New High Performance Water Vapor Membranes To Improve Fuel Cell Balance of Plant Efficiency and Lower Costs

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Project ID # FC148

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Overview of Current Project

Timeline

- Start: July 28, 2015
- End: July 27, 2017
- Phase IIB Effort Complete: 90%

Barriers

- Performance – stack water management
- Mechanical Durability
- Cost

Budget

- Total Phase IIB project funding
  - DOE share: $999,994
  - Contractor share: $500,000
- Funding received in FY 16:
  - $466,533
- Total funding planned for FY17:
  - $533,461

Partners

- Dana Holding Corporation
- General Motors
- Membrane Technology Research

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Relevance to DOE

Design and develop high performance, low cost water vapor membrane for cathode humidification

DOE Barriers	2020 DOE Cathode Humidification System Targets	Tetramer Targets Year 1	Tetramer Targets Year 2
Performance	• Maximum Operating Temperature >95 °C • Maximum Pressure differential 75 kPa • System water transfer at full flow = 5 g s^{-1}	• Maximum Operating Temperature ≥100 °C • Maximum Pressure differential 75 kPa • System water transfer at full flow = 5 g s^{-1}	• Maximum Operating Temperature ≥120 °C • Maximum Pressure differential 75 kPa • System water transfer at full flow = 5 g s^{-1}
Durability	• 5000 hours with < 10% drop in performance	• 2000 hours with < 20% drop in performance	• 5000 hours with < 10% drop in performance
Cost	• \$10/m^2 at 500,000 systems per year	• ≤ \$20/m^2 500,000 systems per year	• ≤ \$10/m^2 500,000 systems per year

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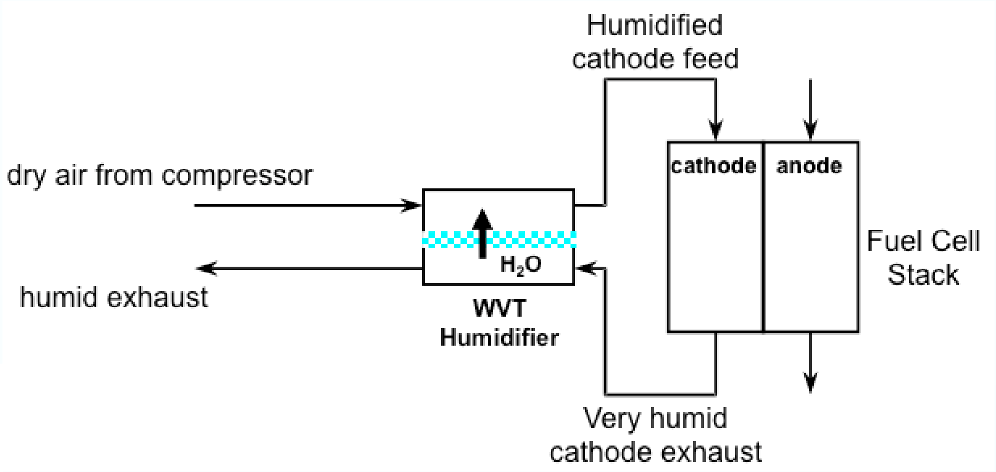
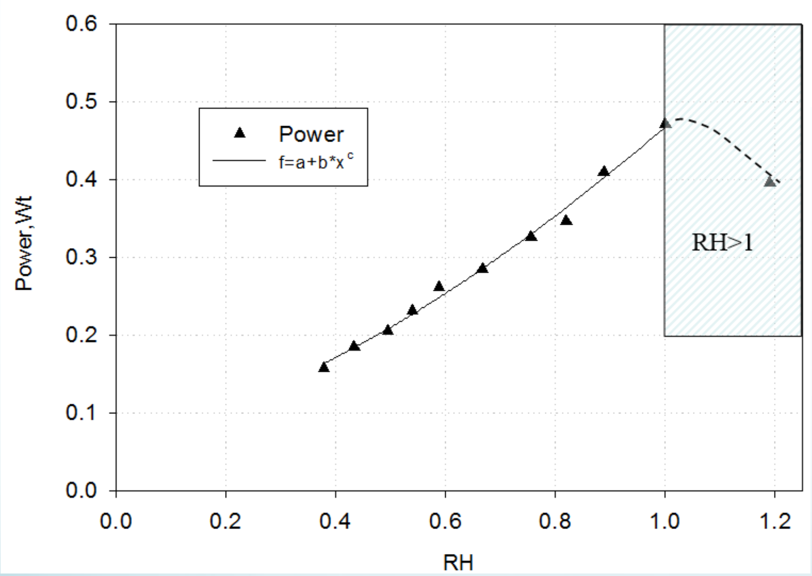
Relevance and Motivation

Fuel cell PEMs are more durable and perform more efficiently at higher hydration levels.





Water Vapor Transport (WVT) unit transfers moisture that is formed from fuel cell reactions within the stack from the cathode exhaust to the feed.

More efficient, low-cost humidifiers that recycle the water generated from cathode effluent both increase performance and lower balance of plant costs.

Size of fuel cell stack can be decreased by running under wetter conditions.

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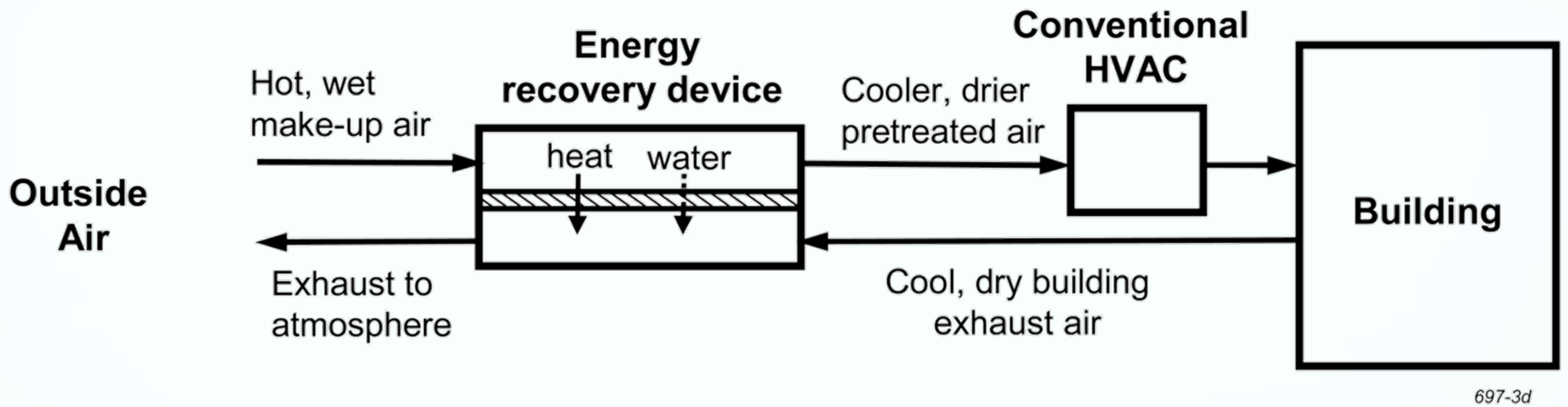
Relevance-HVAC Energy Savings



- On a summer day in the South Carolina midlands and coastal plains, two thirds of the total energy costs for air conditioning are attributable to moisture removal.
- A membrane dehumidifier decreases the compressor load on a conventional air conditioning system, resulting in energy savings of up to 40%.
- Large, shorter term accessible market will increase volume and lower the cost of the membrane for fuel cell applications.

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Approach – State of the art

Current state of the art FC Automotive Cathode Systems have either:

- No Humidification
- Tubular Humidification
- Planar Humidification (in development)

Humidification Advantages:

- Increased FC stack Power Density
- Increased FC stack Durability

Humidification Perceived Disadvantages:

- Costly as a unit
- Large (additional part in system)
- Potential Failure Item

Approach – Tetramer WVT Membranes

- High RH% to cathode provides durability to the FC stack Membrane and can act as a contamination filter
- Recent Market Want:
  - Increasing the Fuel Cell Stack Temperatures benefit the size/cost of the Fuel Cell stack and front end module if cathode RH is sufficient.
  - Fan Power and Rad Size can be reduced by 30% by increasing FC stack temperature from 80 °C to 90 °C making a smaller front end thermal package
- Challenges for the Humidifier Membrane:
  1. High water transfer Flux is required by the membrane at higher temperatures
  2. All materials in the humidifier need to compatible and durable with hotter environment
  3. Membrane needs to be durable and have a low leakage to reduce parasitic power losses while surviving the 500 hour accelerated or 5000 hour non-accelerated durability

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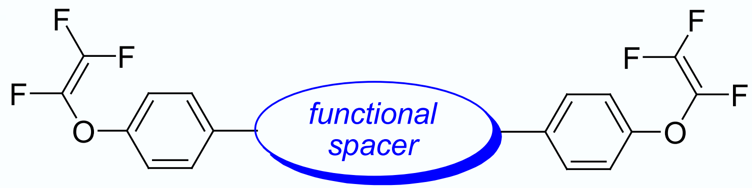
Approach: New PFCB Polymer Technology

versatility • processability • performance

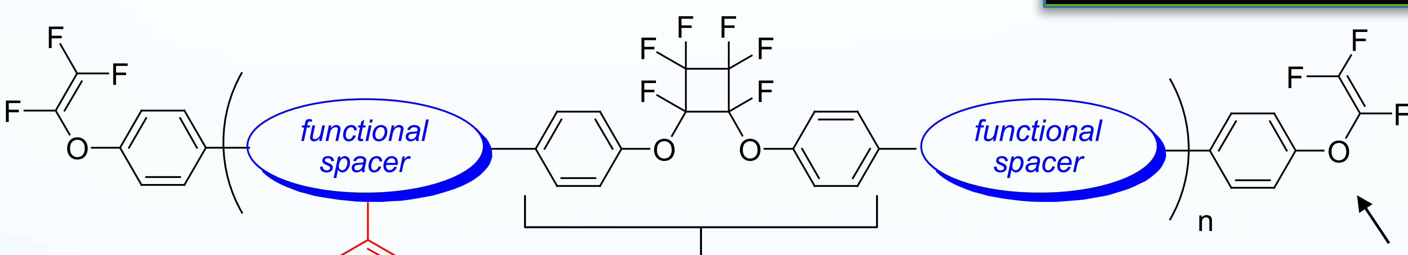
thermal activated trifluorovinyl ethers →

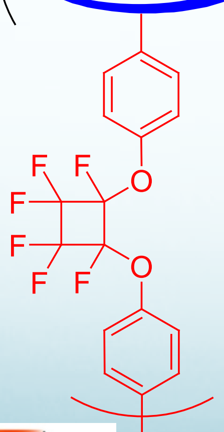


melt or solution polymerization

functional spacer

Linkages can provide elastomeric, water transport, chemical resistance, crosslinking, gas transport management, etc. functionality





tailored branching and crosslinking

PFCB linkage: Fluoropolymer / polyarylene ether performance
(cis/trans) → processability / amorphous

Intact latent reactivity for solution or melt post-process cure

250°C cure producing durable, high T_g transparent thermoplastic or thermoset (T_g 120-300°C, T_d 400°C)

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Approach – Tetramer WVT Membranes

Polymer Design Elements

Design proprietary polymer architectures which provide multiple water transport paths while mitigating or eliminating degradation pathways.

BLOCK A	BLOCK B	BLOCK C	BLOCK D
Water Permeability	***Mechanical Strength***	***Processability***	**Stability**
Hydrophilic groups, Ionic or Intermolecular attractions	Rigid structures Hydrophobic linkages	Stereoisomeric structures, Solubilizing groups	Chemical resistance, Crosslinking

Optimize our polymer molecular architecture and film formation processes to extend durability, optimize the membrane support and sealing system, optimizing and scaling up the manufacturing process, and work closely with Dana Holding Corporation to build a cost effective prototype fuel cell humidifier satisfying any global auto manufacturer's demands.

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Phase IIB Achievements

- Proprietary polymer architectures which provide multiple water transport paths while mitigating or eliminating degradation pathways were produced.
- Hydrophilic / Hydrophobic Tuning to ensure performance is met while durability of the membrane is kept
- Over 32 polymer structures have been explored for trade-offs to understand
- Over 100 membranes have been made
- 3 Successful roll coating trials
- Prototype was made and given to OEM for testing

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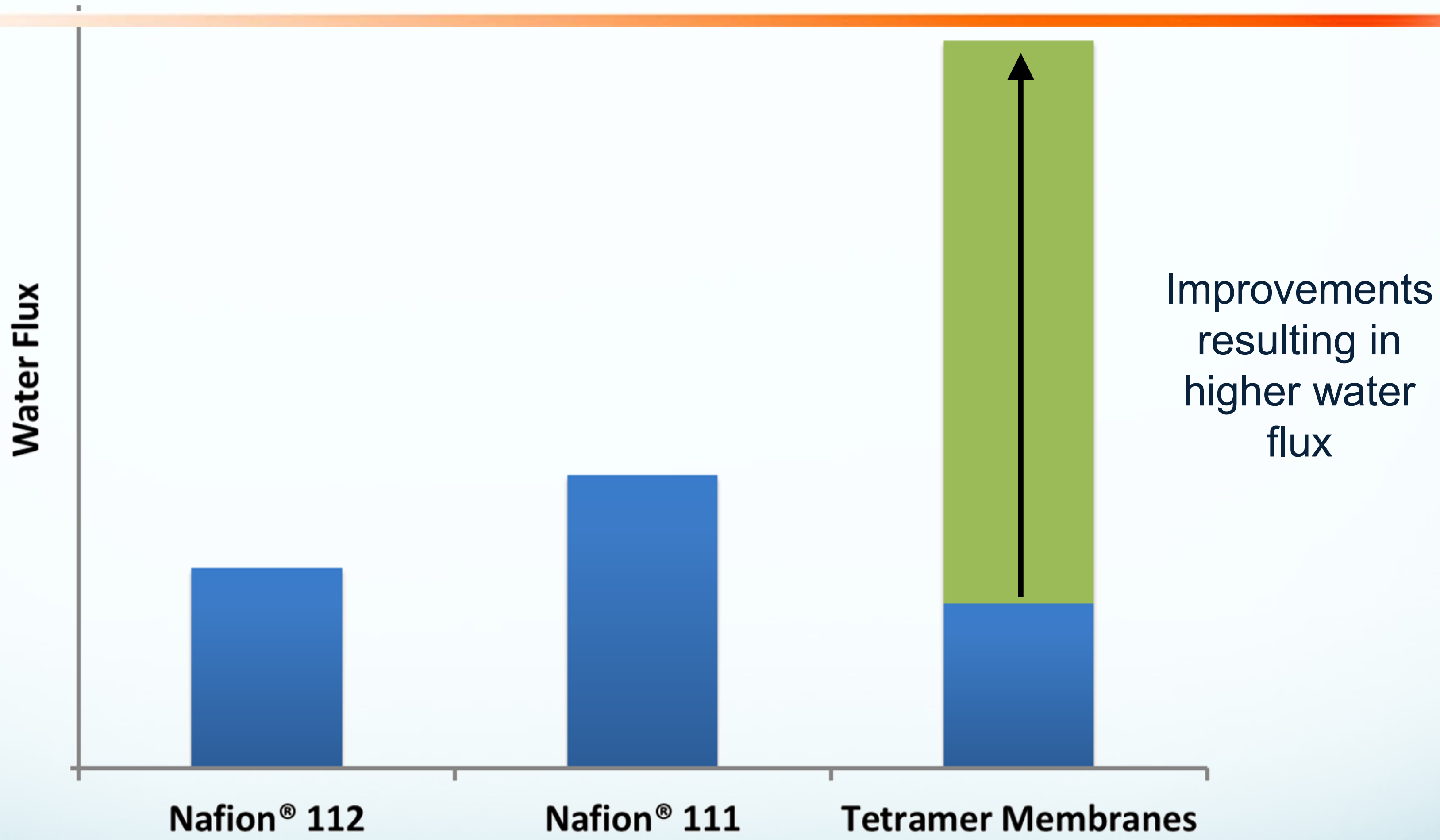
WVT Technical Accomplishments: Water Vapor Membranes Versus Competition



- Tetramer WVT membranes showed high water vapor gas permeation. These materials exceeded current commercial materials.

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WVT Technical Accomplishments

- RECENT TESTING OF TETRAMER WVT MEMBRANES BY INDUSTRIAL PARTNERS UNDER VARYING REAL WORLD COMMERCIAL CONDITIONS LOOK PROMISING vs. COMPETITOR MEMBRANES

- INDUSTRIAL PARTNER TESTING HAS EXPANDED TO INVOLVE SIGNIFICANTLY HIGHER TEMPERATURES THAN DOE TARGETS RANGING FROM 80 ^{o}C TO >120 ^{o}C.

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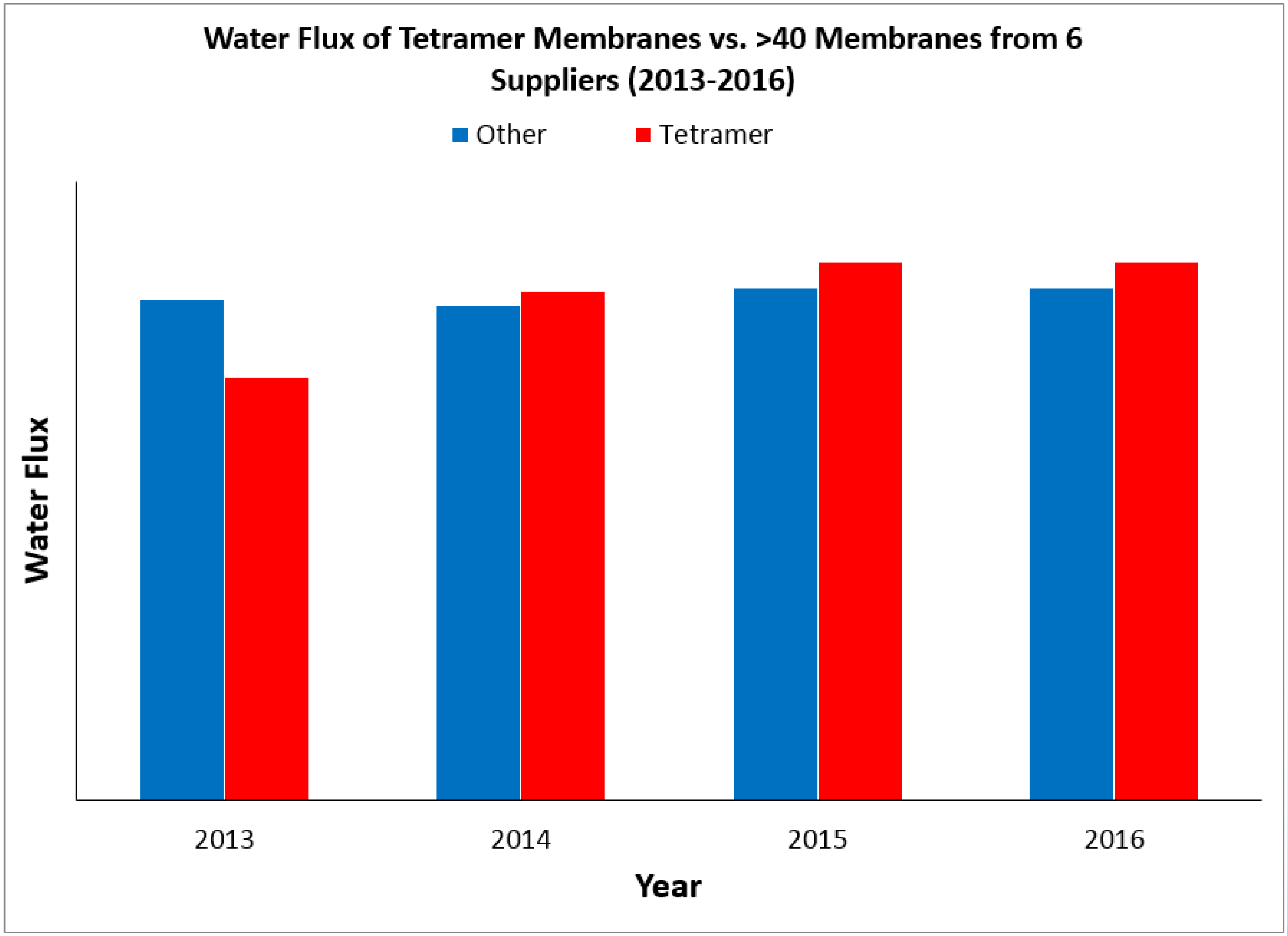
PHASE IIB COMPARISON OF TETRAMER'S MEMBRANES *vs* BEST OF COMPETITION



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Accomplishments - Phase IIB Results vs Performance Targets

Our Phase IIB specific targets are designed to produce a commercial product having the following specifications:

	Performance Targets	Results vs Targets
DOE Target	1) System water flux at beginning of life performance of 5.0 g s^{-1} for 80kW FC flow rates at 80 °C cathode inlet temperature	1) Currently at >5 g s^{-1} @ 80 °C with 2 m^2 membrane in system ✓
Market Adjusted Target	1) System water flux at beginning of life performance of 5.0 g s^{-1} for 80kW FC flow rates at 120 °C cathode inlet temperature	1) Currently at >7 g s^{-1} @ 120 °C with 2 m^2 membrane in system ✓
DOE Target & Market Adjusted Target	2) Crossover leak rate of < 10 ccm/m^2 at beginning of life and < 100 ccm/m^2 at end of 500 hr accelerated test	2) Currently at < 10 ccm/m^2 at beginning of life and < 100 ccm/m^2 at end of 500 hr accelerated test ✓

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Accomplishments - Phase IIB Results vs Performance Targets

Our Phase IIB specific targets are designed to produce a commercial product having the following specifications:

	Performance Targets	**Results vs Targets**	
DOE Target	3) Water Flux Durability – After 500 hours demonstrate < 10% water flux loss under DOE conditions (80 °C)	3) <1% loss in water flux after 500 hours at (80 °C)	✓
Market Adjusted Target	3) Water Flux Durability – After 500 hours demonstrate <10% water flux loss after 5 point cyclic high stress (120 °C) accelerated testing	3) Currently at 27% loss after 500 hrs with a 5 point cyclic high (120 °C) stress accelerated test	✗
DOE Target & Market Adjusted Target	4) Scale-up metrics consisting of 3 lots each with less than 5% variation in water flux	4) Successfully scaled-up 3 lots with less than 5% variation in water flux	✓

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Accomplishments - Phase IIB Results vs Performance Targets

Our Phase IIB specific targets are designed to produce a commercial product having the following specifications:

	Performance Targets	Results vs Targets
DOE Target & Market Adjusted Target	5) Prototype demonstration at Dana Holding targeted to the automotive fuel cell market	5) Prototype manufactured at Dana and delivered to customer and on test at OEM ✓
DOE Target & Market Adjusted Target	6) Prototype HVAC demonstration membranes in commercial manufacturing process	6) Currently in discussion with commercial HVAC membrane suppliers IN PROGRESS
DOE Target	7) Material cost target of $10/m^2$ at high production volumes	7) Membrane cost <$15/m^2$ at 500,000 systems per year ✗
Market Adjusted Target	7) Material cost target of $15/m^2$ at high production volumes	7) On target for <$15/m^2$ at 500,000 systems per year ✓

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Collaborations

Partners

- **Dana Holding Corporation (Industry)** has participated in testing and qualification of membrane materials according to automotive specifications.
- **General Motors (Industry)** has been a strong partner for over 5 years and has been very active in testing our materials
- **Membrane Technology Research (Industry)** has participated in membrane testing.

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Future Work for Phase IIB

- Continue durability testing
- Determine prototype longevity with customer
- With Dana Holding Corporation determine market demand for fuel cell humidification.
- Determine value proposition for HVAC membrane
- Any proposed future work is subject to change based on funding levels.

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Water Vapor Membrane Development Summary

Relevance – Need still exists for improved low cost water vapor membranes for cathode humidification modules of fuel cells and HVAC applications.

Approach – Tetramer's new synthetic approach for new polymer molecular architectures has been validated as shown by increased water vapor transport.

Technical Accomplishments – Detailed on previous slides. New monomers and polymers were successfully synthesized which have shown improved water vapor transport and represent a best in class performance at temperatures above 120 °C.

Collaborations – Partners in place to evaluate polymers and build prototype modules with down selected materials.

Future Work – Evaluate Prototype results and feedback to customer. Market analysis is needed to determine commercial demands.

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Publications and Presentations

None to date

Response to Previous Year Reviewers' Comments

Not reviewed last year

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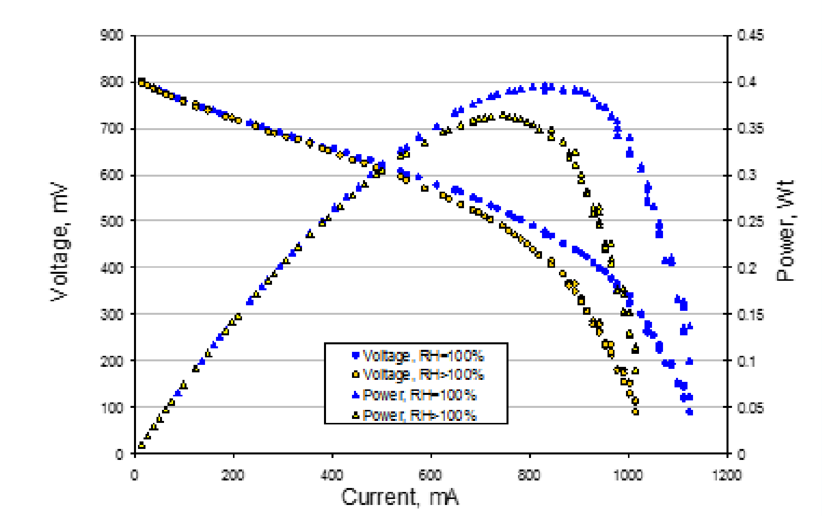
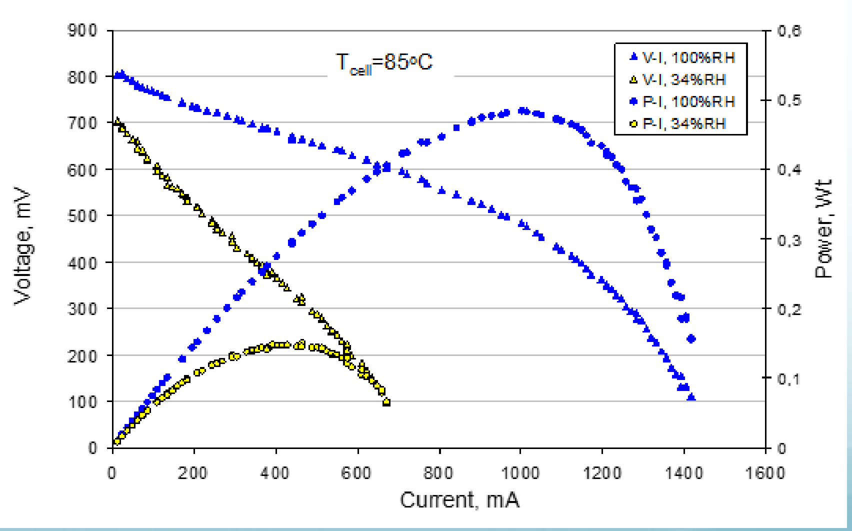
Backup Slides

Fuel Cell Humidification Need





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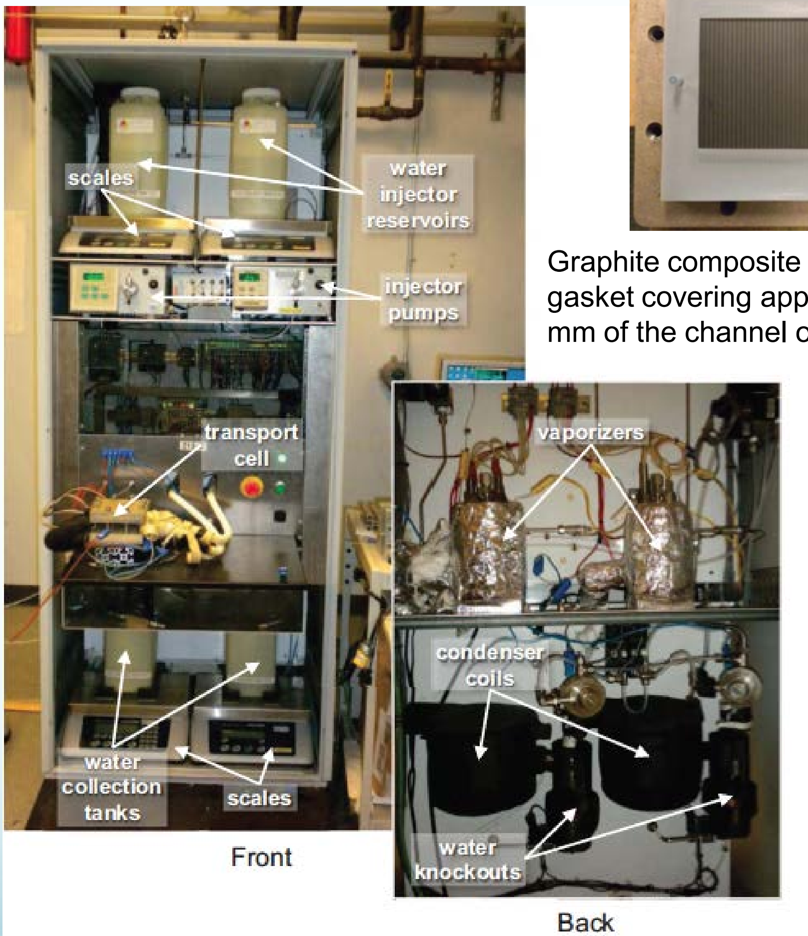
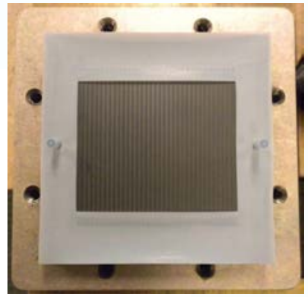
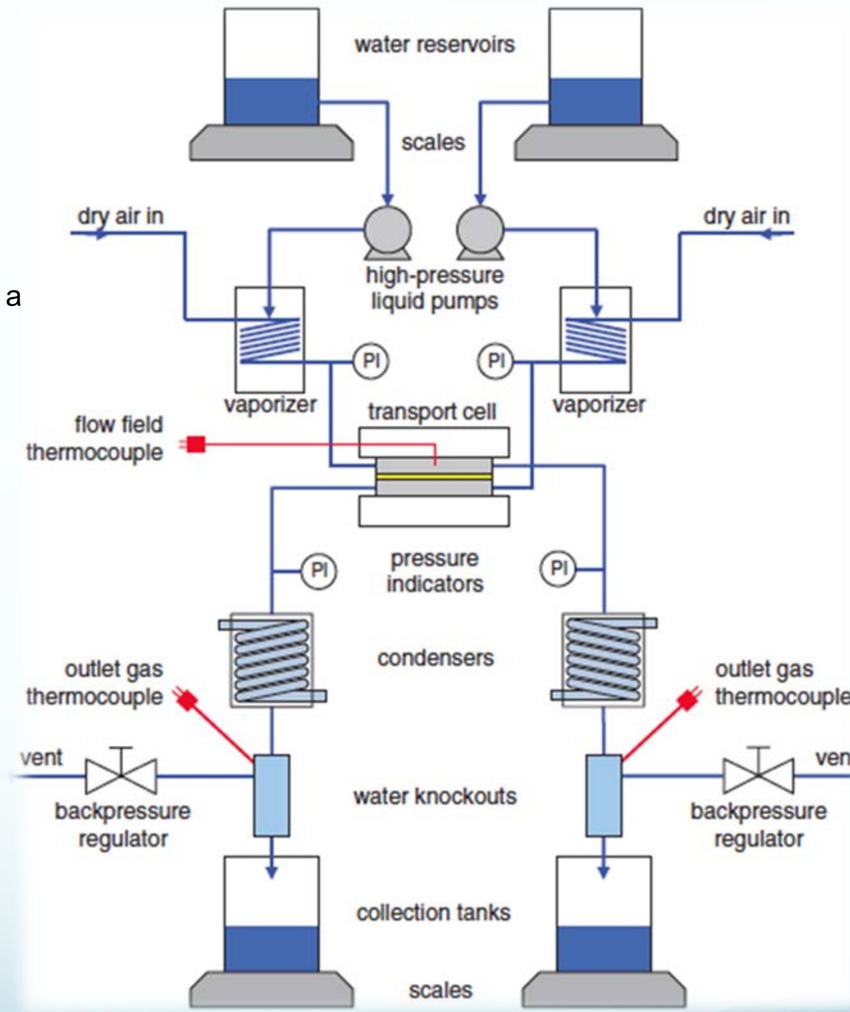
Water Vapor Test Stand



Photographs of the test stand showing the location of various components



Graphite composite flow field with a gasket covering approximately 5 mm of the channel on either end



Schematic illustration of the test stand components

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Journal of The Electrochemical Society, **159** (9) F518-F59 (2012)

Examples of Test Conditions

Condition	Dry air in				Wet air in			
	Dry gas flow ($SLPM/cm^2$)	Absolute pressure (kPa)	Temp (°C)	RH (%)	Dry gas flow ($SLPM/cm^2$)	Absolute pressure (kPa)	Temp (°C)	RH (%)
DOE Conditions	0.23	183	80	0	0.20	160	80	80
Market Cond. 1	0.13	178	80	0	0.13	146	80	69
Market Cond. 2	0.26	260	99	0	0.23	220	95	80
Market Cond. 3	0.29	246	120	0	0.24	220	95	80

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