Highly conductive, stable and robust hydroxide exchange membranes based on poly(aryl piperidinium)

Award: DE-AR0000771

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Hydrogen as Energy Source

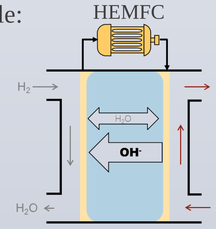
- Pressing need for alternatives to gasoline engine cars to:
  - reduce green house gas emissions
  - meet proposed legislation banning gasoline cars (California, EU, China, etc.)
  - lower oil dependence

	Gasoline[1]	Battery[2]	PEM fuel cell[5]	HEM fuel cell[6]
Zero tailpipe emissions	✗	✓	✓	✓
Range (miles)	460	220-310[3]	312	~300
Refueling time (mins)	5	40 (80%) 75 (100%)[4]	5	~5
Cost (US/kW)	30	57	45	30

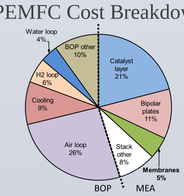
1. 2017 V4 Toyota Camry, 27mpg combined. 2. Tesla Model 3. 3. Toyota Mirai. 4. Supercharging. 5. Mobile connector

- Fuel cells are a proven solution but currently too costly due to their acid operating environment
- The fuel cell operational environment is defined by the membrane used
- More applications than fuel cells require stronger membranes than commercially available:
  - Desalination
  - Electrolyzers

HEMFC



PEMFC Cost Breakdown



Setzler, B. P., Zhuang, Z., Wittkopf, J. A., & Yan, Y. (2016). Activity targets for nanostructured platinum-group-metal-free catalysts in hydroxide exchange membrane fuel cells. *Nature nanotechnology*, 11(12), 1020-1025.
James, B. D., Spisak, A. B. (2012). Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2012 Update, report by Strategic Analysis, Inc., under Award Number DEEE0005236 for the US Department of Energy, 18.

PAP Advantage

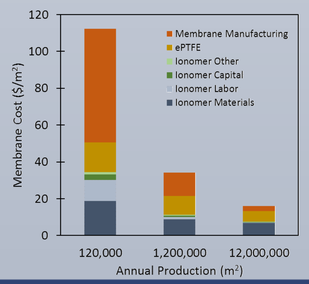
- Combining alkaline stability, high conductivity, and low cost via advanced polymer design and engineering
- **Platform technology:** Opens the doors for new materials to be integrated into devices — **Highest collateral benefit on cost reduction**

Operation pH → Less corrosive alkaline environment

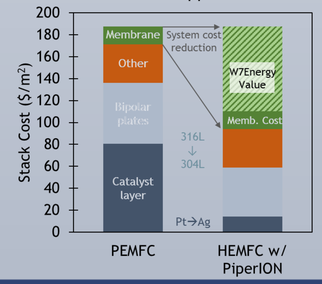
Construction materials → Cheaper construction materials

Final fuel cell cost → Cost reduction on 75% of fuel cell system

Membrane cost structure

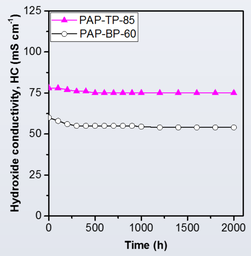


Value for Application

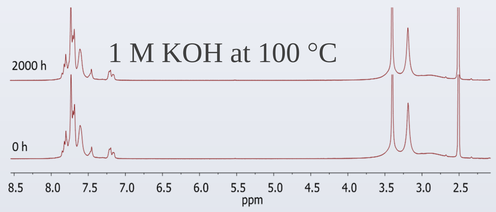


Performance and Stability

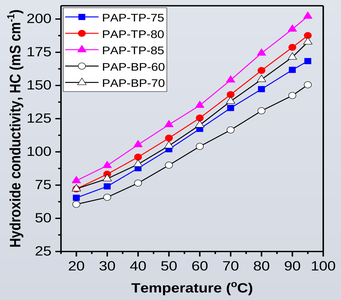
Stable conductivity



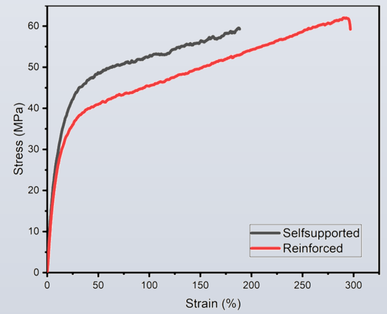
Alkaline stable



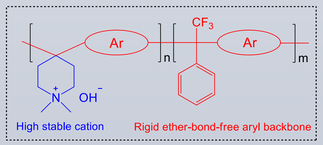
Conducting



Robust



PAP-TP-X Hydroxide Exchange Membrane (HEM)

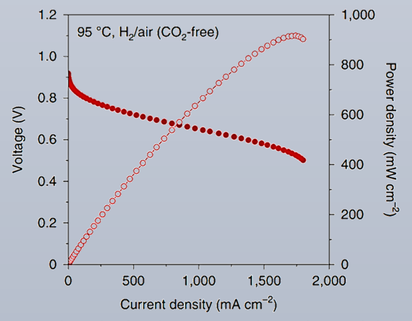


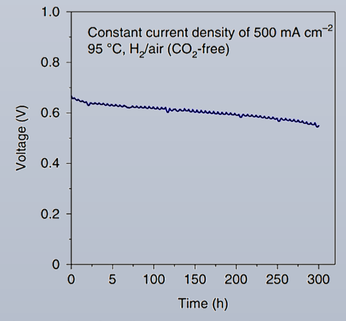
- Maximize functional groups
- Eliminate weak bonds
- Strong polymer backbone

High-performing

Durable

H_2/Air (CO_2 free)





Wang, Junhua, et al. "Poly (aryl piperidinium) membranes and ionomers for hydroxide exchange membrane fuel cells." *Nature Energy* (2019): 1.

Poly(aryl piperidinium) HEM vs. Commercially Available HEMs

		W7Energy	Dioxide Materials	Tokuyama	Fumatech	
Product Name	Units	**Piperion TP-85**	Sustanion X37	A201	FAS-50	FAA-3
Thickness	µm	**20**	50	28	45 - 55	45-50
Ion exchange capacity	meq g^{-1}	**2.2**		1.7	1.6 - 2.0	2.02
Counter ion		**CO_3^{2-}**	Cl^-	OH^-	Br^-	Br^-
Conductivity (25°C)	mS cm^{-1} (wet OH^-)	**80**	70	46	3 - 8 (Cl-)	25
Water uptake	wt%	**60**	90	44	10 - 25	40
Dimensional swelling (in-plane)	% (linear)	**8**	6	2	0 - 1	17
Ultimate tensile strength (50°C and 50%RH)	MPa	**50**			30 -40	
Elongation at break	%	**175**	10-40 (wet)		15 - 60	
Young Modulus	MPa	**425**	20 (wet)		1000-1800	
Recommended Temperature	°C	**< 120**		< 60		
Recommended pH		**0-14**	2-14	0-14	0-11	0-11

Scaling Up

Produced 1Kg of PAP-TP-85 and are testing it for multiple applications. Produced tenths of square meters of roll-to-roll self supporting and reinforced membranes

Non-reinforced membrane with superior ion conductivity, thermal and chemical stability and outstanding mechanical properties

Ionomer with adequate shelf life and ion conductive properties on par with the membrane

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