High Temperature, High Pressure Electrolysis

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Project PD117

Project Overview

Timeline

- Project Start Date: 2/18/2014 (PI)
- Project End Date: 12/17/2016

Budget

- Fast-track $1.0M
  - Giner $780k
    - $141 k Spent
  - Virginia Tech $370k
    - $81k Spent
    - Contract delayed with passing of J.McGrath

Partners

- Virginia Tech

Barriers Addressed

- Hydrogen Cost $4-5/kg

Technical Targets

Phase I

- 2x Conductivity:Permeability Ratio at end of Ph I

Phase II

- 3x Ratio
- 95°C Operation for 1000 h
  5000 psi operation for 1000 h
- Stack Delivery to DOE (NREL?) at end of PhII

Overall Objective

To reduce cost of PEM Electrolysis for energy storage by improving membranes capable of increasing operating pressure, efficiency and durability

High Pressure Delivery

- Increased Simplicity
- Lower Overall CAPEX

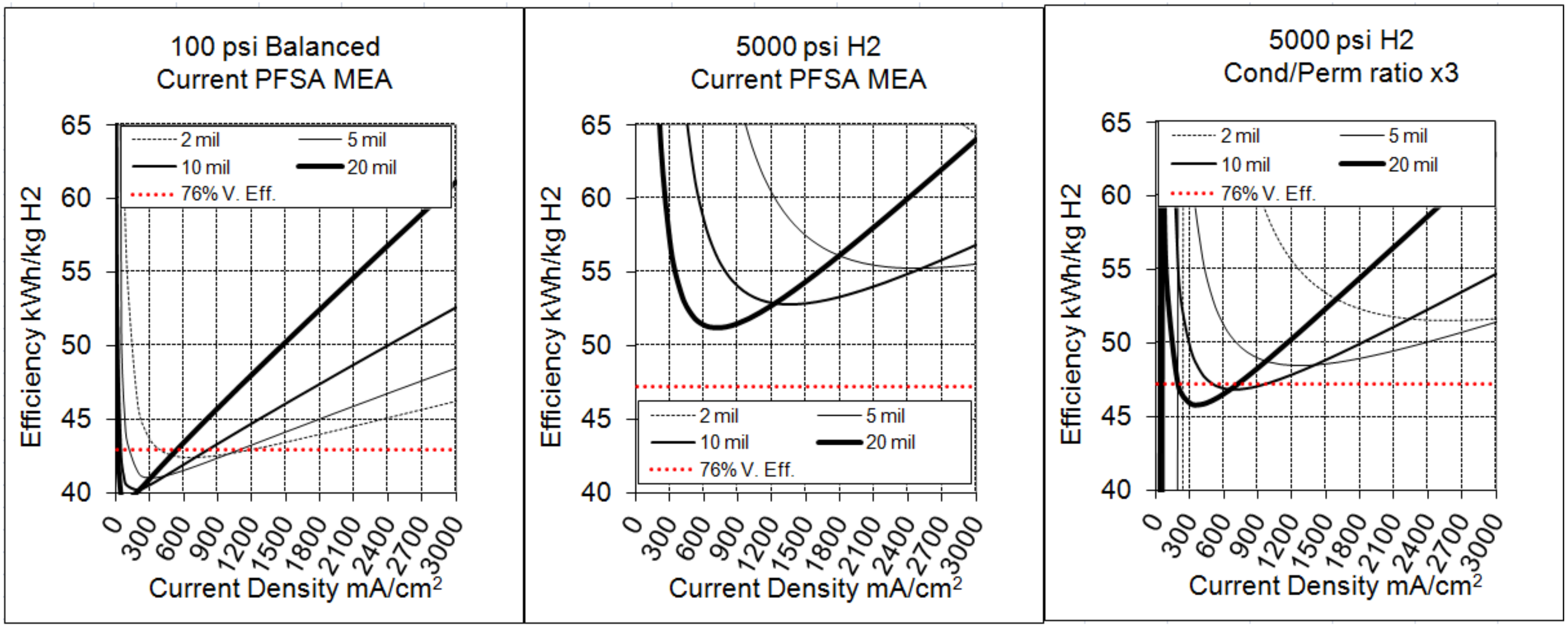
High Temperature Operation

- Higher Efficiency
- Lower OPEX
- Lower BOP

Long-Term Durability

- Lower Maintenance/CAPEX

Relevance: Pressure



Not Possible to have high efficiency at high pressure with current membranes
Increasing ratio is key to having large operating range: Essential for Renewables!

Relevance: Pressure

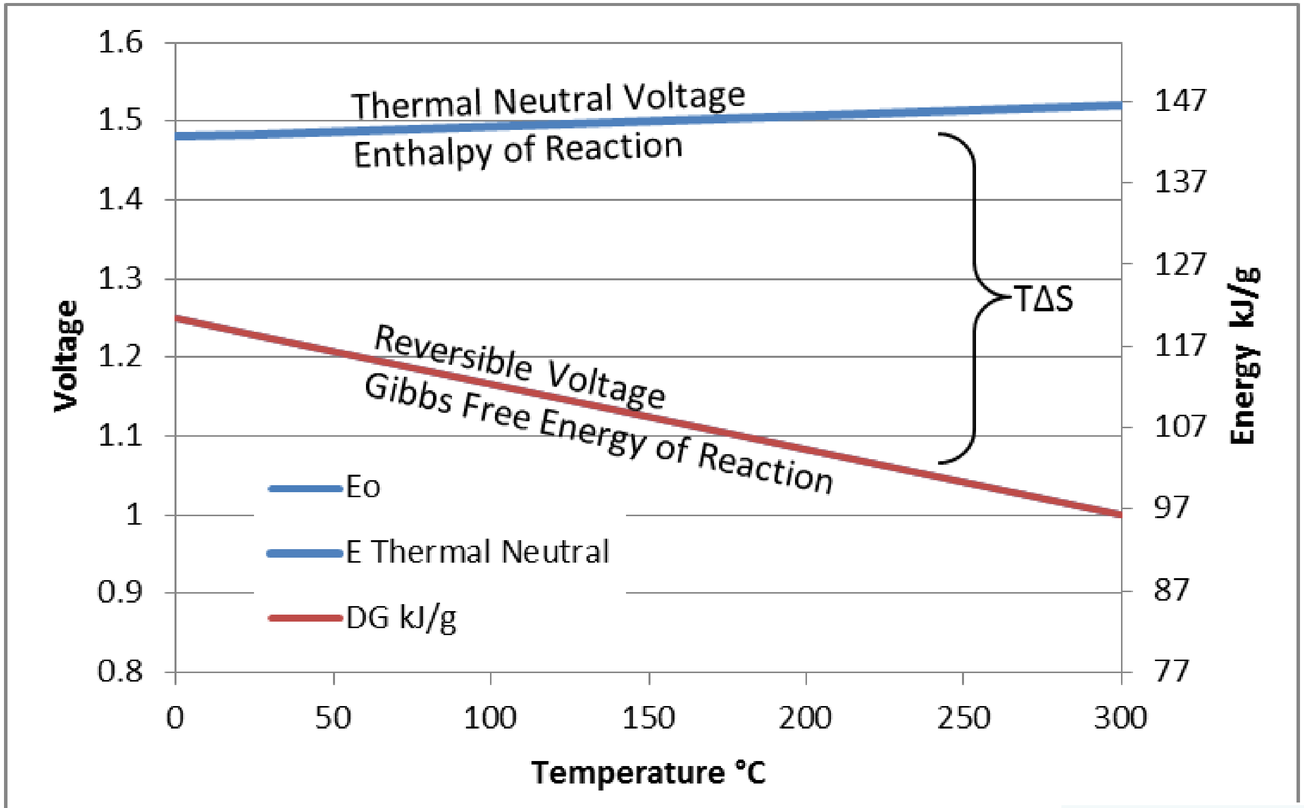
MEA
(After Disassembly)

Pressure always on to increase it!

Reduce Compression And maintenance costs

60°C 3500 PSI electrolyzer Nafion® 110

Relevance: Temperature

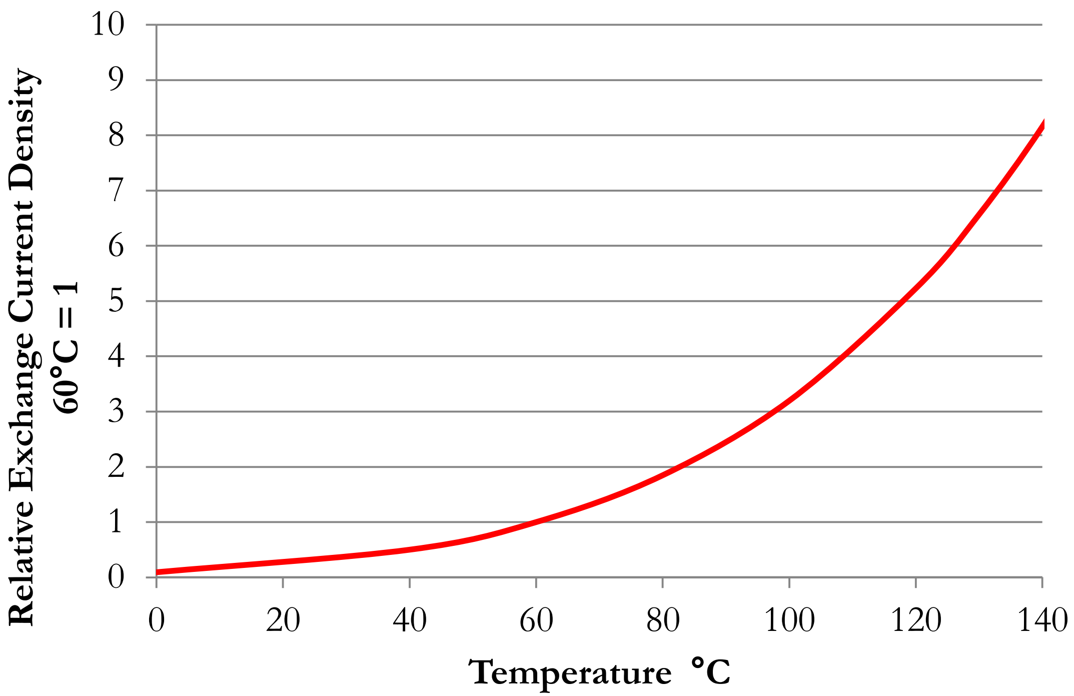


David Anthony, James Rand and Ronald Dell *Hydrogen Energy Challenges and Prospects* 2008.

Nearly 1 mV/°C decrease in Reversible Voltage

Larger TΔS means less heat to remove

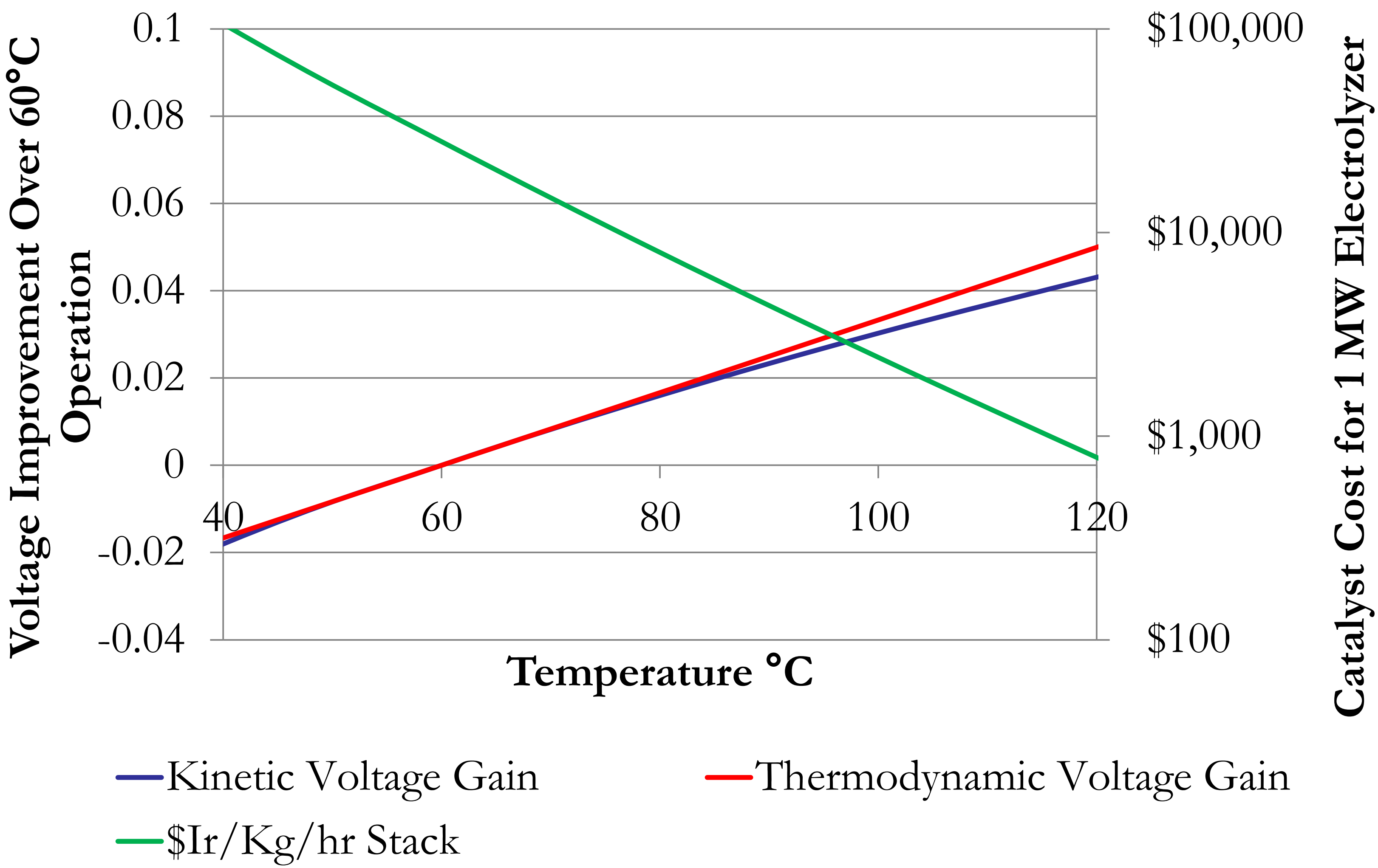
Relevance: Temperature



Oxygen Evolution Reaction
Has a High Activation Energy
~ 30 kJ/mol

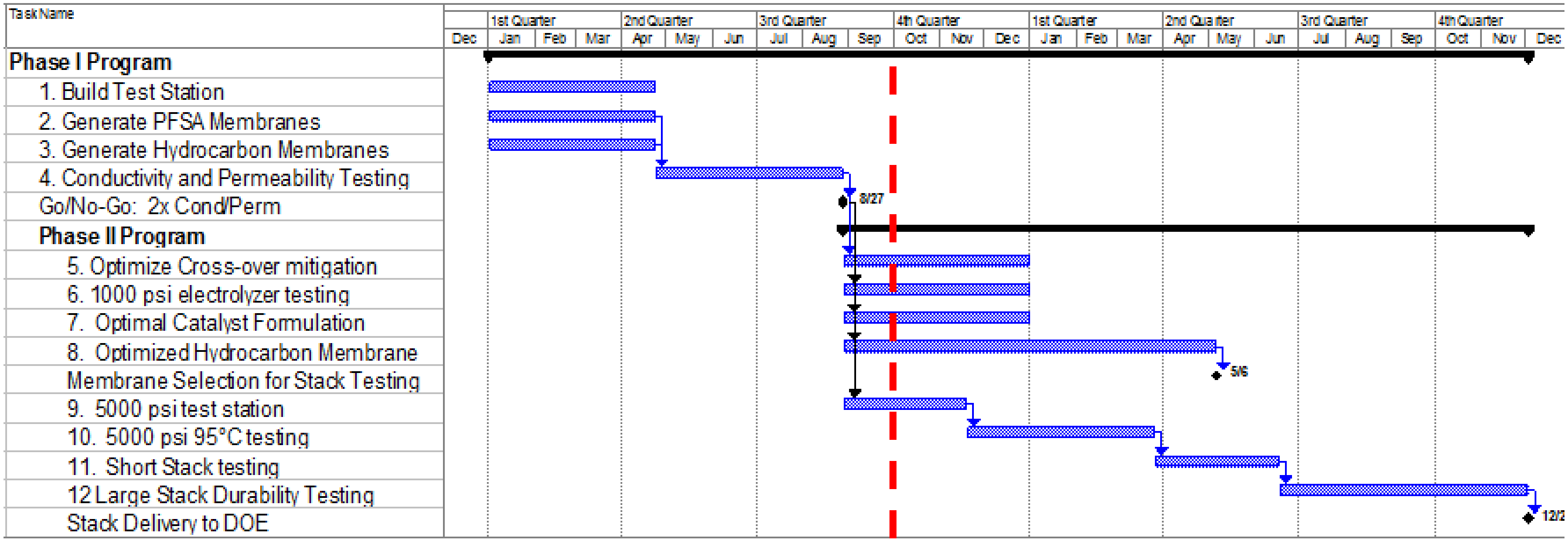
Going from 60 to 100°C results in an almost order of magnitude increase in kinetics

Relevance: $



Voltage Improvement Over 60°C Operation
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
40
60
80
100
120
Temperature °C
$100,000
$10,000
$1,000
$100
Catalyst Cost for 1 MW Electrolyzer
Kinetic Voltage Gain
Thermodynamic Voltage Gain
$Ir/Kg/hr Stack

Approach



Phase I just completed

- Build Test Stand
- Address Pressure with Hydrocarbon Membranes, Support structures, additives
- Address Temperature with additives for chemical durability and support for structural
- Measure Conductivity/Permeability Ratio

Accomplishments: Task 1. Build Test Station: 100% Complete

5000 PSI System Capable of Stack Testing is Available

Fabricated on DOE Home Refueling Program

Modified for diagnostic testing, individual cell monitoring

Accomplishments: Task 2. Generate PFSA Membranes 100% Complete

- Four Types of Membranes:

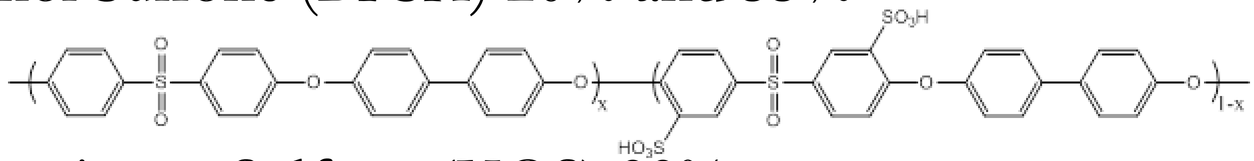
1. Different EW
2. Additives to limit crossover
3. Additives to limit degradation
4. Hydrocarbons

COMPLETED

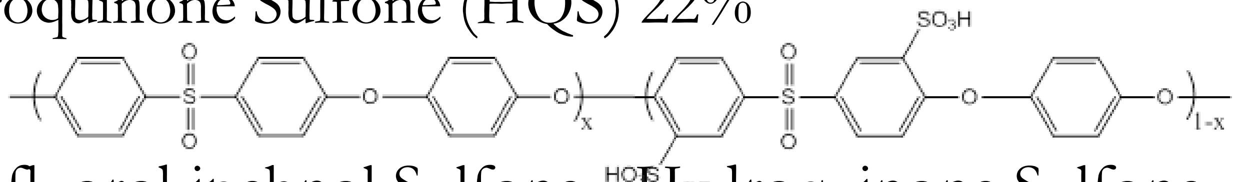
- Nafion® 1100 EW
  - Used as the standard
- Nafion® 1100 EW treated with cross-over additive
- Solvay Aquivion® 790 EW
  - Short-chain PFSA
- 3M 825 EW
  - Short-chain PFSA

Accomplishments: Task 3. Generate HC Membranes 100% Complete

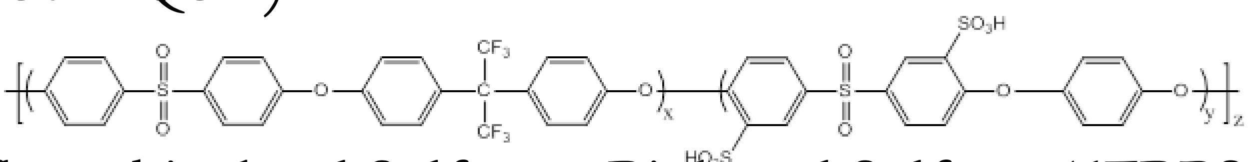
- Biphenol Sulfone (BPSH) 20% and 33%



- Hydroquinone Sulfone (HQS) 22%

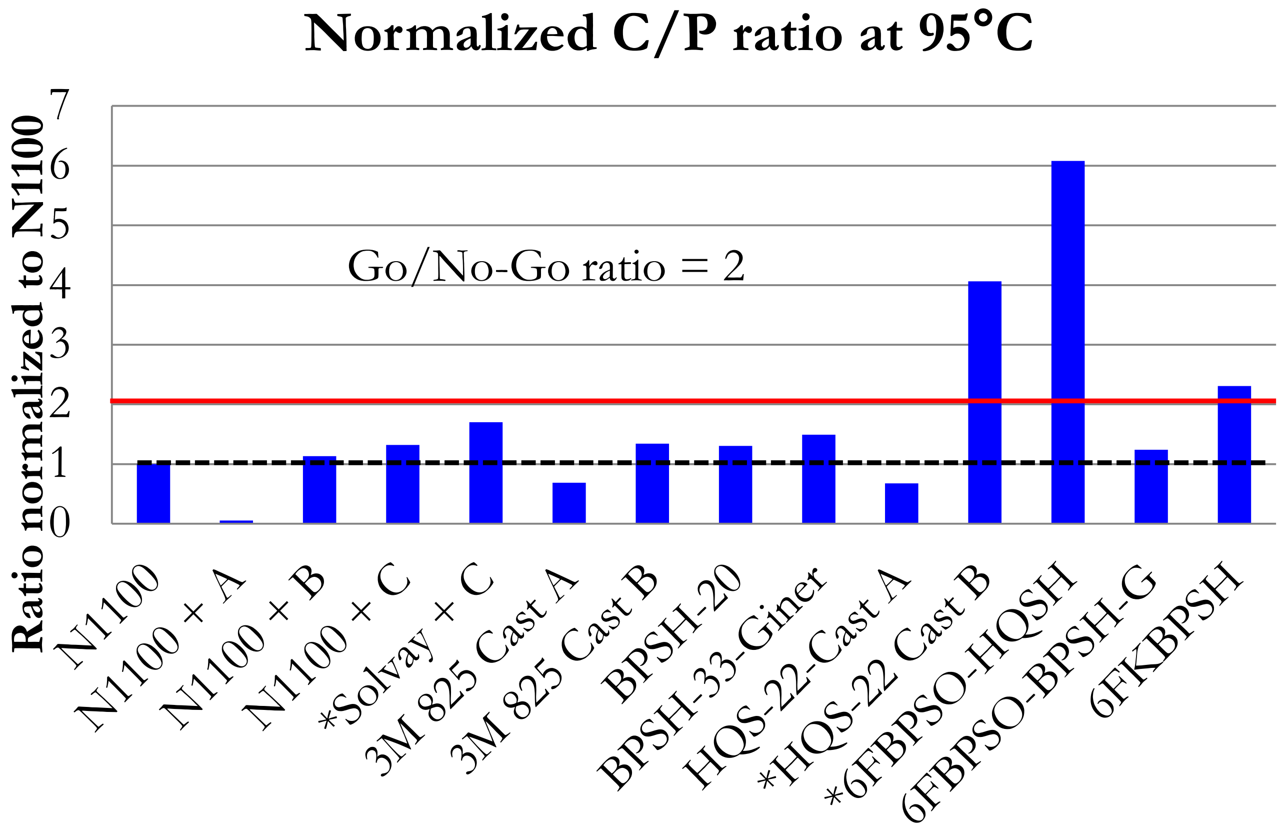


- Hexafluorobipehnol Sulfone - Hydroquinone Sulfone (6FBPS0-HQSH)



- Hexafluorobipehnol Sulfone - Biphenol Sulfone (6FBPSO-BPSH)
- Hexafluoroketone Bipehnol Sulfone (6FKBPSH)

Accomplishments: Task 4. Measure Conductivity to Permeability Ratio



Hydrocarbon membranes bind water more tightly, leading to lower permeability

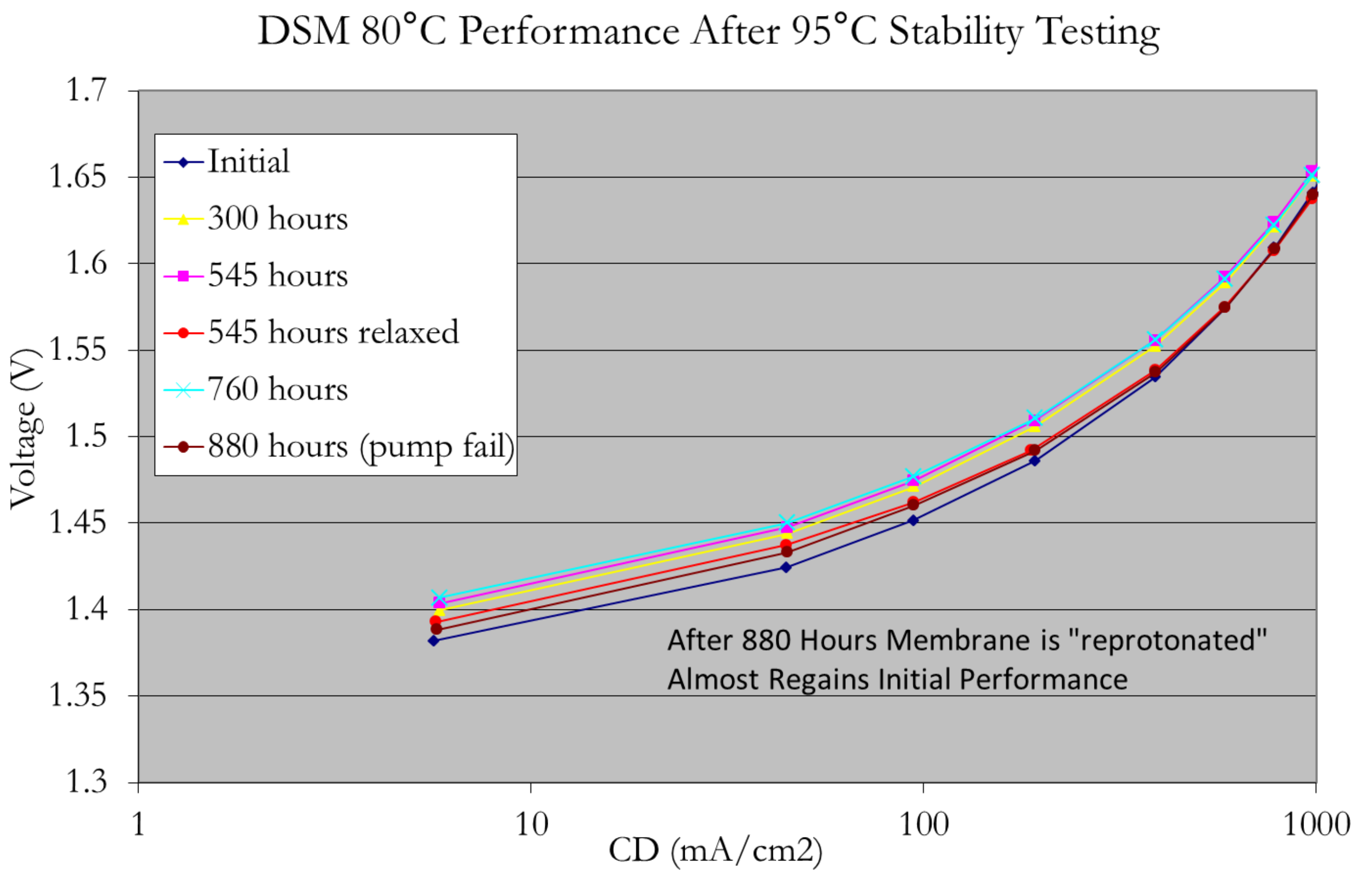
Exceeded go/no-go with 3 membranes, almost 4.

Accomplishments: Task 6. 95°C 1000 psi, 1000 h

Membrane	Pressure	Temperature	Stabilized	Estimated Lifetime* (Hrs)
N117	100 psi	80°C	None	10,000
N115**	1000 psi	95°C	Yes	>30,000
830 EW DSM	100 psi	80°C	None	1000
830 EW DSM	100 psi	95°C	Yes	>25,000

*Loss of 5% Fluoride
**1000 h of testing, ongoing
1500 mA/cm^2 Operation

Accomplishments: Task 6. 95°C 1000 h



Catalyst Appears to be Stable; losing ~ 5 mV over ~1000h

Collaborations

- Virginia Tech
  - Subcontractor, generating alternative membranes
  - Employed Student at Giner for one Week to maximize interaction
- 3M
  - Supplying ionomer
  - Gratis –
    - Thanks!

Future Work:

- Task 5. Crossover Mitigation of Alternative PEMs
- Task 6. 1000 psi, 95°C testing
- Task 7. Optimal Catalyst Formulation
  - Effective lower loading
  - Post-mortem testing
- Task 8. Hydrocarbon Testing/Modification
- Task 9-10. 5000 psi, 95°C testing
- Task 11. Short Stack Testing
- Task 12. Long-term verification (5000h goal)

Summary

- Four membranes developed with a 2x Conductivity/Permeability Ratio improvement
- 1000 h at 95°C demonstrated
- 500 h at 95°C and 1000 psi demonstrated
- MEA testing of hydrocarbon materials to begin