Novel non-PFSA Proton Exchange Membrane for Fuel Cell Application

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Xergy Inc.

2019 DOE Annual Merit Review

April 29th ~ May 1st, 2019

XERGY®

Project ID: fc311

Overview

Timeline and Budget

- Project Start Date: 03/01/19
- Project End Date: 02/28/21
- Total Project Budget: $1,250,000
  - DOE Share: $1,000,000
  - Recipient Share: $250,000

Partners

- **Xergy Inc.**: Prime Contractor
- Rensselaer Polytechnic Institute (**RPI**): Sub-Contractor, Research Institution
- University of Delaware (**UD**): Sub-Contractor, Research Institution

Barriers

- Cost
- Durability
- Performance

Rensselaer

Dare to be first.

UNIVERSITY OF DELAWARE

Relevance

Objective: To develop a novel composite polymer electrolyte membrane (PEM) using uniquely designed hydrocarbon-based aromatic sulfonated polymers and reinforcement technology to meet the DOE durability, cost and performance targets for PEM fuel cell vehicles and provide enhanced characteristics over state-of-the-art PEMs.

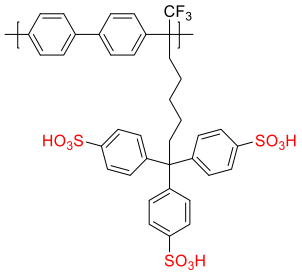
FY 2019 Objectives

ID	Technical Metric	Timeline and Target
1	In-Plane Proton Conductivity (measured at 80°C at 50%, 70% and 95% RH conditions)	**Q4**: ≥15, 20, 60 mS/cm at 50%, 70%, and 95% RH
2	Dimensional Swelling Ratio (in x-, y- directions in water at 25 °C in SO_3H form)	**Q4**: ≤15% change
3	Mechanical Strength (Tensile strength & elongation at break (strain) measured at 25°C and 50% RH in SO_3H form)	**Q4**: ≥25 MPa strength, ≥80% strain
4	Mechanical Durability under RH Cycles (80°C, Dry/Wet cycles between 0% RH and 90°C dew point)	**Q4**: 5,000 cycles with ≤15 mA/cm^2 H_2 crossover
5	Chemical Durability (90°C, H_2/Air, dry/wet cycles between 0% RH and 90°C dew point)	**Q4**: 250 hours with ≤15 mA/cm^2 H_2 crossover or ≤ 20% loss in OCV
6	Area Specific Resistance (ASR) (determined via electrochemical impedance spectroscopy under H_2/N_2 at 80°C using 50%, 70%, and 95% RH)	**Q4**: ≤0.06 Ohm cm^2 @ 80°C and pH_2O from 25-45 kPa (~ 50-100% RH)
7	Maximum Operating Temperature	**Q4**: 90°C

Approach: Milestones & Go/No-Go Decision

Task Number	Task or Subtask (if applicable) Title	Milestone Number* (Go/No-Go Decision Point Number)	Anticipated Quarter
1	Intellectual Property Management Plan (IPMP)	1	Q1
2	2.1 Synthesis of BP-Ar3 polymer variants	2.1	Q3
	2.2 Hydrolytic stability and proton conductivity evaluation of BP-Ar3 copolymer membranes	2.2	Q4
	BP-Ar3 PEM Synthesis	**Go/No-Go 1***	Q4
3	Demonstrate imbibing of BP-Ar3 polymers into porous mesh with desired thickness	3.1	Q3
		3.2	Q4
		3.3	Q6
4	4.1 Mechanical property testing of reinforced composite materials	4.1a	Q4
		4.1b	Q7
	4.2 Electrochemical property testing of reinforced composite materials	4.2a	Q4
		4.2b	Q7
5	5.1 BP-Ar3 based MEA with electrochemical characterization	5.1a	Q4
		5.1b	Q7
	5.2 Durability testing of the BP-Ar3 MEAs	5.2a	Q4
		5.2b	Q7
6	Cost Analysis of Polymers and Membranes and Commercialization	6	Q8

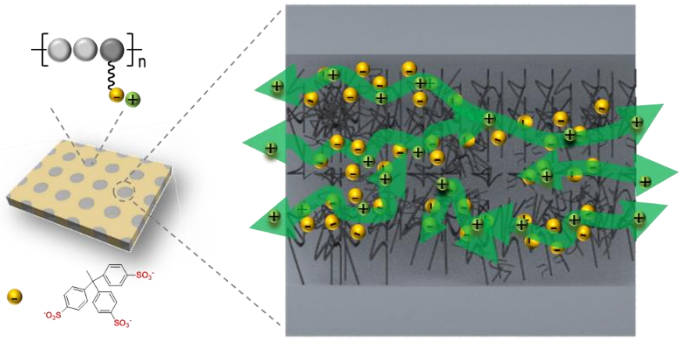
Approach: Ionomer + Reinforcement



Chemical Structure of the BP-Ar3 PEM

Ionomer:

- *Hydrocarbon backbone*
- *Flexible tether-chain*
- *Nano-scale phase separated morphology*
- *IEC range (can be controlled up to 3.81 meq. g^{-1})*

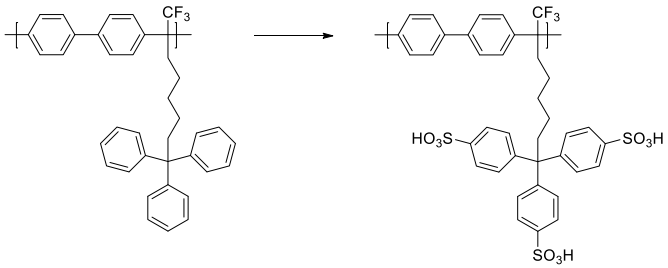


Schematic diagram of reinforced BP-Ar3 PEM

Reinforcement technology:

- *Low-cost system*
- *Thin (10 –15 μm) membrane*
- *Low internal resistance*
- *Sufficient strength for PEM fuel cell application.*

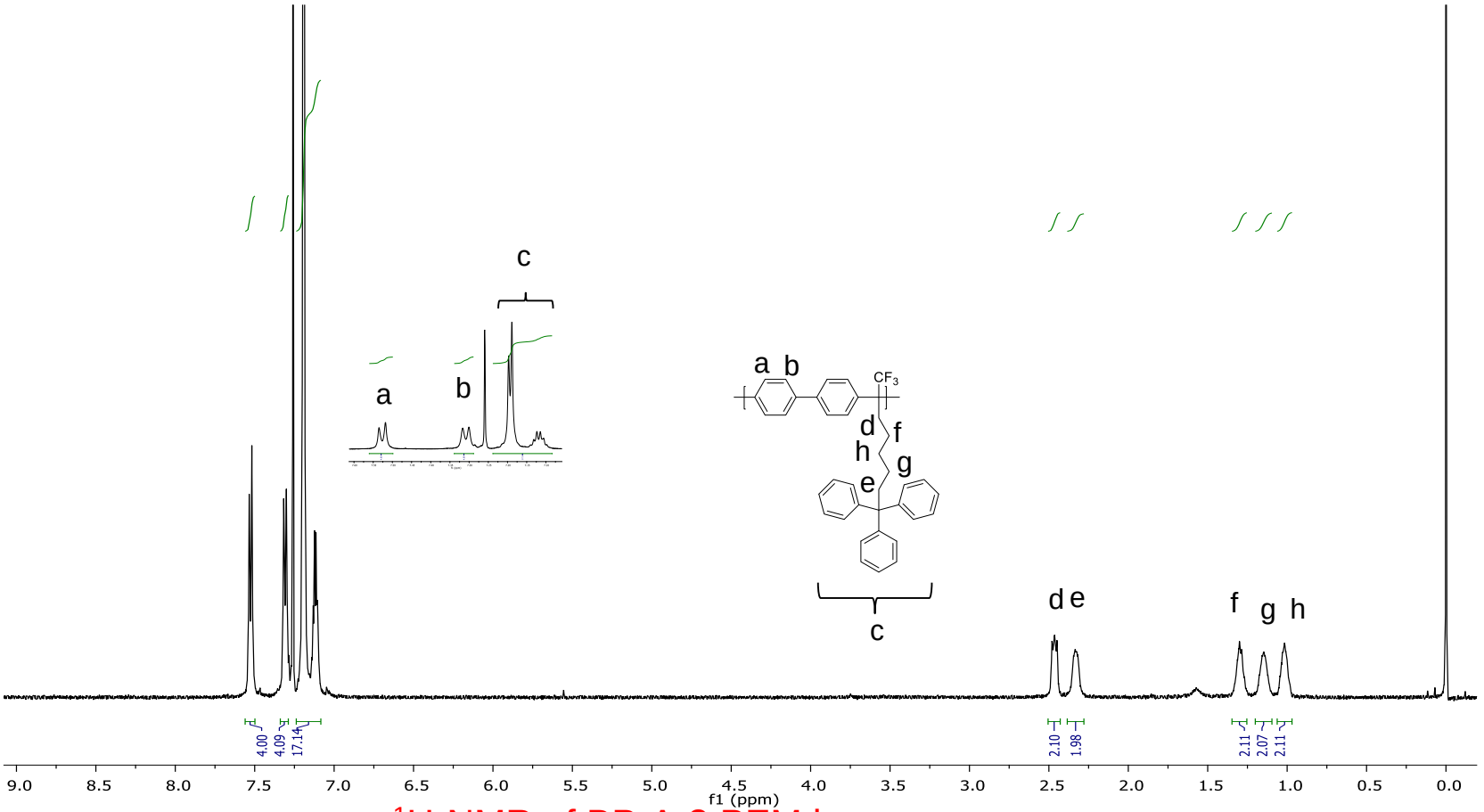
Accomplishments: Synthesis of PEM Ionomers



BP-Ar3 PEM ionomer precursor

BP-Ar3 PEM ionomer

- Optimized and scaled up the synthesis of BP-Ar3 PEM ionomer precursor
- Optimization of sulfonation of ionomer precursor to synthesize BP-Ar3 PEM ionomer is in progress



^{1}H-NMR of BP-Ar3 PEM ionomer precursor

Responses to Previous Year Reviewers' Comments

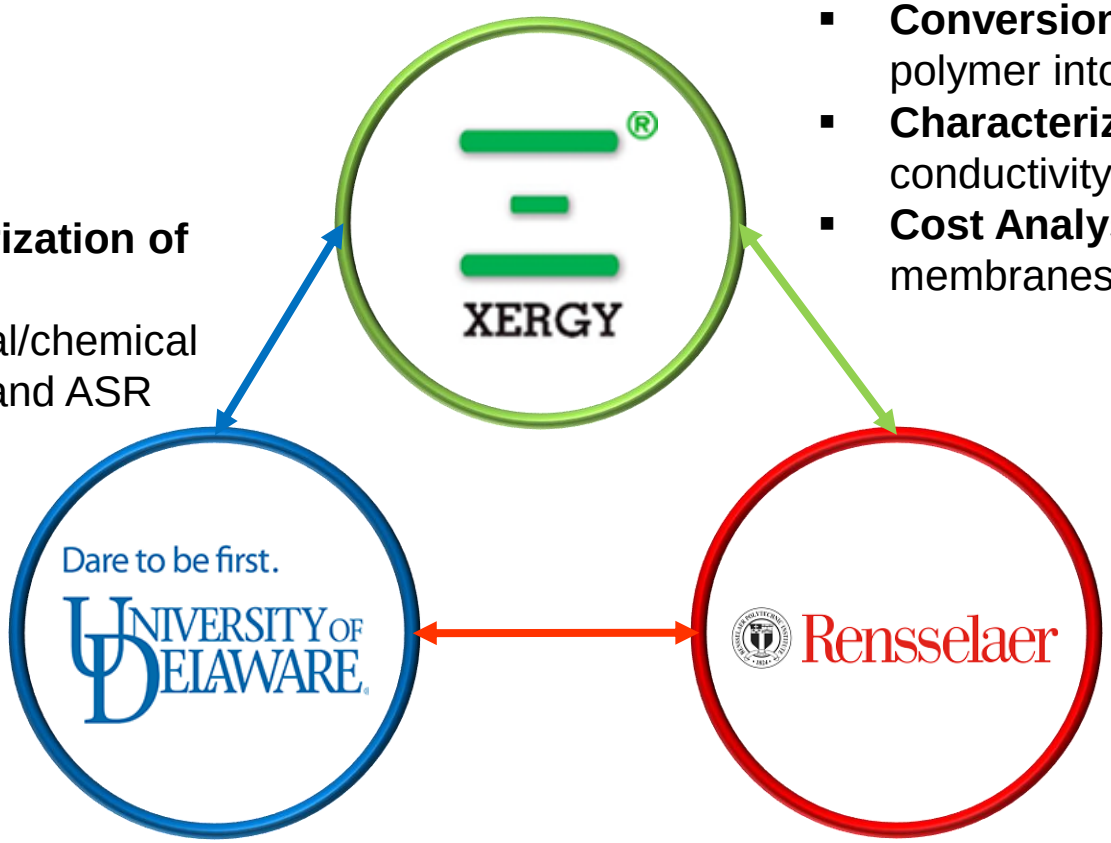
- This project was not reviewed last year

Collaboration & Coordination

Feedback about Membrane Performance vs. MEA Performance vs. Ionomer Chemistry

Target: Development of a novel composite PEM using uniquely designed hydrocarbon-based aromatic sulfonated polymers and reinforcement technology.

- **Characterization of** PEM MEA mechanical/chemical durability and ASR



- **Conversion** of proton exchange polymer into reinforced membranes
- **Characterization** of membrane conductivity and mechanical strength
- **Cost Analysis** of polymers and membranes and commercialization

- **Synthesis** of varied ionic (co)polymers
- **Characterization** of ionic polymers (M_n, IEC)

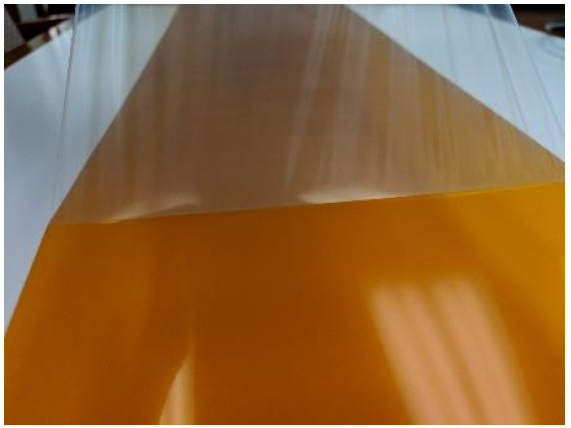
Outcomes:

- Generation of response surface of membrane and MEA performance vs. ionomer chemistry
- Down-selection of best candidate for chemical and mechanical durability testing in MEA

Remaining Challenges and Barriers

- **Challenges and Barriers:** Durability of the novel BP-Ar3 composite membrane is unknown and the greatest challenge. Team will systematically identify failure modes.

- **Strategy:** Robust ultra-thin composite membrane production with ePTFE/ePE reinforcement and use additives in the membrane formula



Proposed Future Work

Remainder of FY 2019

- Large scale (>10 g) down-selected ionomer synthesis
- Identify MEA durability limiting factor
- Demonstration of BP-Ar3 and composite membranes that satisfy Q4 Metrics

FY 2020

- Optimization of ionomer synthesis and composite membrane fabrication to demonstrate of BP-Ar3 and composite membranes that satisfy Q8 Metrics
- Scale-up of ionomer synthesis for down-selected materials (RPI, Xergy already have experience with prior scale-ups)
- Develop commercial fuel cell stack at Xergy Inc.

❖ *Any proposed future work is subject to change based on funding levels.*

Technology Transfer Activities

- Initiated a joint venture between RPI and Xergy Inc, and established Orion Polymer Corp. to supply research grade ionic polymers and membranes samples to clients. Orion has obtained licensing agreement from RPI for the scale-up synthesis of ionic polymers.
- Xergy Inc. has initiated discussions with 3rd party companies regarding commercial product sales.
- Patents and IP
  - Xergy has extensive membrane and fuel cell patent portfolio.
  - Xergy and RPI have joint IP on composite membranes made with these new chemistries
- Manufacturing scale-up
  - Xergy and RPI/UD have had membrane scale-up activities supported by DOE ARPA-E, STTR, EERE programs
  - Xergy has two roll-to-roll composite membrane production lines

Summary

- **Objective:** To develop a novel composite PEM using uniquely designed hydrocarbon-based aromatic sulfonated polymers and reinforcement technology to meet the DOE durability, cost and performance targets for PEM fuel cell vehicles and provide enhanced characteristics over state-of-the-art PEMs.
- **Relevance:** Proposed project activities include the development of an intellectual property management plan, synthesis/characterization of a BP-Ar3 ionomer, demonstration of incorporation of BP-Ar3 ionomers into porous support materials, composite membrane characterization, electrochemical characterization of BP-Ar3 based Membrane Electrode Assemblies (MEA), and cost analysis.
- **Approach:** Synthesis of the novel BP-Ar3 ionomer/reinforced composite membrane and characterize them in PEM MEA fuel cells to meet DOE target.
- **Collaborators:** Xergy, RPI and UD developed experimental plan to create a response curve of composite membrane performance in MEA vs. ionomer chemistry.