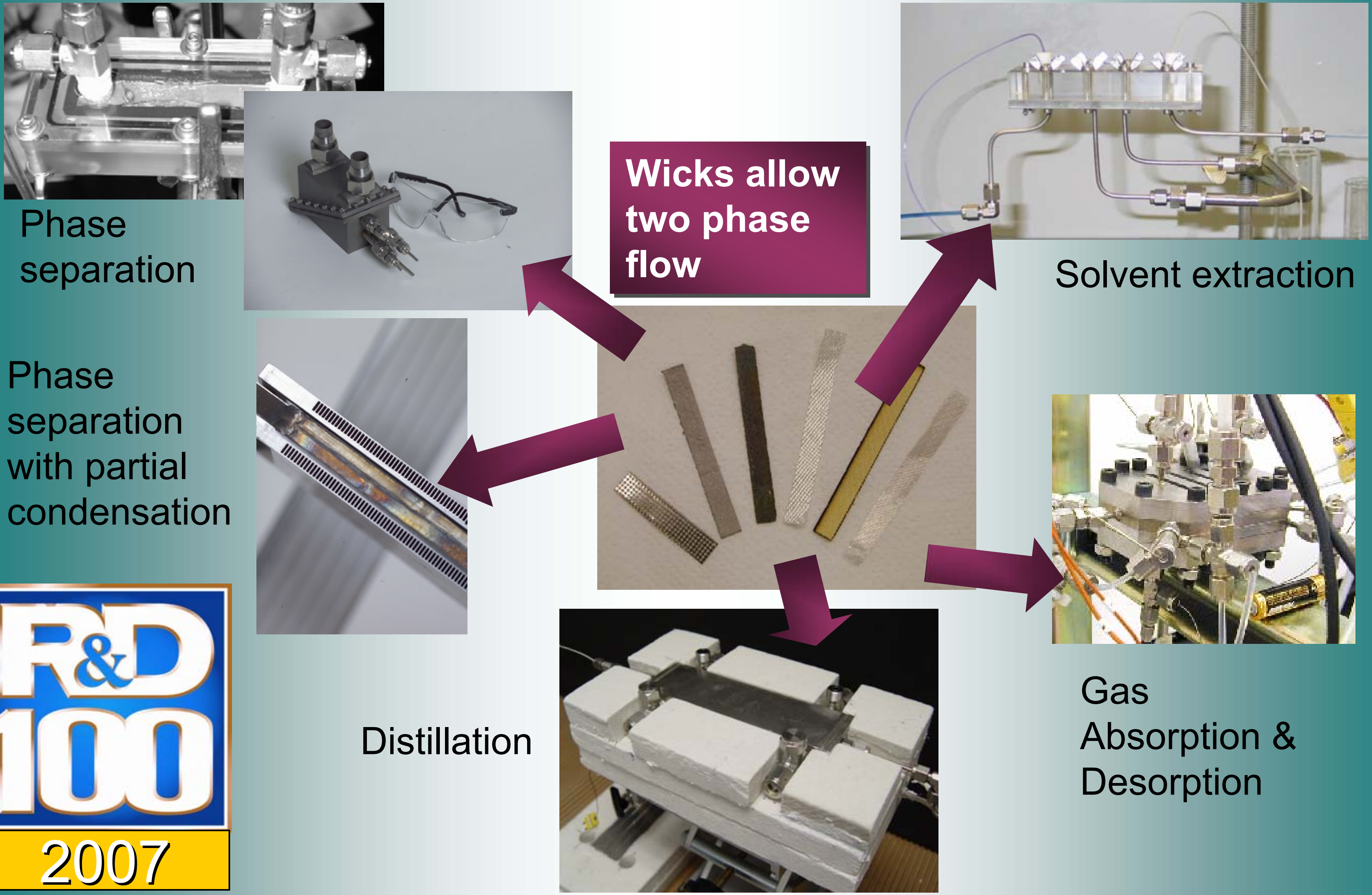
Efficient heat transfer using laminar microchannels, heats cathode air feed to a close approach temp (~10°C) with incoming cathode exhaust

Interconnect wicks are built into headers to remove excess water during normal operation and supply water during start up.

Capillary forces convey water condensed from the humid exhaust to the dry incoming air and also prevent cross over of air by precluding air intrusion into the wick.

Approach

Based on a Family of Separations Technologies



Wicks allow two phase flow

Phase separation

Solvent extraction

Phase separation with partial condensation

Gas Absorption & Desorption

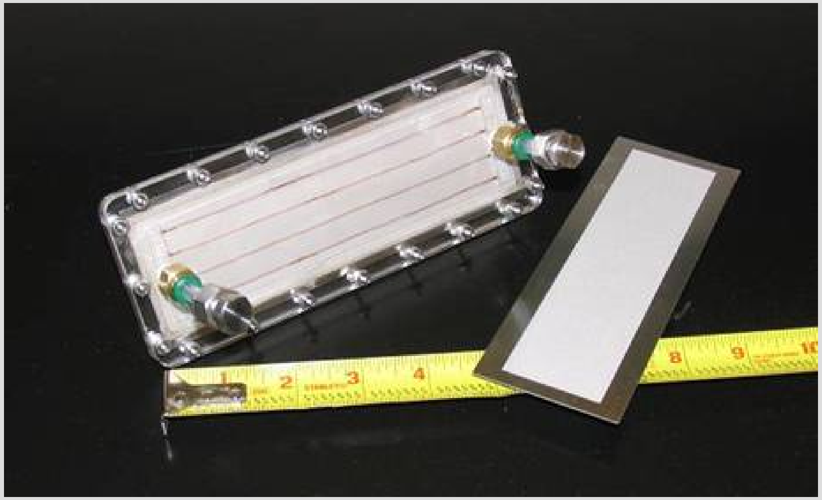
Distillation

R&D 100

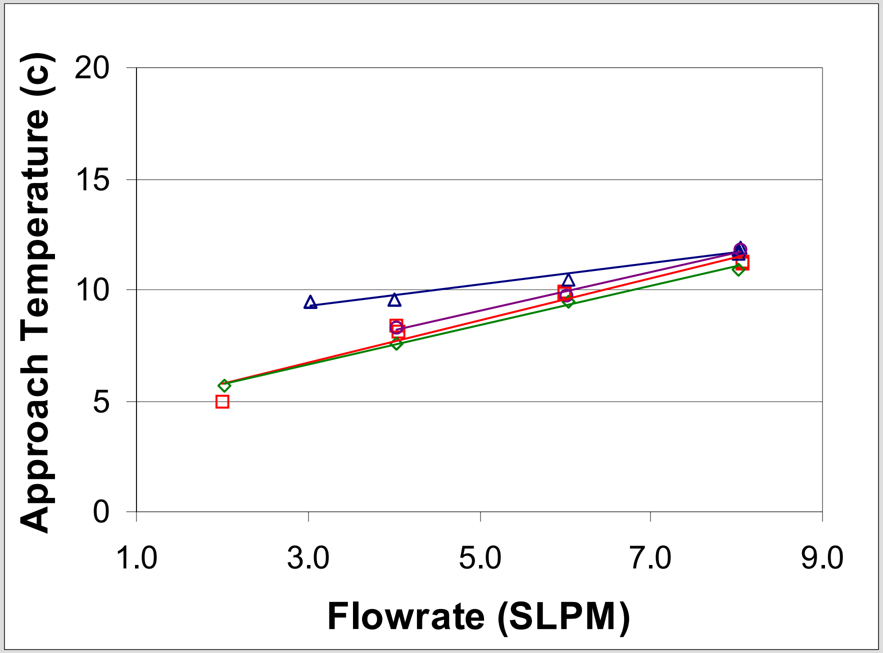
2007

Single Channel Demonstration and Testing

The technology is feasible and size and weight targets are achievable based on measured performance data.



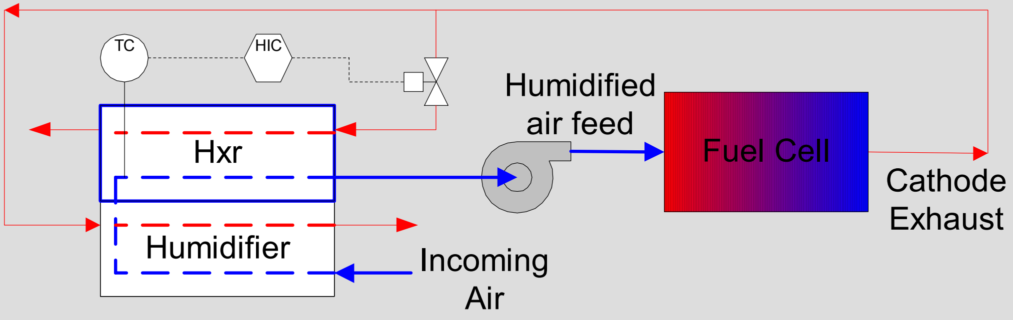
- Demonstrate and characterize concept
- Evaluate alternative porous materials
- Validate heat and mass transfer model
- Support scale-up to multi-channel devices
  - 1 kW to 10 kW scale



- Heat transfer limited on the cold side
- Cold side exits at 100% RH
- Nu number 70% higher for interleaved device
- Start-up
  - Immediate after 2-day wet shutdown
  - 30 minutes from bone dry

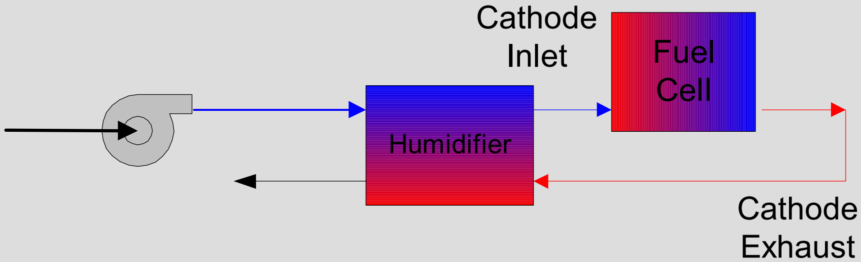
System Integration

Saturated air stream from the humidifier has implications for system integration. Active controller permits control of cathode feed RH.

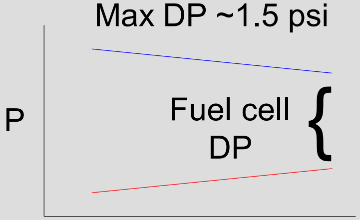


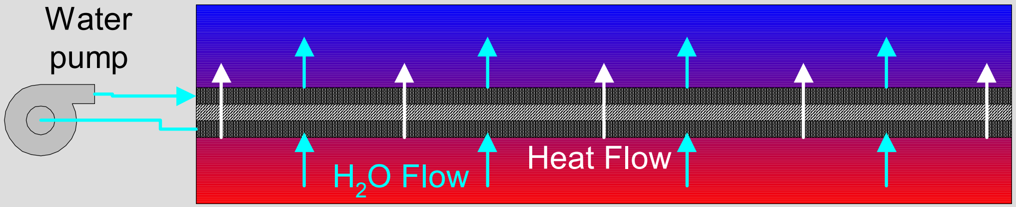
- Integrate heat exchanger to superheat feed air stream
  - Exchanger integrated into humidifier
- RH controlled by splitting hot stream flow
- Independent control of air feed temp requires second controller

Placing humidifier after blower/compressor adds FC pressure drop to humidifier differential pressure.



- Constrains the fuel cell pressure drop
- Or hot and cold streams must be hydraulically separated in the humidifier
  - Adds separator plate size and weight
  - Complicates water management





Heat and Mass Transfer Modeling

- One dimensional model to support design
- Correlation-based Heat and Mass Transfer
  - Heat Balance Equations (Chilton-Hougen method)

$$\alpha_h \phi \left(T_h - T_{hw}\right) + \lambda \dot{n}_h = \frac{k_w}{t_w}\left(T_{hw} - T_{cw}\right) = \alpha_c \phi \left(T_{cw} - T_c\right) + \lambda \dot{n}_c$$

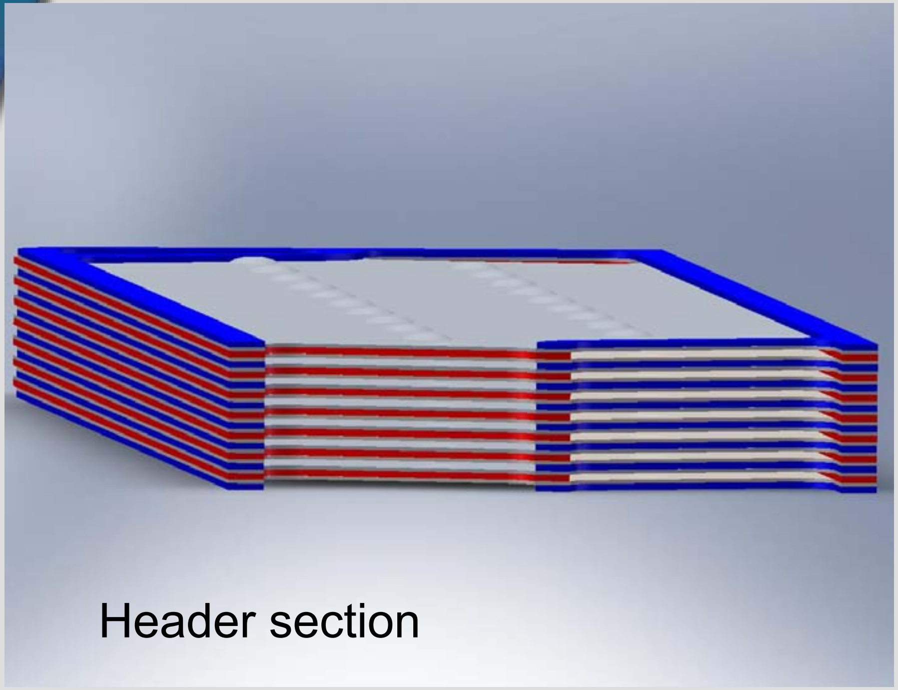
  - Mass Transfer Equations

$$\dot{n}_h = \beta_h \ln\left(\frac{P - p_{sat}(T_{hw})}{P - p_h}\right)$$

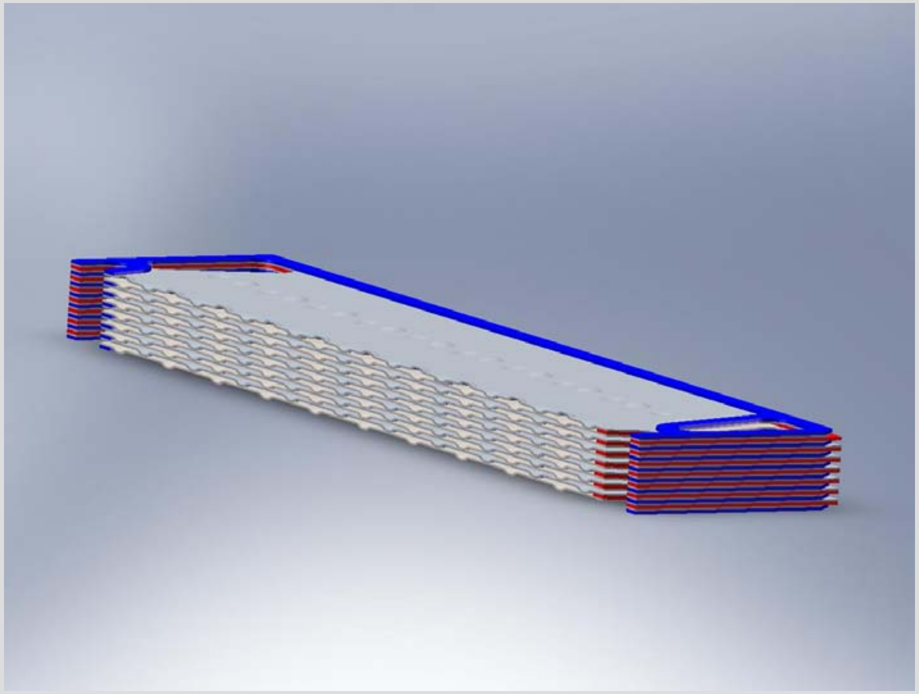
  - Chilton-Colburn Analogy

$$\beta_h = \left(\frac{\Pr_h}{Sc_h}\right)^{2/3} \frac{\alpha_h}{Cp_h}$$

Design and Fabrication of kW Scale Prototypes

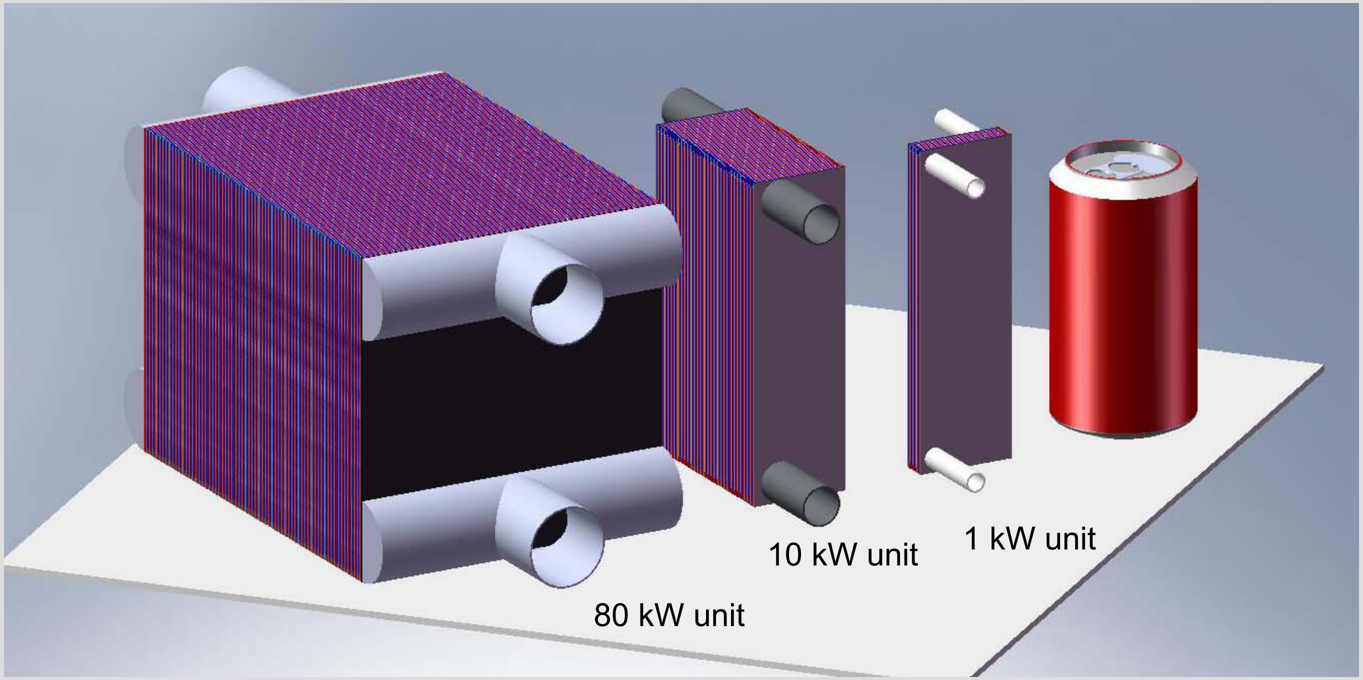


Header section



- Flat plate design for multi-channel devices
- Internal channel spacing controlled by pressing features into wicks
- Scalable by width and number of layers
- Bonding done with low temperature process

Design and Fabrication of kW Scale Prototypes



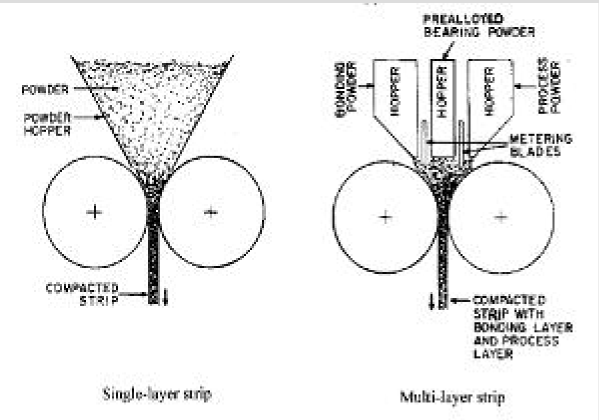
Scale	Volume	Weight	Power Density	Specific power
1 kW_e Target			8 kW_e/L	6 kW_e/kg
1 kW_e	0.045 L	0.24 kg	22 kW_e/L	4.2 kW_e/kg
10 kW_e	0.28 L	1.4 kg	35 kW_e/L	7.0 kW_e/kg
80 kW_e	1.9 L	8.7 kg	42 kW_e/L	9.2 kW_e/kg

Sintered Porous Media at the Heart of the Technology

- Key performance metrics
  - Bubble point – precludes air crossover
  - Permeability – sufficient water flux and distribution
  - Conductivity – directly in the heat transfer pathway
  - Cost – most expensive material cost

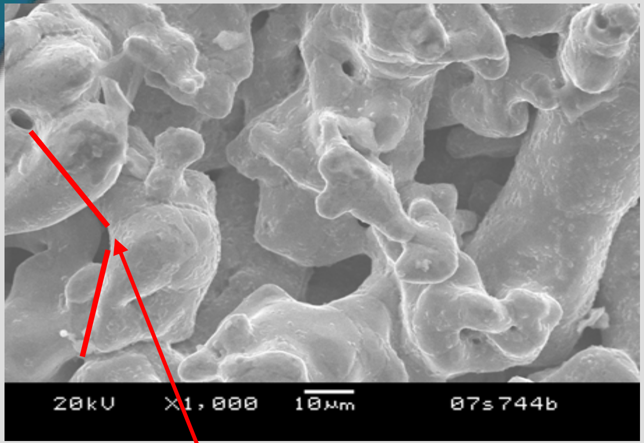
- Develop low-cost, high volume material
  - Direct powder rolling with ADMA

Pall Supramesh baseline material

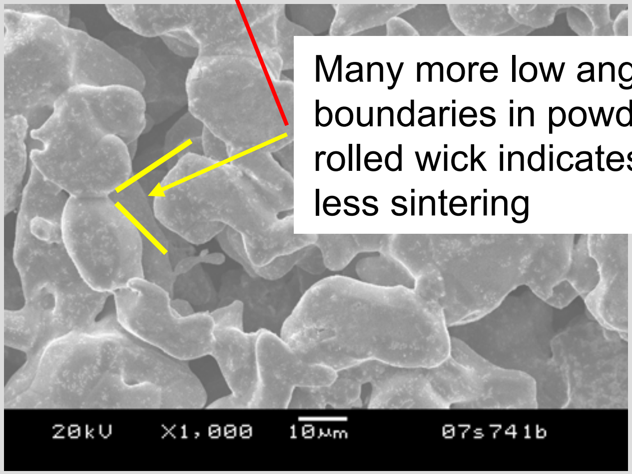


  - 0.005 to 0.030 inch thicknesses
  - Layered structures possible

Comparison of Porous Materials



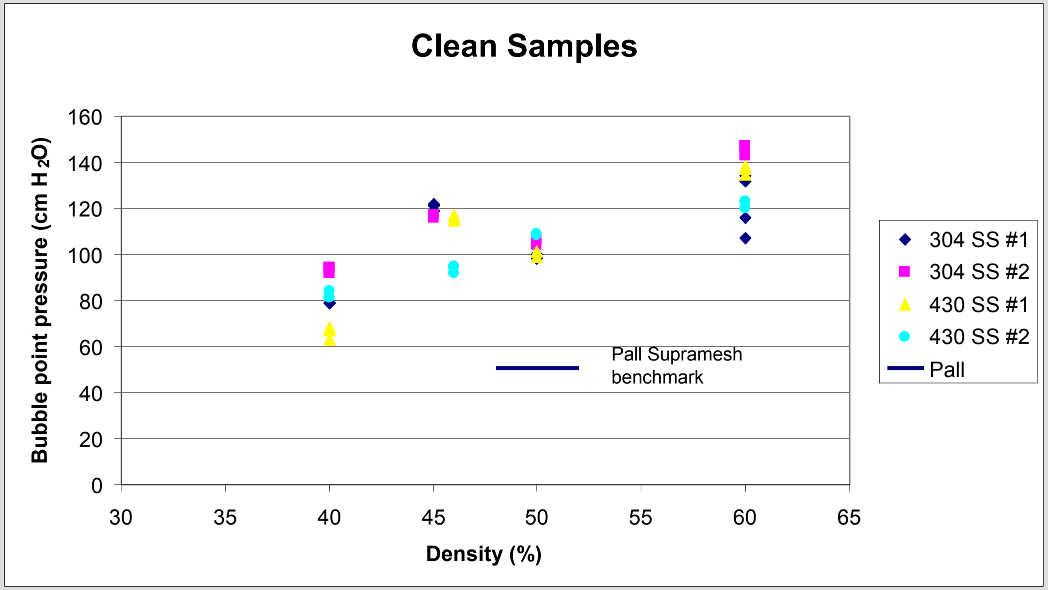
Previously used wick materials



Many more low angle boundaries in powder rolled wick indicates less sintering

Powder rolled sheet

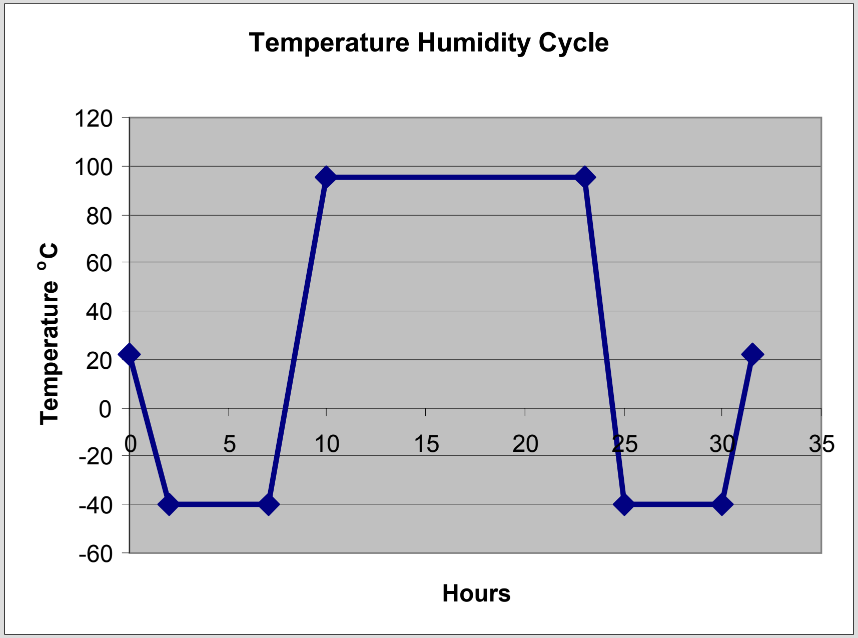
- Material properties as good or better
  - ~2X higher bubble point pressure
  - Comparable permeability – 2-3 orders of magnitude margin
  - Conductivity not significant transport resistance



Durability Testing

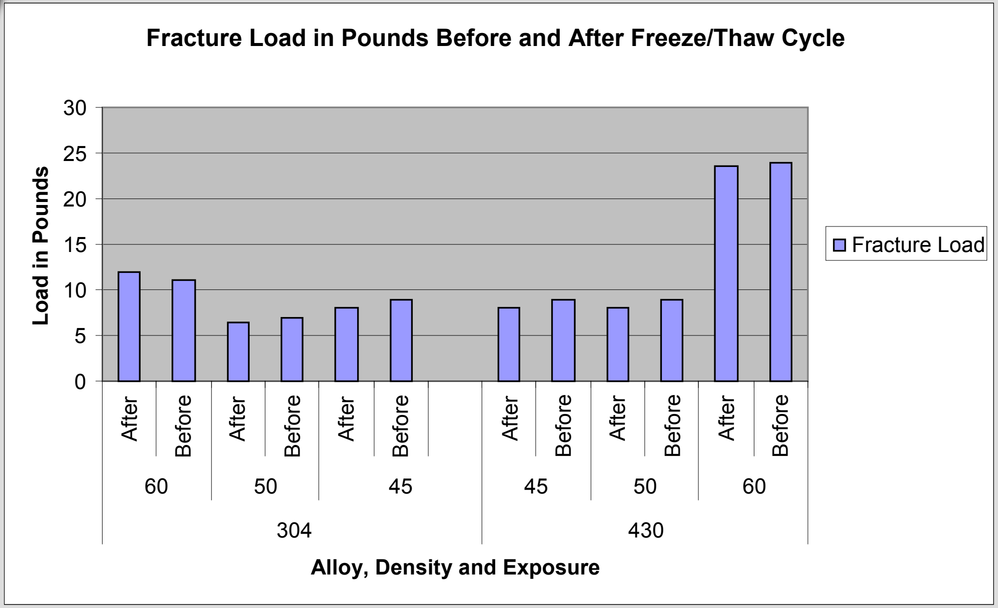
Freeze/Thaw Characterization

- Samples of the porous wick from 304 and 430 stainless were subjected to Mil-STD-331C temperature humidity cycle
  - 28 day cyclic exposure from -40^{o}C to +95^{o}C in 95% RH
- Samples were tensile tested with and without exposure
  - Standard E8 sample

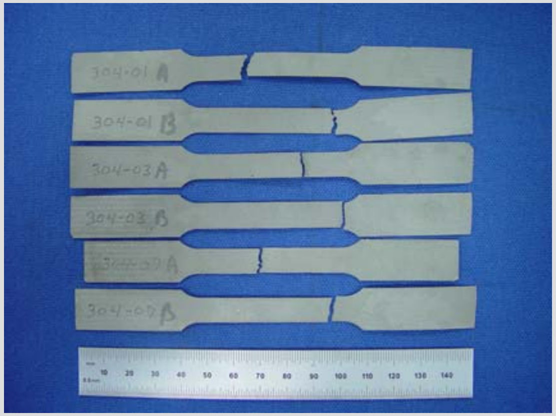


Cycle repeated for 28 days with 95% RH at 95^{o}C

Wick Strength with Freeze/Thaw



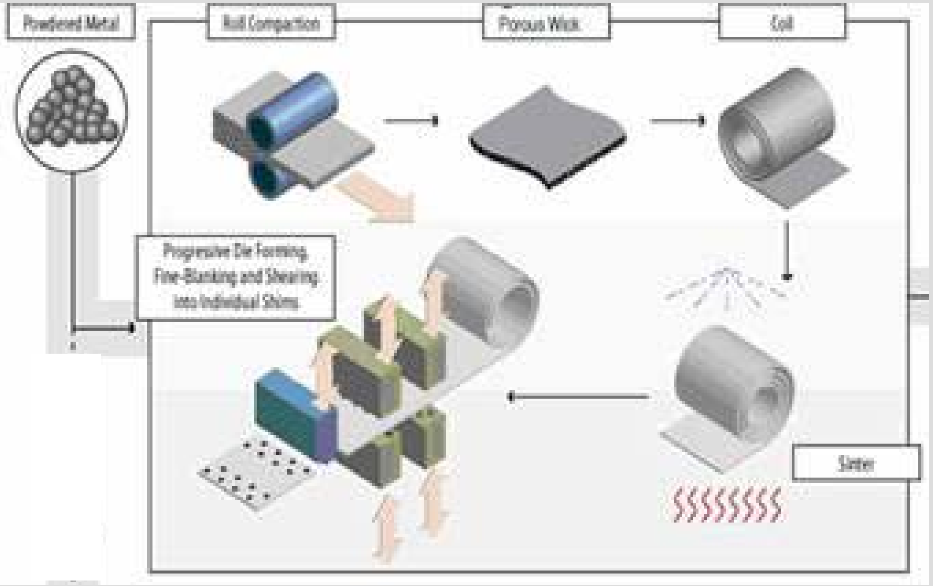
- Tensile fracture load did not show variation with exposure
  - Average change less than sample to sample variation
- Highest tensile strengths were measured in the 60% dense wicks
  - Exhibited classic tensile ductility up to 2%

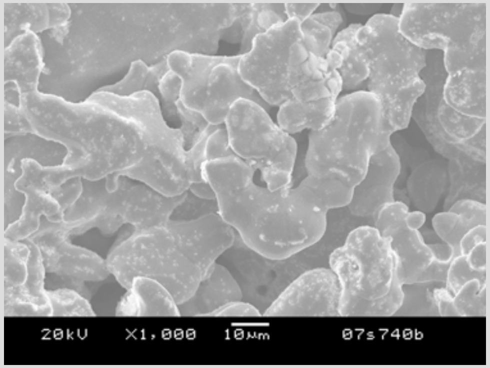


Failed 304 Tensile samples

Manufacturing Cost Estimate

- Materials of Construction
  - Wick will likely be 430 Stainless; approximately $8/lb with $0.5/lb for powder roll and anneal – atomized and unscreened powders
  - Vapor layer likely to be a epoxy vinyl ester resin with a glass fiber mat to reduce thermal expansion mismatch
- Porous wick will be coiled and processed using progressive die stamping and fine blanking
  - Tool cost on the order of $200K with a piece cost of approximately $0.40
- Outer shell and plenum fabrication method and cost to be determined
  - Likely to be a resin infusion process
    - Pressure (vacuum), temperature and times to be determined





430 Stainless wick structure

Manufacturing Cost Estimate

80 kW_e Scale Humidifer

- Wick material will be approximately 9lbs
    - Tooling amortization is favorable and low strength porous wick will enhance die life
    - About 41,000,000 wicks per year – 278 per 80kW device
    - Total Wick cost will be about $111 per device
        - Stainless steel prices are very high
- Vapor layer materials and end plates will be approximately 1lb
    - In volume epoxy vinyl ester and glass mat is approximately $5/lb
    - Tooling amortization will be a low contributor to cost
    - Cycle time will be primary issue
        - Driven by viscosity and cure time; must not wick into stainless while rapidly wicking into glass fiber mat

Stacking Video

Future Work

- **FY08**
  - Complete testing and analysis of the 1 kW_e prototype
    - Validate design model
    - Vary operating conditions, including flows, temperatures, and hot and cold stream RH
    - Evaluate start-up and transient response
    - Assess reliability and durability—start-up from a frozen condition
  - Validate low cost manufacturing process
    - Costs for manufacturing 80-kW_e device at <\$3/kW_e
  - Develop integration approach for automotive fuel cell systems
    - Assess impact of ancillaries to size, weight, and cost of overall system
  - Design and fabricate a 10 kW_e prototype device
- **FY09**
  - Demonstrate 10 kW_e device in a fuel cell system

Summary

- Microwick approach offers advantages for PEM Fuel Cell systems
  - Small size due to high power density heat transfer and rapid mass transfer
  - Passive operation
  - Low pressure drop enabling operation with blowers
  - Orientation independent
  - Self recovery during process upsets
- Feasibility demonstrated in single channel device
- Go criteria for size, weight and projected cost are met
  - Power density >8 kW_e/L and specific power >6 kW_e/kg
  - Mass manufactured at <$3/kW
- Scalable prototype built for 1 kW_e and testing in progress