Novel membranes for Electrochemical Hydrogen Compression enabling increased pressure capability and higher pumping efficiency

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Xergy Inc.

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Project ID #: pd173

Overview

Timeline and Budget

- Project Start Date: **04/09/18**
- Project End Date: **01/08/19**
- Total Project Budget: **$154,065**

Partners

- **Xergy Inc.**: Prime contractor
- Rensselaer Polytechnic Institute (**RPI**): sub-contractor, research institution

Barriers

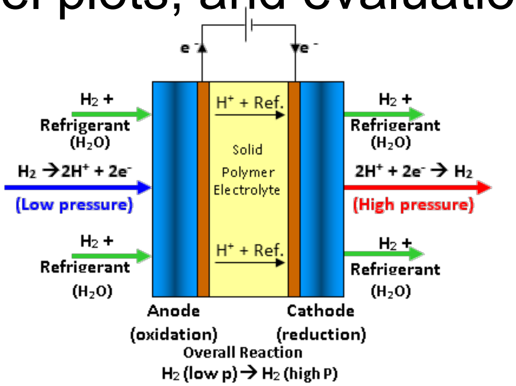
- With current membranes, **humidified H_2 is required** for ECC operation (i.e. risks of cell drying or flooding due to membrane hydration).
- Membrane **cost** is still relatively **high** compared to mechanical compressors.
- Membrane mechanical **stability** under high pressure differential is **challenging.** Pressure output and pump efficiency need to be improved to meet targets.

Relevance

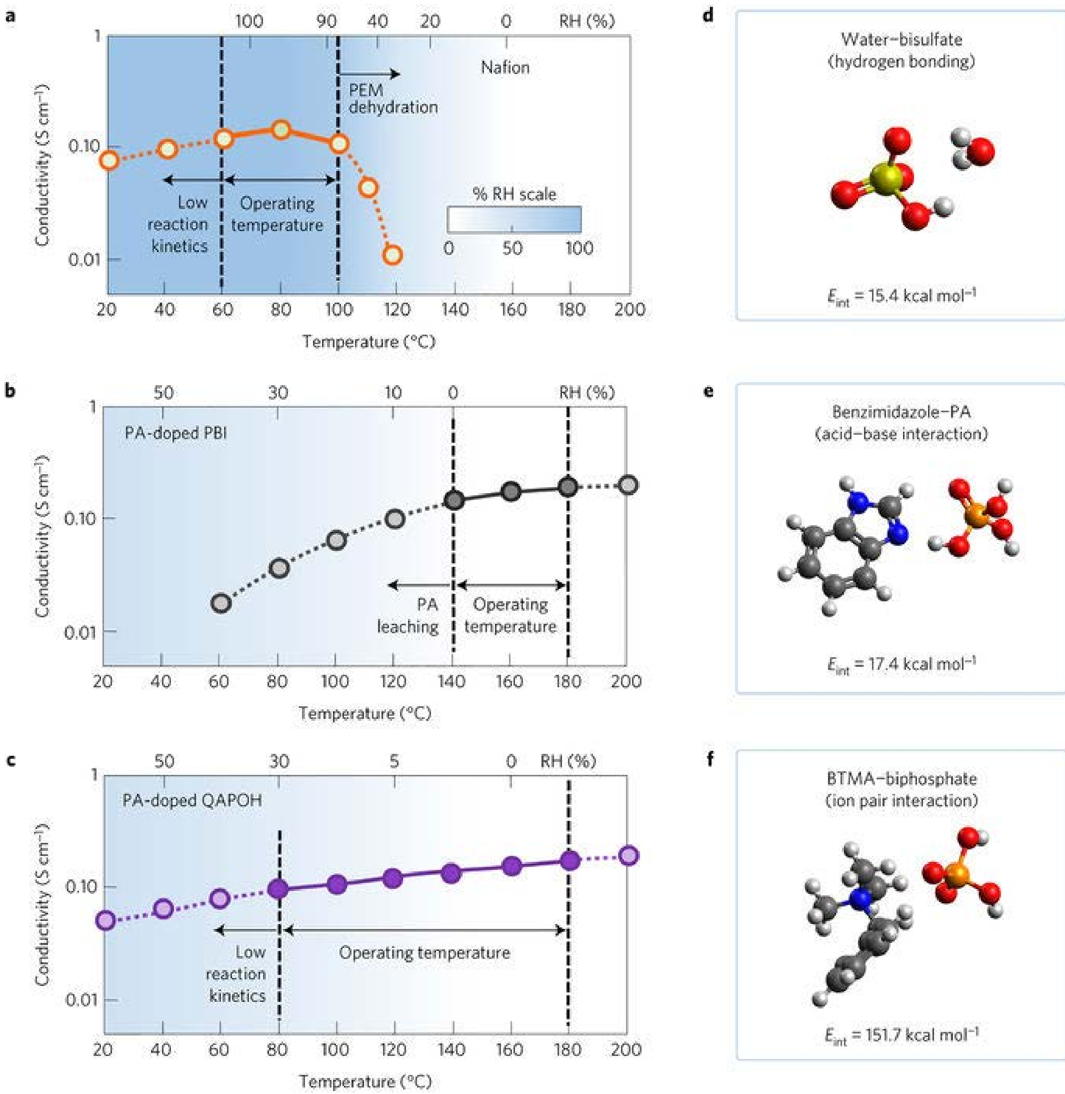
➢ **Objectives:** DOE target: Electrochemical Hydrogen Compression (ECC) - **1.4 kWh/kg** for **1 kg/hr.** Hydrogen stream with outlet pressure of **875 bar** (from **100 bar** (inlet))

➢ Phase I of this project will include:

- **Synthesis** of the novel **ionomer** and **membrane samples** (both free standing and reinforced)
- **Create a variables vs. performance map** (followed by bench-top evaluation of key performance characteristics, including polarization curves, Tafel plots, and evaluation of performance over time.)



Approach: Quaternary Ammonium-Biphosphate Ion-Pair Polymer for High Temp. PEM



a. Low-temperature PEM (*e.g.* Nafion) requires a high level of hydration to conduct H^+

- Limited temp. operation (<100 ^oC)
- Require a complicated water supply system

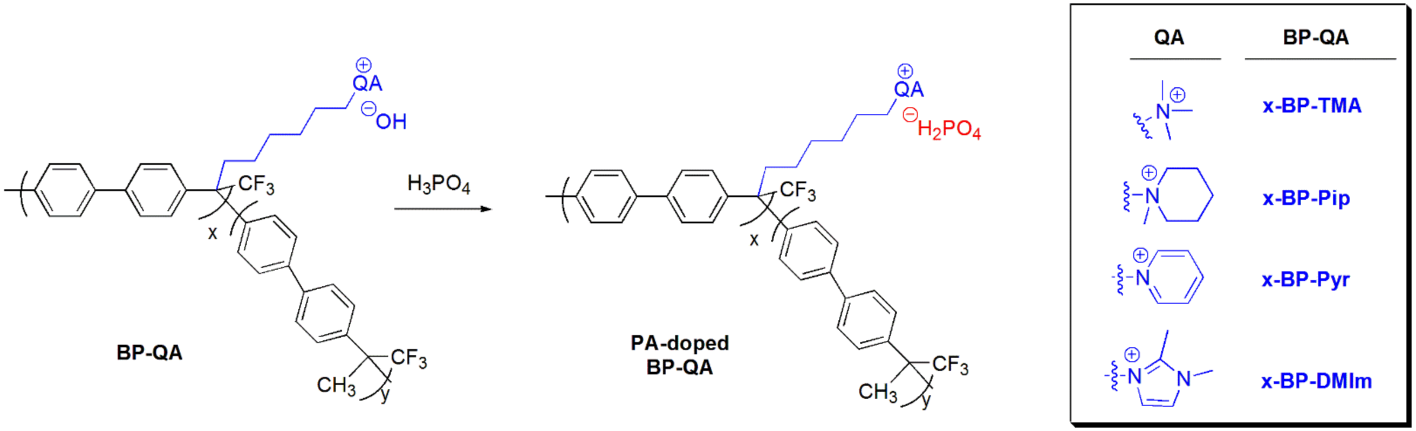
b. Phosphoric acid-doped PBI can transport H^+ effectively up to 180 ^oC

- But H^+ conductivity drops when exposed to water <140 ^oC

c. Quaternary ammonium-biphosphate ion pairs can conduct H+ over a wide range of conditions (80–180 ^oC, 20–70% RH)

Ref: Lee, K.-S., *et al.*, Nature Energy, 2016. **1**: p. 16120.

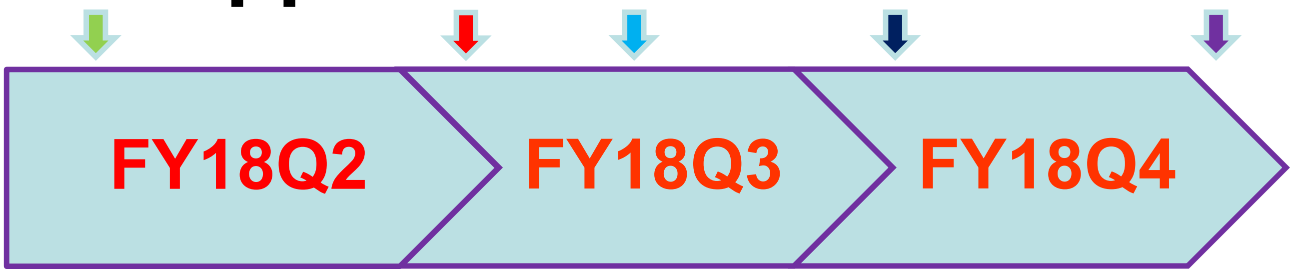
Approach



QA-Biphosphate Biphenyl PEMs & Reinforced Composite Membranes

- RPI has recently developed QA-functionalized biphenyl polymers (BP-QA)
  - Made of all C-C bonds in backbone
  - Excellent chemical and mechanical stability
- In this project, we propose to **modulate the interaction of QA with biphosphate anion by changing cation head groups with different basicity strengths**
  - x-BP-TMA, x-BP-Pip, x-BP-Pyr, x-BP-DMIm (x indicates mol% of QA repeat unit)
  - To reduce ionic resistance of PEM while maintaining sufficient mechanical strength for high pressure differential, BP-QA will be impregnated into a porous mesh to produce reinforced composite PEMs at Xergy

Approach: Milestones



Milestone 1. Define variables for ionomer sampling and create ionomer samples

Milestone 2. Ionomer synthesis and membrane fabrication

Milestone 3. Compressor performance analysis

Milestone 4. Optimization and fabricate ionomer and membrane based on performance map

Milestone 5. Validate compressor performance vs. expectations from designed experiment map

Responses to Previous Year Reviewers' Comments

- This project was not reviewed last year

Collaborators

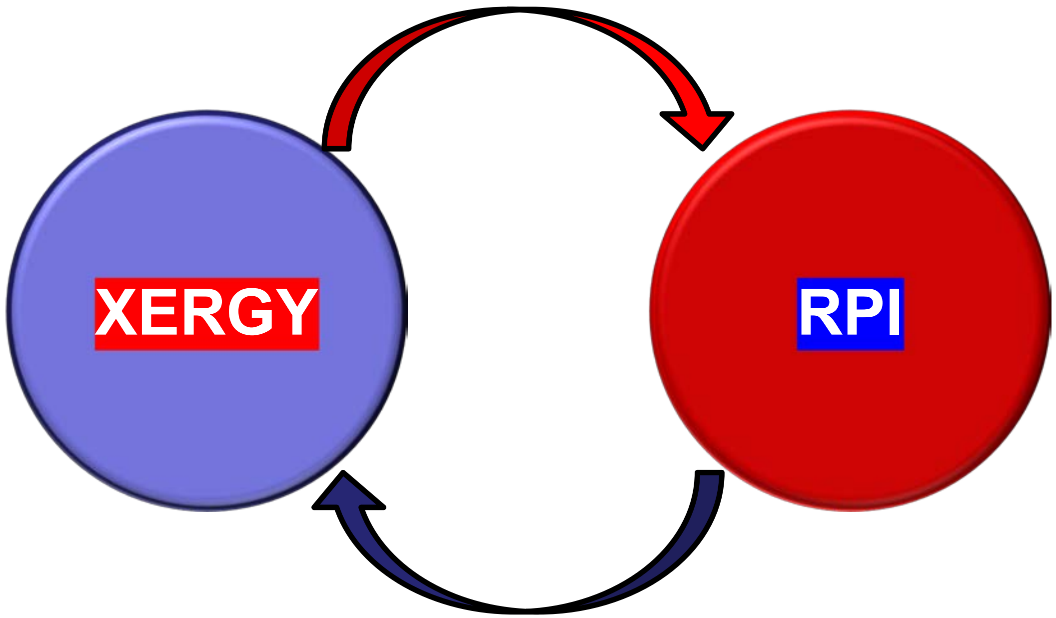
- **Rensselaer Polytechnic Institute (RPI) (sub-contractor, research institution):**
  - Synthesize various biphenyl (BP)-based ionically-conducting polymers
  - Vary ionic functional groups to tune IEC and phosphoric acid-doping interaction
  - Characterize ionic polymer chemistries (morphology, IEC)
- **Xergy Inc.:**
  - Convert these ionic polymers into both free-standing and reinforced membranes
  - Characterize mechanical properties of membranes
  - Characterize ECC performance across various membrane chemistries

RPI and Xergy have collaborated on several DOE projects and already have the infrastructure in place for this type of partnership

Collaborative Strategy

Feedback about membrane performance vs. chemistry

- **Conversion** of ionic polymers into free-standing and reinforced membranes
- **Characterization** of membrane performance in electrochemical compressor



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

Shipment of polymers for conversion/optimization

Outcomes:

- Generation of response surface of membrane and ECC performance vs. ionomer chemistry
- Downselection of best candidate for high-pressure and durability testing

Remaining Challenges and Barriers

- **Challenge:** Durability testing of ECC cell is time-consuming and difficult to conduct with multiple candidate chemistries
- **Risk:** Cannot fully characterize durability of all candidates during funding period
- **Strategy:** Employ quicker tests such as membrane performance metrics (mechanical properties, conductivity) and low ΔP tests to downselect candidate chemistries. Select the best two for durability testing

Proposed Future Work

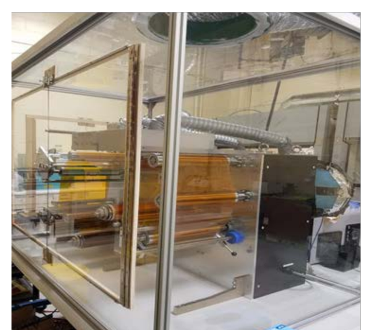
- **FY18** (within scope of STTR):
- Evaluate ionic polymer chemistries using STTR funding over the next 9 months
- Develop and optimize ECC cell and stack to meet DOE targets and work towards commercialization at Xergy

- **FY19** (beyond scope of STTR):
- Scale-up of ionomer synthesis for downselected materials (RPI, Xergy already have experience with prior scale ups)
- Develop commercial high-pressure ECC stack for other applications at Xergy Inc.

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

Technology Transfer

- Xergy Inc. has already discussed with 3rd party companies regarding other high-pressure ECC applications
- Patents and IP
  - Xergy has extensive ECC patent portfolio including high-pressure ECC (> 55 patents in process)
  - Xergy and RPI have joint IP on composite membranes made with these new chemistries
- Manufacturing scale-up
  - Xergy and RPI have had membrane scale-up activities supported by ARPA-E programs
  - Xergy has two composite membrane production lines



Summary

- **Objectives:** DOE has set a target for electrochemical hydrogen compression of **1.4** kWh/kg for raising a greater than 1 kg/hr stream of hydrogen from 100 bar (inlet) to 875 bar (outlet).

- **Approach:** Synthesis of the novel ionomer/reinforced membrane and create a variables vs. performance map to meet DOE target

- **Collaborators:** Xergy and RPI will develop experimental plan to create a response surface of membrane performance in ECC vs. chemistry

- **Future work:** Scale-up of membranes and high-pressure ECC stacks for commercialization