MATERIALS AND MODULES FOR LOW-COST, HIGH PERFORMANCE FUEL CELL HUMIDIFIERS

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W. L. Gore & Associates, Inc.
May 12, 2011

Project ID: FC067

Overview

TIMELINE

- ✓Start date: 4/01/2010
- ✓End date: 3/31/2012
- ✓~40% complete as of 03/15/2011

BUDGET

✓DOE:	$1,492,163
✓Contractors:	$373,040
✓Phase 1 DOE Funds obligated:	$817,701

- ✓ Currently under budget by ~20%

DOE PLAN BARRIERS ADDRESSED:

- ✓ System cost, fuel cell performance and durability
- ✓ Task 7, "Develop balance of plant components"
  - B - Reliable, cost-effective fuel cell systems.
  - E - System thermal and water management.
  - A and C (indirectly) – Fuel cell durability and performance.

TEAM

- ✓Prime - W. L. Gore & Associates, Inc.
- ✓Subcontractor - dPoint Technologies

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Objectives

Demonstrate a durable, high performance water transport membrane; and a compact, low-cost, membrane-based module utilizing that membrane for use in automotive, stationary and/or portable fuel cell water transport exchangers.

Relevance

More efficient, low-cost humidifiers can increase fuel cell inlet humidity:

- **Reduce system cost and size of balance of plant.**
- **Improve fuel cell performance.**
- **Potentially decrease size of fuel cell stack by running under wetter conditions.**
- **Improve fuel cell durability.**

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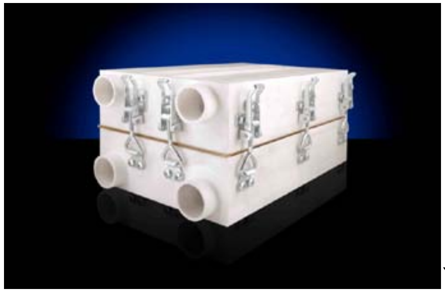
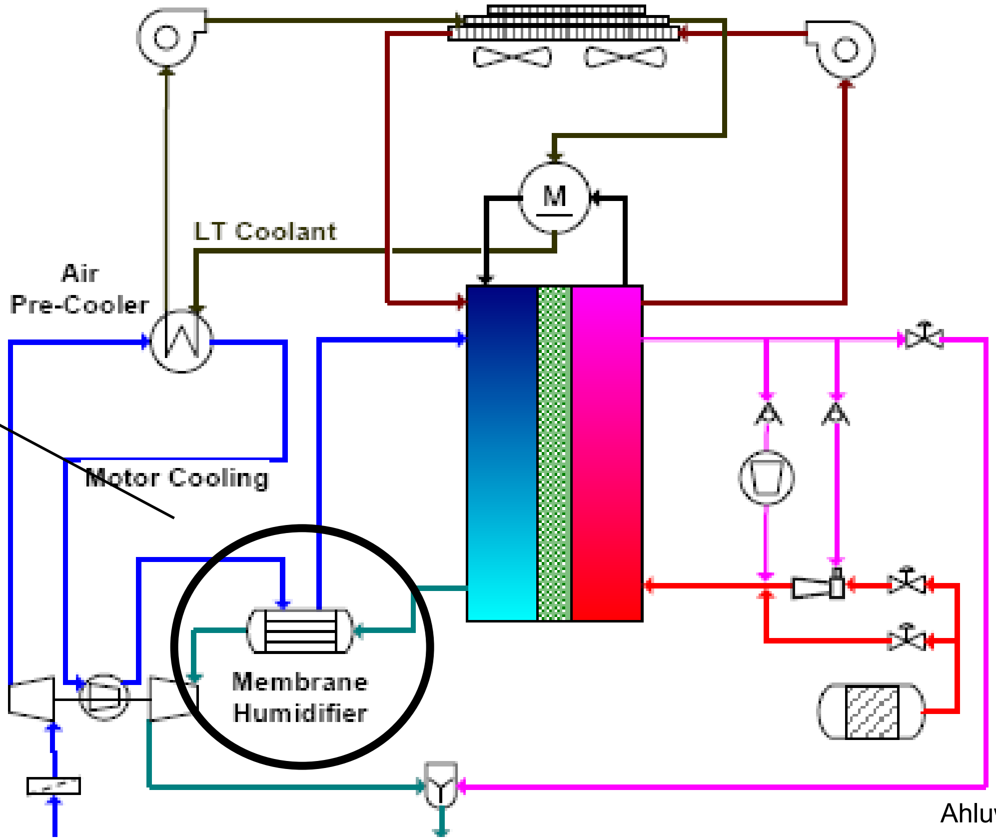
Background



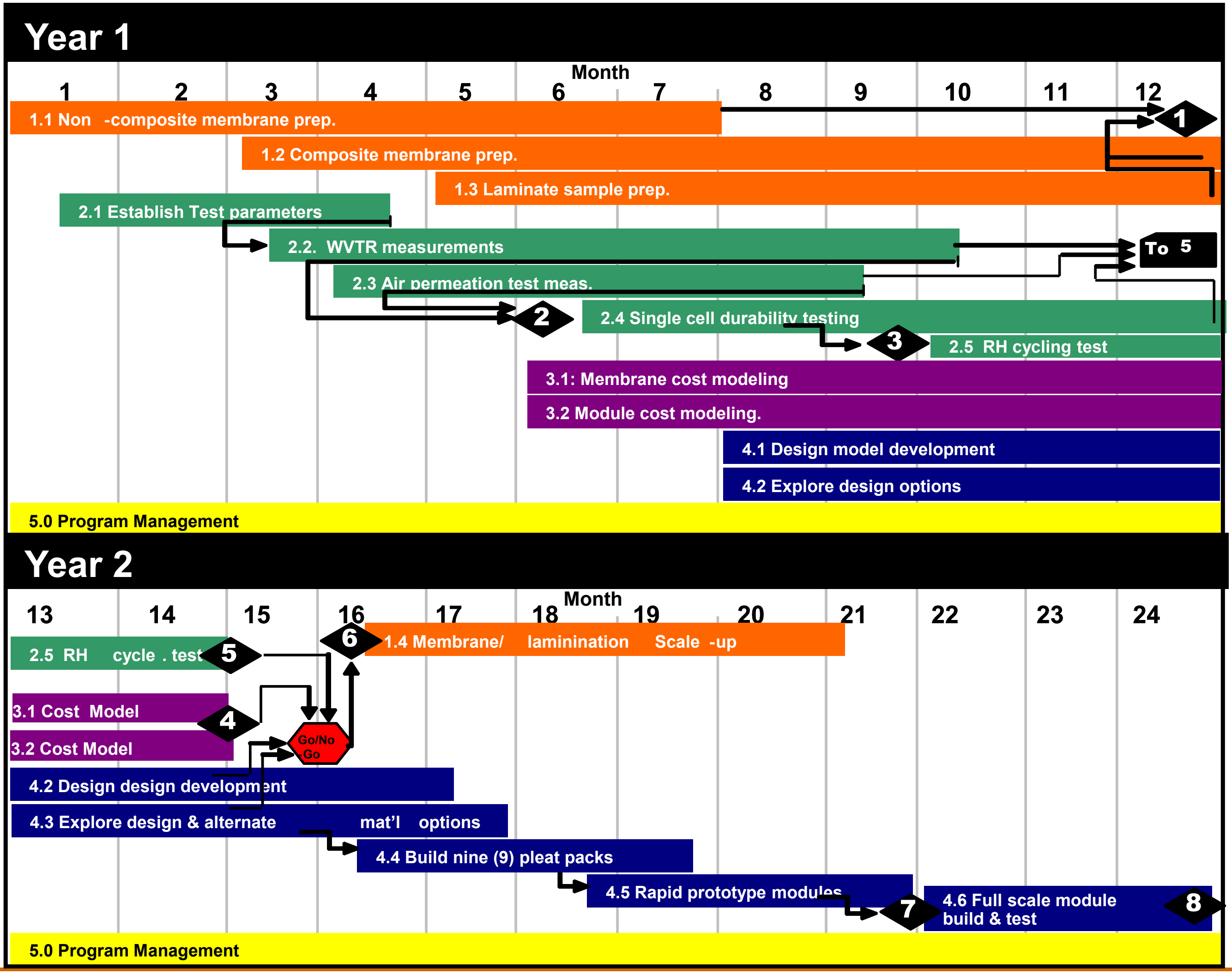
dPoint module



Ahluwalia, et. al, ANL.

Illustrative block diagram of fuel cell system

Approach: Timeline and Milestones



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Approach: Plan

Task	Completion
Task 1: Materials Preparation • Initial material selection/preparation • Scale-up to m^2 sizes	75%
Task 2: Materials Testing • Identify conditions • Water transport measurements • Durability by hot soak & RH cycling • Air permeability	75%
Task 3: Cost Modeling • Membrane and module level	60%
Task 4: Module Design, Test and Build • Design exploration • FEA models • Design/build alternatives using rapid prototyping • Build/test full scale module	10%
Task 5: Project Management and Reporting	~45%

Go/No-Go
15 months
June 2011

- Module Volume < 8 L
- Module cost < $150
- Membrane life > 5000 h hot soak
- Membrane life>1000 h RH cycling
- Membrane > 0.030 g/cm^2-min at 80 ºC

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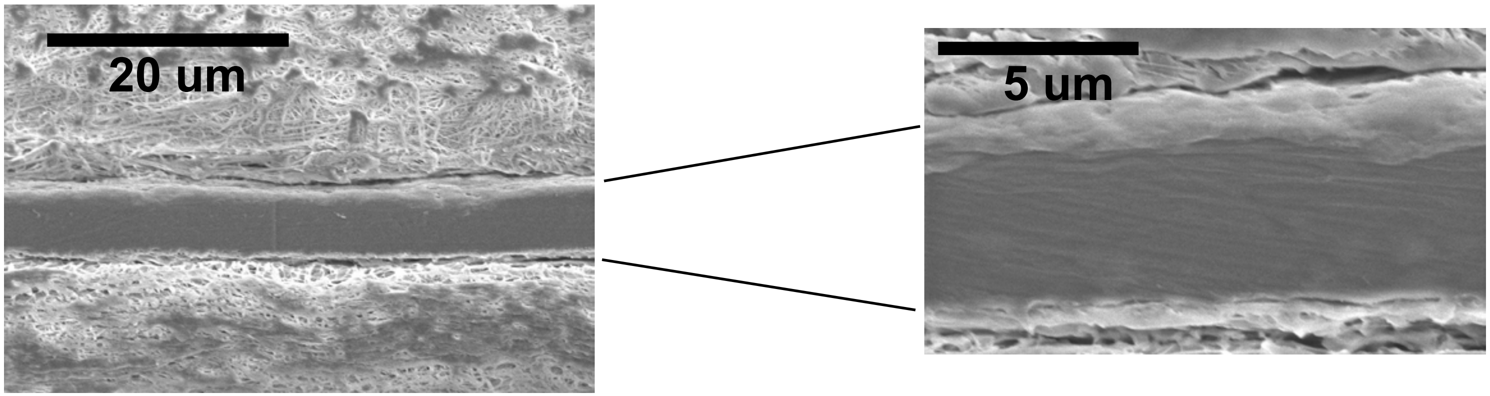
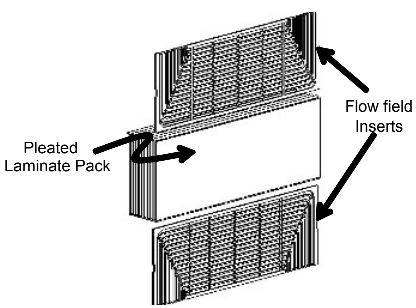
Approach: Technical

- **Membranes: Utilize unique, high performance, GORE™ Humidification Membranes**

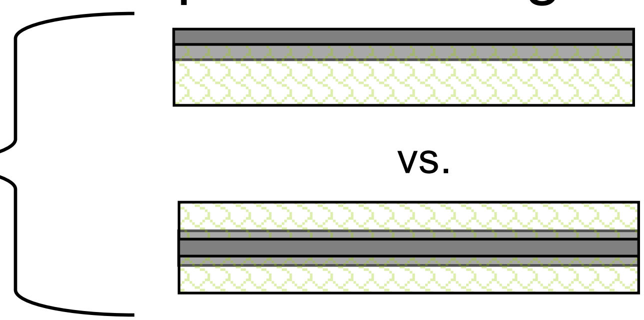


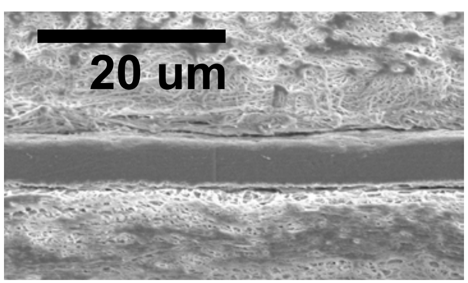
- **Modules: Optimize flow field, pleat geometry and module design to take advantage of very high transport rate materials, while maintaining low-cost assembly process**

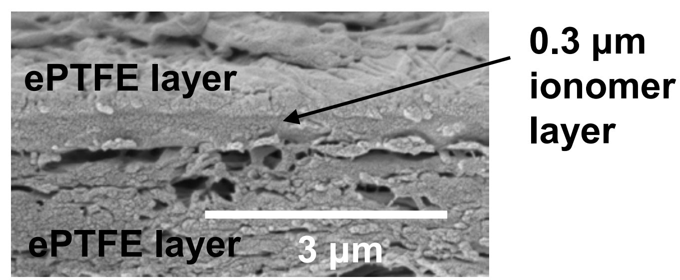


Technical Accomplishments
Task 1: Materials Preparation

- Wide range of materials made and tested including variations in:
  - ✓ PFSA ionomers with various equivalent weights
  - ✓ Hydrocarbon ionomers
  - ✓ Laminate structures
  - ✓ Microporous supports
  - ✓ Ionomer layer thickness

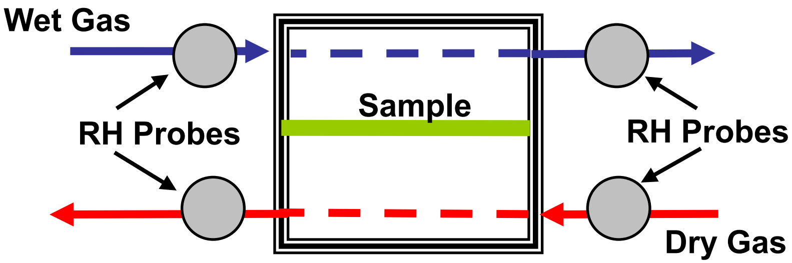


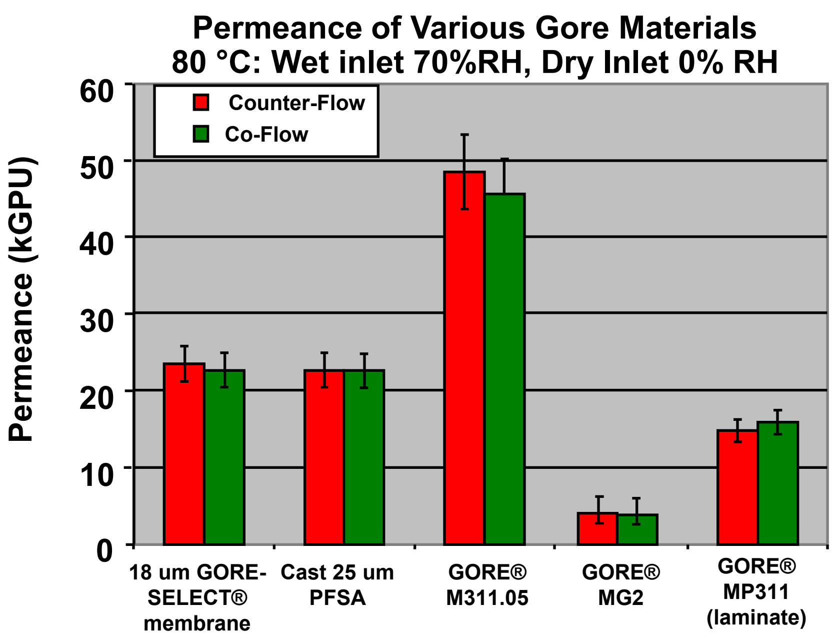




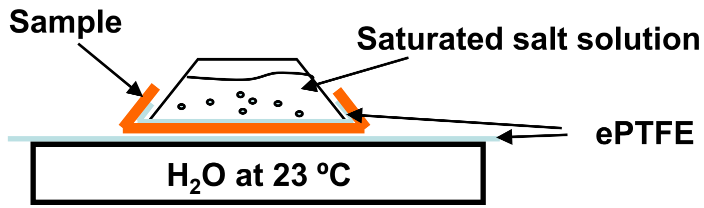
Technical Accomplishments
Task 2: Water Transport Measurements

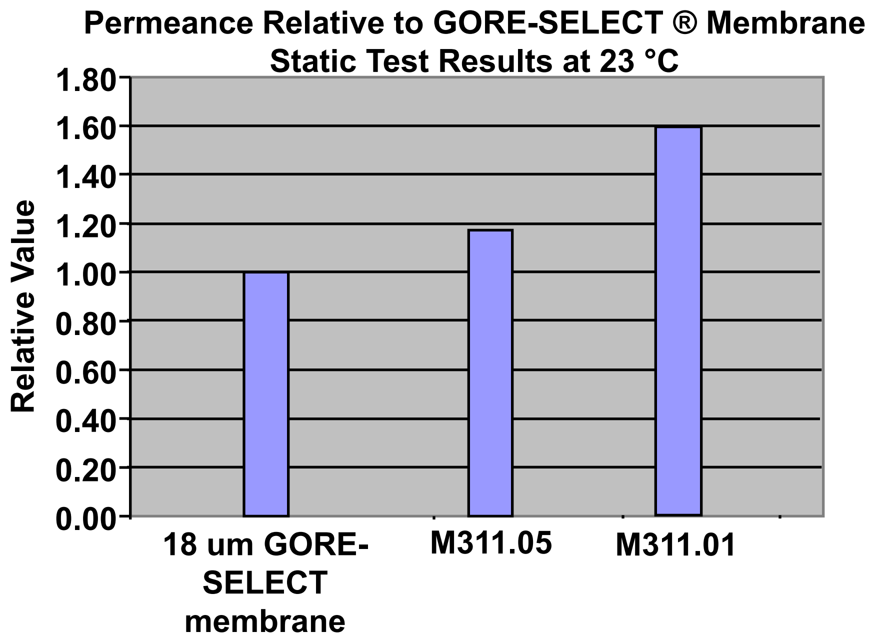
Permeance: Dynamic



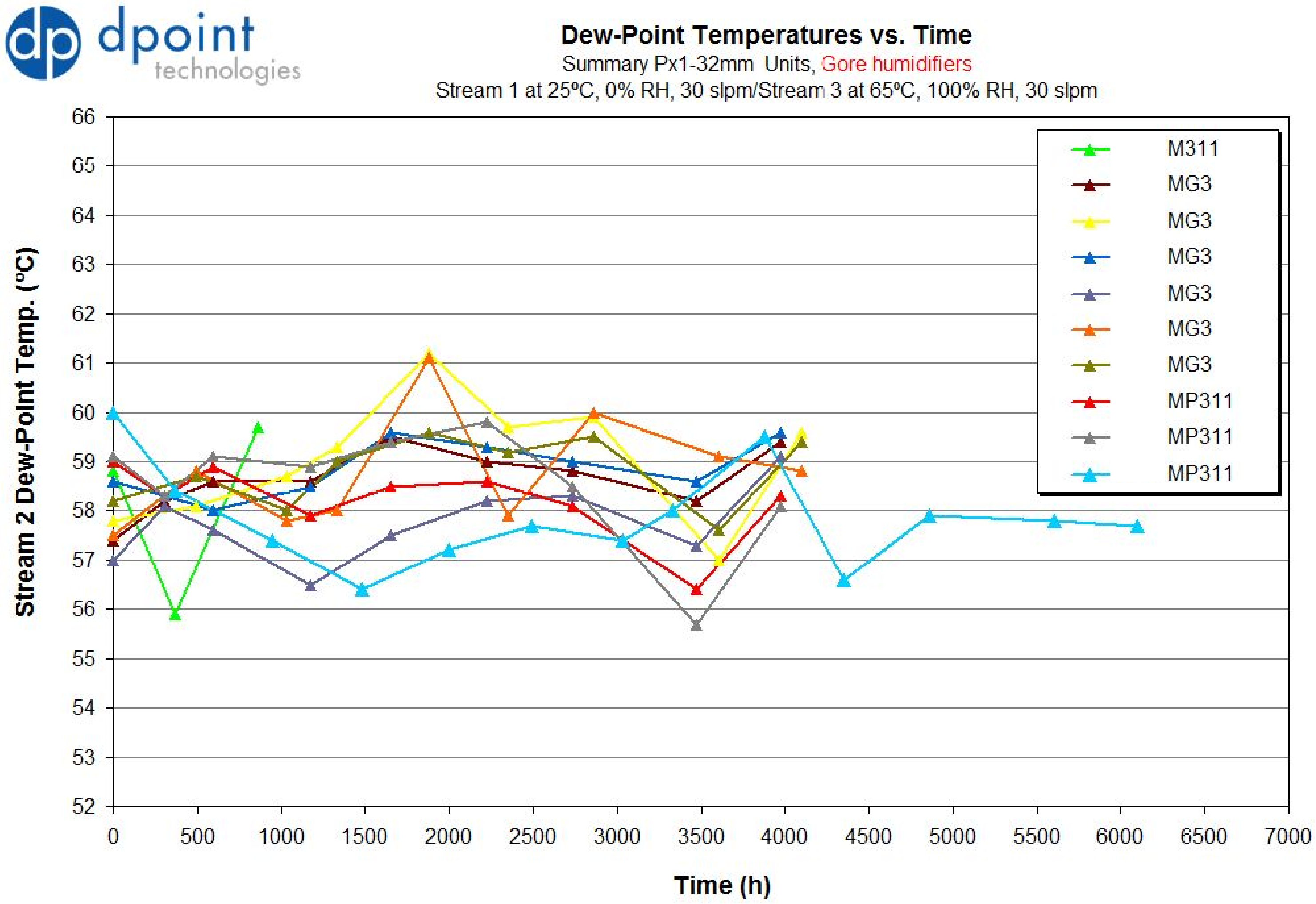


Permeance: Static

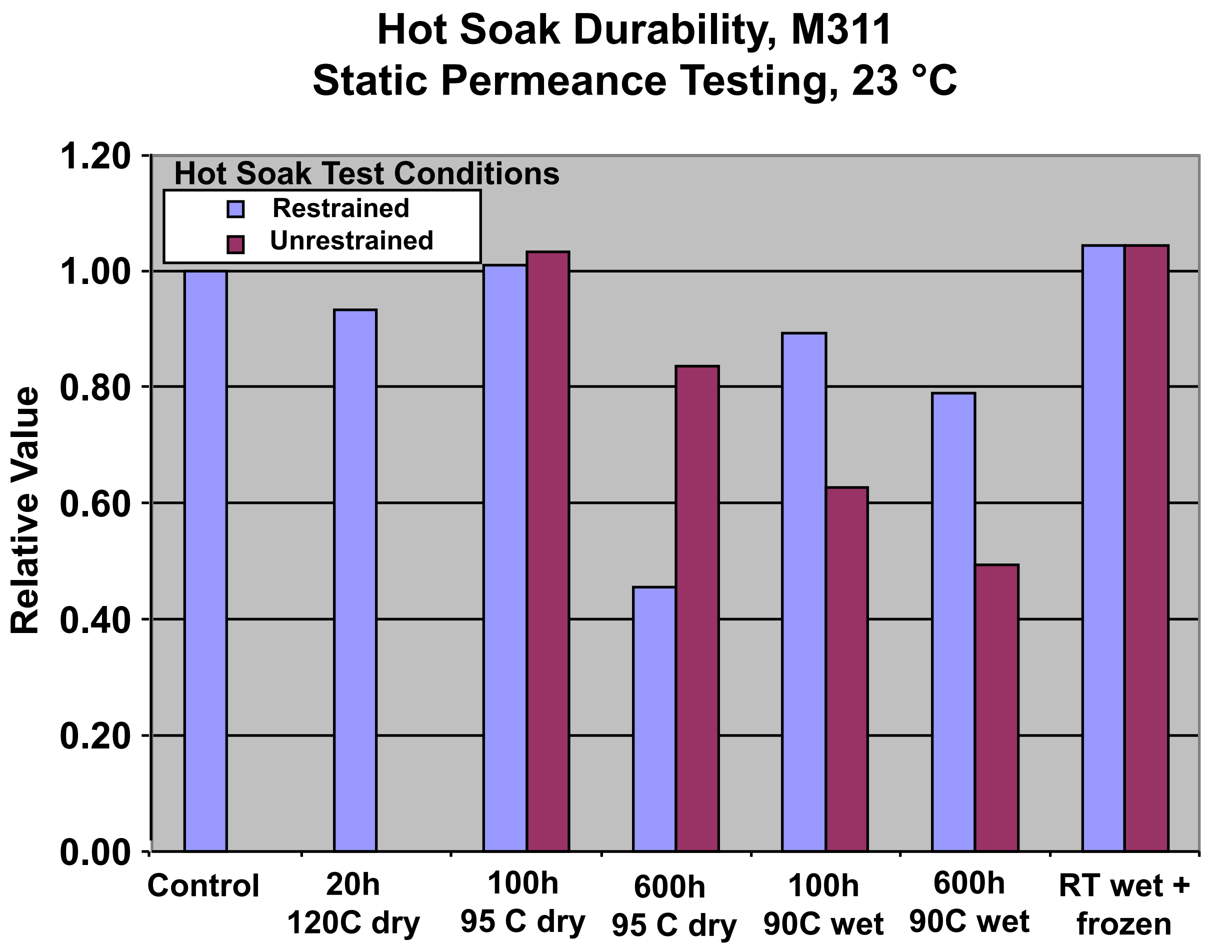




Technical Accomplishments
Task 2: Membrane Durability Testing

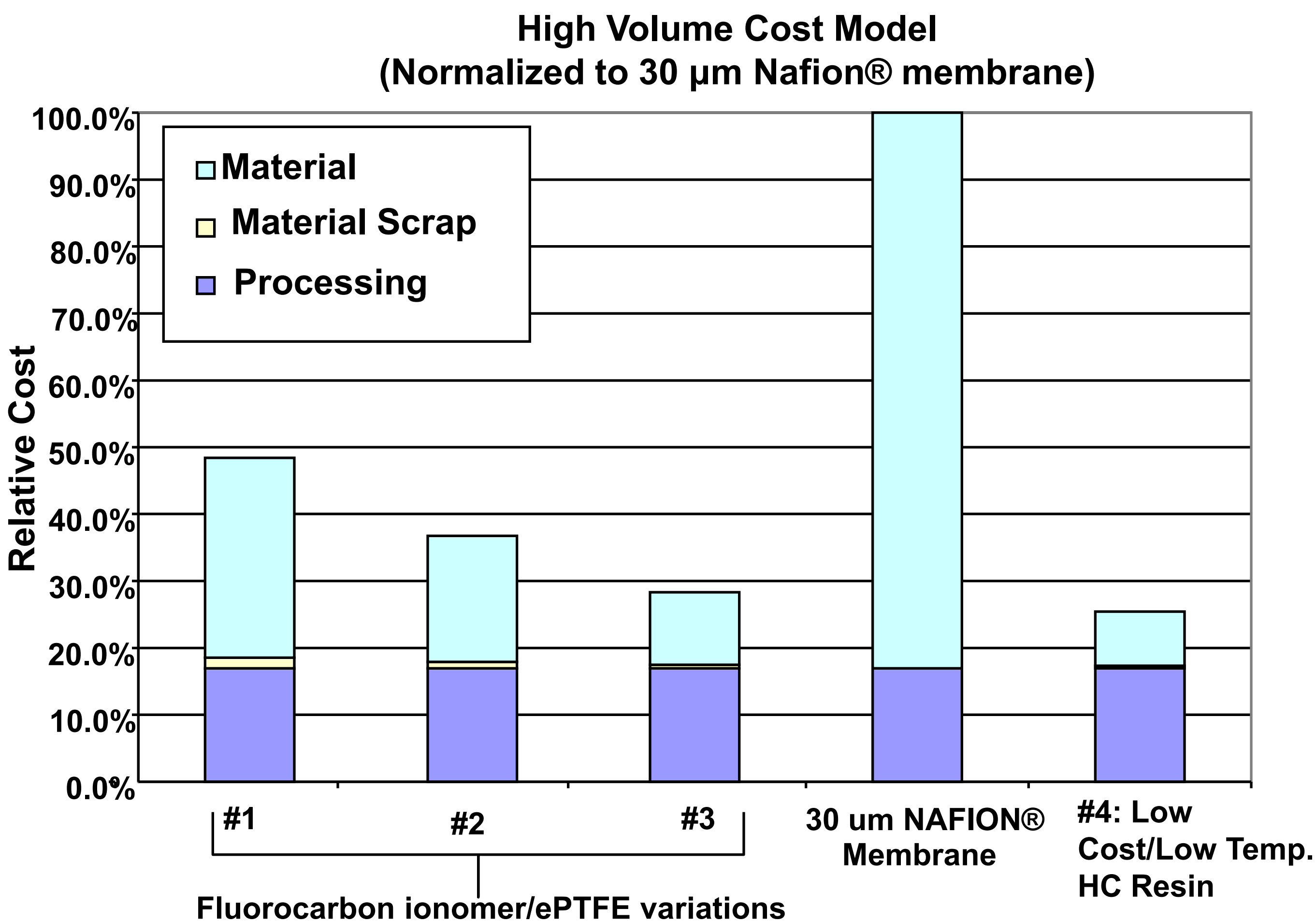


Technical Accomplishments
Task 3: Membrane Durability



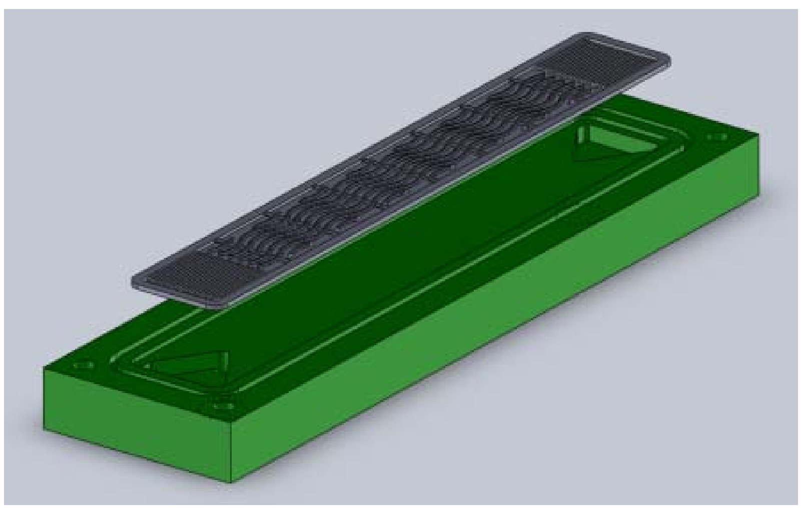
Note: All membranes were air impermeable before and after testing.

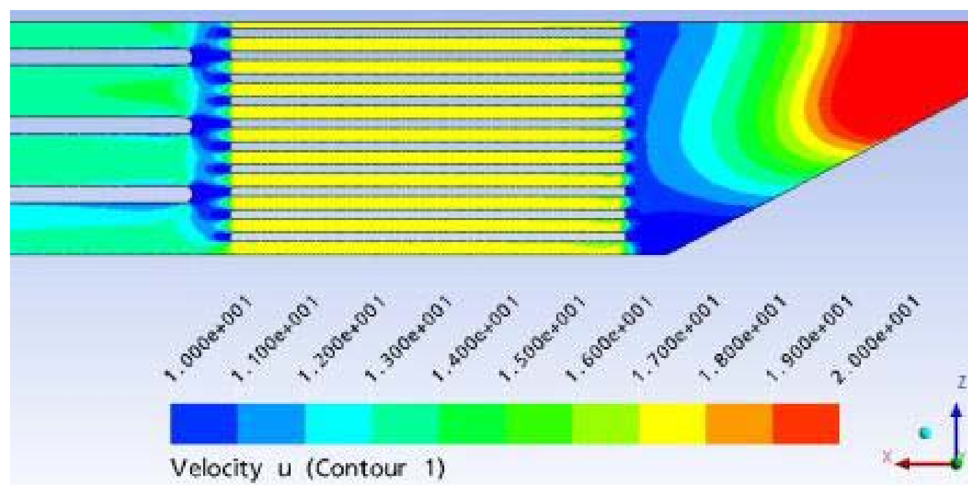
Technical Accomplishments
Task 3: High Volume Membrane Cost Estimates



Technical Accomplishments
Task 4: Module Design, Development and Testing

- Analysis of dpoint PX, DX designs, and ERV's, heat exchangers, literature review, heat and humidity design consultants, and brainstorming yielded ~40 module concepts that could meet cost and transport targets.
- CFD modeling, and results from small prototype builds using 10 different flow fields leads to following conclusions:
  - ✓ Small linear channels yield the best transfer per pressure drop than any other option.
  - ✓ Small pitches make volume requirements easier to meet.
  - ✓ Cross-flow designs has many desirable features, and fewer drawbacks than other design alternatives.





Technical Accomplishments
Task 4: Module Design, Development and Testing (cont)

- Currently constructing our first cross flow humidifier module
  - ✓ Subscale, 10 cm square, 0.8mm pitch, 40 layers, 0.4 m^2 membrane.
  - ✓ Preliminary flow field testing at 80 °C/75%RH on this design shows promising results.
  - ✓ Based on limited single cell testing, membrane area of ~1.3m^2 required for full scale module flow and transfer requirements.

Collaborations

- **Subcontractor**
  - dPoint Technologies
    - Design and build low-cost module using new membrane
- **Partners providing Input at no cost**
  - ✓ Automotive OEMs have provided data on conditions
    - GM, Ford, Daimler, Volkswagen, etc. under NDA
  - ✓ Argonne National Laboratory modeling of Gore membranes in humidifier modules.
  - ✓ General Motors Corp. – effect of contamination on water transport behavior of Gore membranes.

Future Work

- **Membrane materials and testing**
  - ✓ Extend static testing to 80 C for QC and to increase test throughput.
  - ✓ Continue durability testing: hot soak, RH cycling, and contamination.
  - ✓ Down-select to primary membrane composition and type and scale-up to m^2 manufacturing
- **Module Design, Build and Testing**
  - ✓ Refine and test initial module designs
    - Built at smallest manufacturable pitch with short channels.
    - Available pressure drop will be used to generate mixing within flow or increase footprint, increasing performance.
    - Use rapid prototype plates to speed design iterations.
  - ✓ Module cost models using inputs from Gore on membrane cost.
  - ✓ Build one full scale module with best membrane and module design.

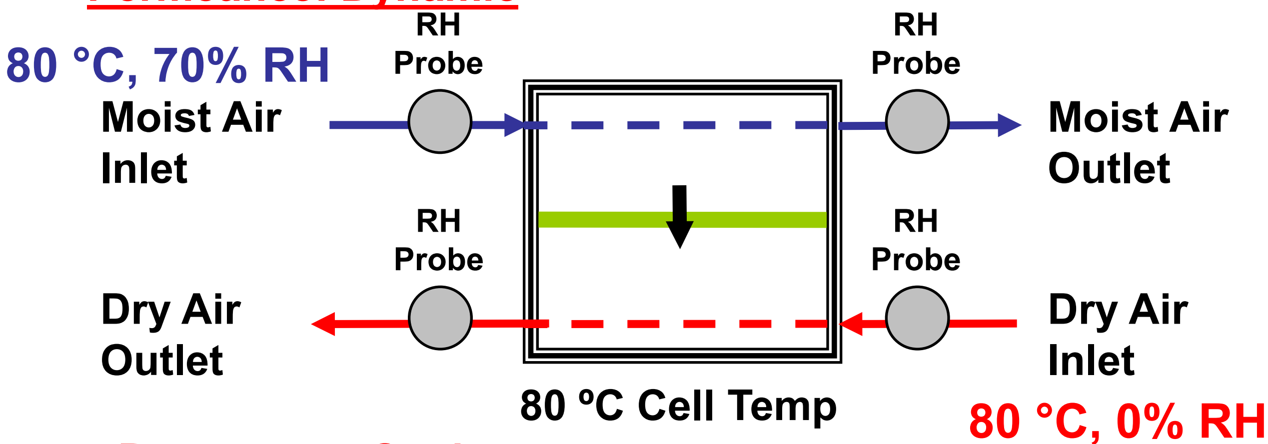
Project Summary

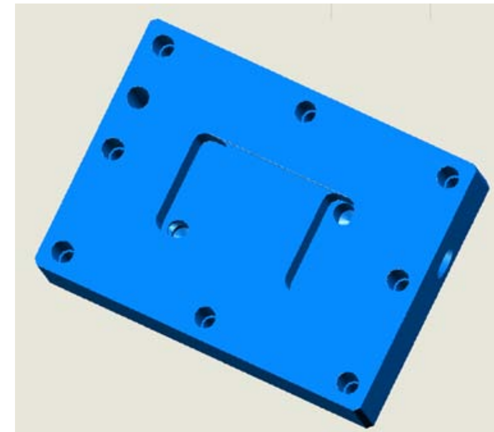
Objective:	Durable, high performance water transport membrane; and a compact, low-cost, membrane-based module
Relevance:	Reduce system cost and size of balance of plant, AND improve fuel cell performance.
Approach:	Utilize unique new gore membranes in modules optimized for high performance and low cost.
Technical Progress:	➢Wide range of new composite membranes prepared and tested. ➢New high throughput water transfer test developed. ➢Initial durability testing completed, little performance degradation seen at 65 C ➢Initial module design and prototyping activity has yielded a design that appears capable of meeting all the module criteria. ➢High volume membrane cost estimates should be low enough to allow team to meet $150 high volume module target.
Collaborators:	➢dPoint (partner in testing and module design and build). ➢Argonne National Laboratory (No cost collaborator in system modeling). ➢GM (No cost collaborator in effect of contaminants on transport behavior).
Future Work:	➢Complete durability testing. ➢Down select final membrane material. ➢Module cost modeling. ➢Finish preliminary module design and test, build final full scale module.

Technical Back Up Slides

Testing Protocol

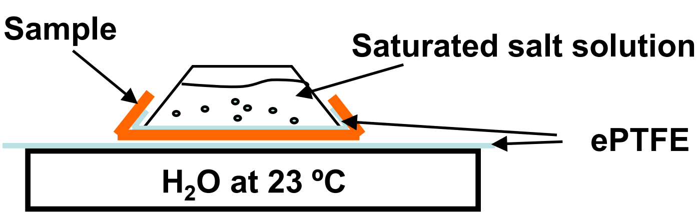
Permeance: Dynamic





Permeance: Static

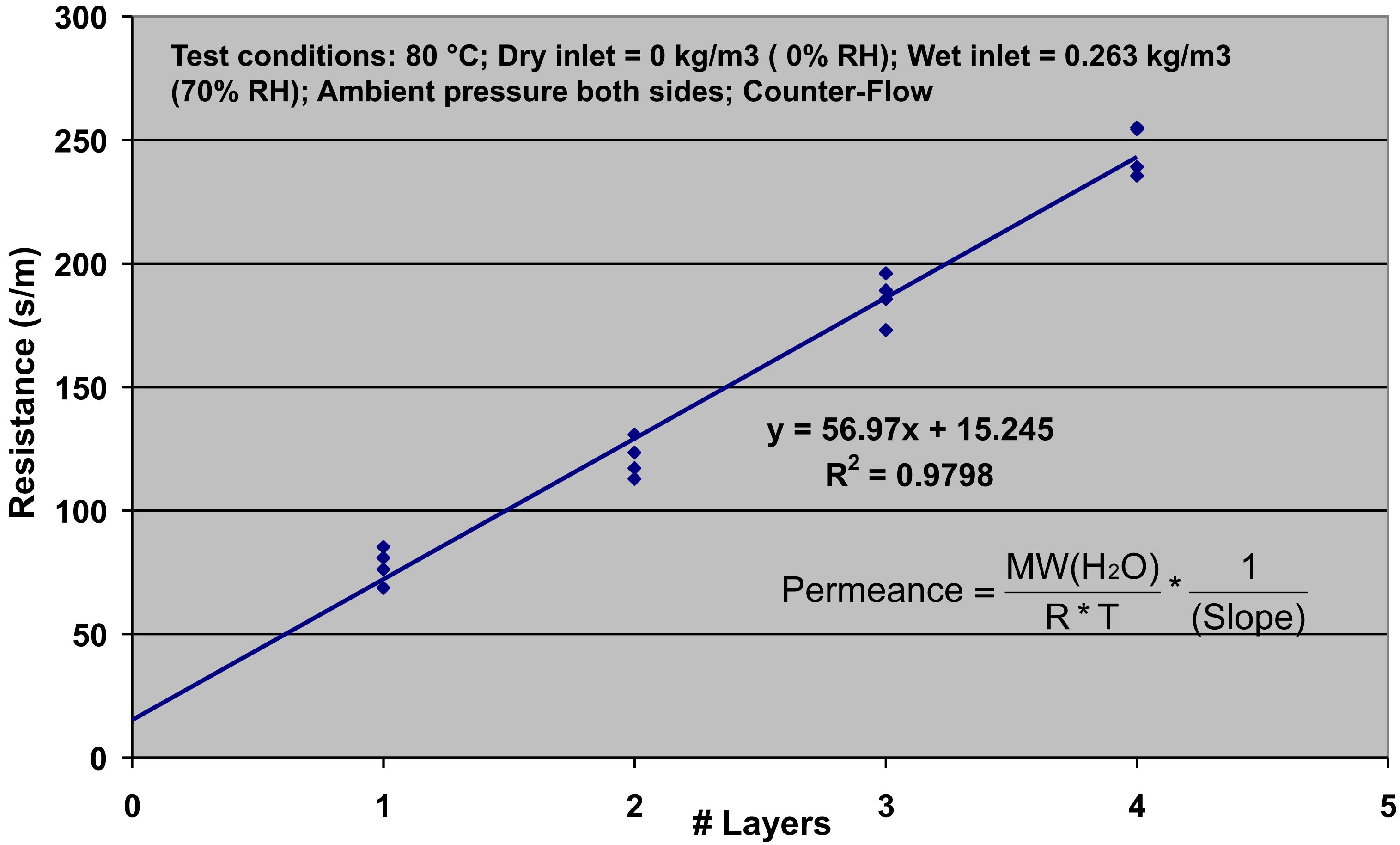
Modified version of ISO Standard 15496



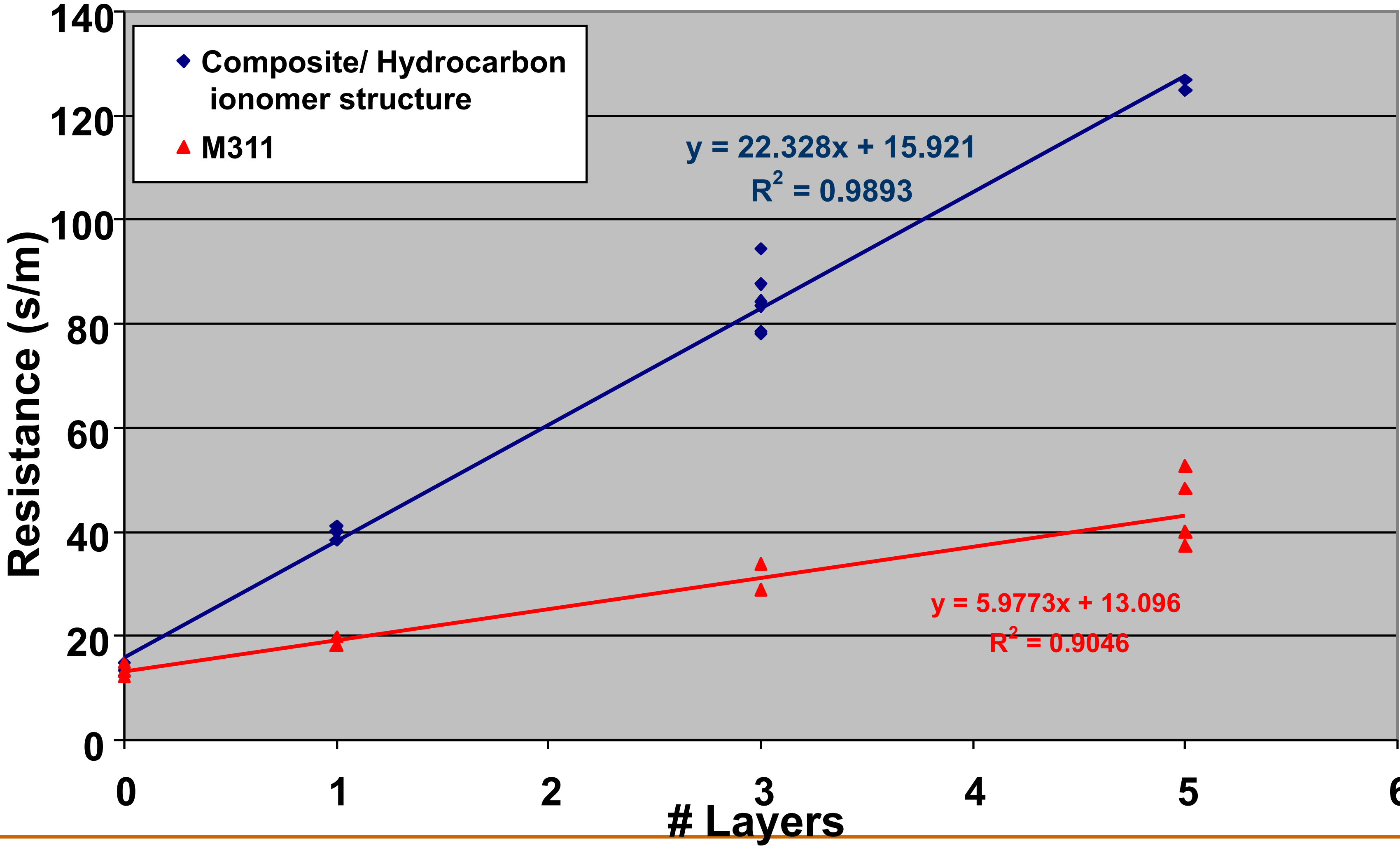
Permeance is a pressure normalized flux:
(kg/m^2-s-Pa)
or
$cm^3(H_2O)$@STP/cm^2-s-cm Hg) ≡ 10^6 GPU

J = Flux = MVTR (kg/m^2-s) $\propto$ Mass(H_2O) in dry outlet

Sample Data GORE-SELECT® Membrane Dynamic High Temperature Test



Permeance from Static Room Temperature Test (Modified ISO 15496 Protocol)



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Initial Correlations
Dynamic vs. Static Testing

	Static Result	Dynamic Result
Permeance(M311)*	203100 Ñ 25400	14750 ± 30700
Test Conditions	23 °C	28 °C
RH Wet	100%	----
RH Dry	23%	----
Delta RH	77%	57%

* Error bars are 95% confidence intervals

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Why are RT Permeance Values higher than high temperature values?

$$\text{Permeance} = \frac{\text{MVTM}}{\Delta P(H_2O)} \sim \frac{D(H_2O)}{P_{vap}} \sim \frac{\exp(Ea/RT)}{\exp(\Delta H_{vap}/RT)}$$

ΔH_{vap} = 41 kJ/mol

E_a ~ 20 kJ/mol for $D(H_2O)$ in PFSA

→ As T↓, P_{vap}↓↓ and D(H2O)↓, so Permeance↑