TechConnect World Innovation Conference & Expo

NATIONAL INNOVATION SUMMIT & SHOWCASE

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Hydrocarbon Membranes for Energy and Water Electrochemical Systems

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Acknowledgements

Inventors:

- Dr. Cy Fujimoto, Sandia National Laboratories
- Dr. Michael Hibbs, Sandia National Laboratories

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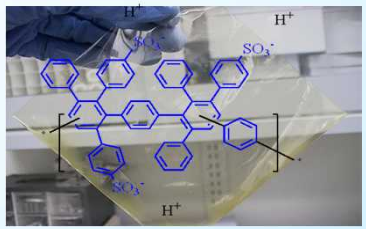
  - Many others …

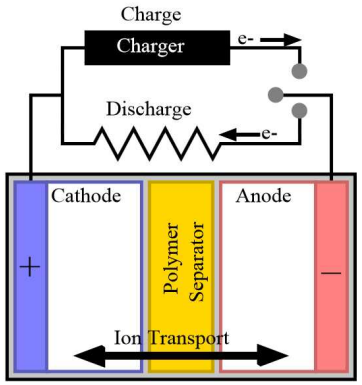
Technology and Markets

Polymer Membranes Play a Critical Role in the H_2 Economy and Renewable Grid Integration

Technology

Polymer membranes are an essential component in electrochemical systems that produce, store, and transform energy.





Two types of membranes:
Acidic : H^+ transport
Alkaline: OH^- transport

Markets

Flow Batteries for -
- Grid Support Functions
- Renewable Energy Integration

Fuel Cells for –
- Zero-Emission Vehicles (ZEV)
- Residential and Commercial Power System

Water Electrolysis for -
- H_2 for ZEV
- Storage of Renewable Energy

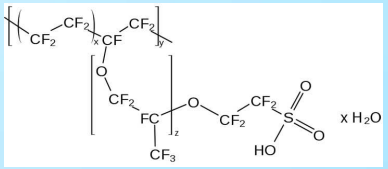
Other Applications -
- Chlorine Production
- Dielectric Separators ..

Competitive Advantage

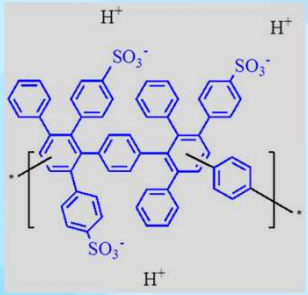
- **For acidic membranes, only one competitor technology - Nafion (Dupont) and derivatives (3M, Asahi, Gore)**
  - Our technology will accelerate market adoption (lower cost), improve performance, enable wider operating conditions, and lower maintenance costs

- **For alkaline membranes, no commercial technology meets performance and durability requirements**
  - Our technology will eliminate the need for precious metal catalysts (Pt/Ir) and reduce the cost of other system components

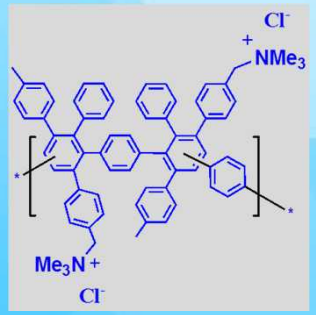
Nafion (Dupont)



Sandia Acidic



Sandia Alkaline



Competitive Advantage Examples

Sandia technology provides higher performance and lower cost

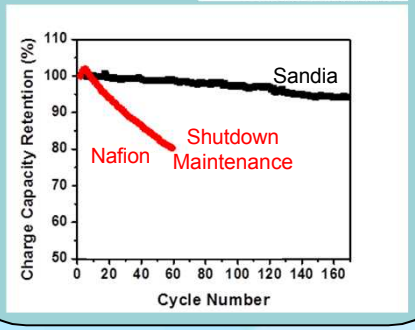
Higher performance in FB

measurements by WattJoule

	Power (mW/cm²)
Sandia	1159 (+23%)
Nafion	946

Lower maintenance in FB

measurements by Pacific Northwest NATIONAL LABORATORY



Lower Cost
Nafion > $200/m²
Sandia < $100/m²

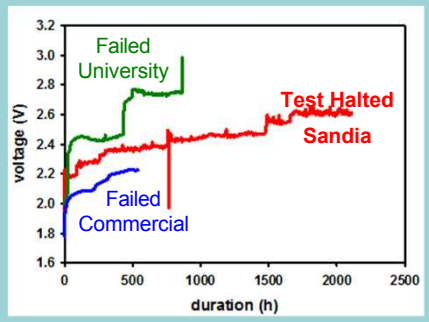
Wider operating conditions in FC

measurements by AUTOMOTIVE FUEL CELL COOPERATION

RH @ 85°C	Nafion (S/cm)	Sandia (S/cm)
30%	0.008	0.004
50%	0.019	0.022
95%	0.19	0.20

Lower cost in electrolysis (no precious metals)

measurements by PROTON THE LEADER IN ON SITE GAS GENERATION



Value of the Innovation

- **Broad market reach**
- **Strong Sandia IP portfolio**
- **Long-history in membrane R&D**
- **Prototype testing with commercial system customers**
- **National Laboratory network for analytical, performance, and durability measurements**

Alkaline Membranes

SNL has filed a provisional patent application directed to SD13741.0/S133266. The application has received serial no. 62/274,592 and a filing date of Jan. 4, 2016, “Poly(phenylene)-based anion exchange polymers and methods thereof” (KIM, YU SEUNG; LEE, KWAN-SOO; FUJIMOTO, CY).

SD12549.1/S132120 “Poly(phenylene alkylene)-based Ionomers”, Application No. 14/694,875, filed April 23, 2015 (Hibbs, Michael)

SD-10987.0/S-10090: "Poly(phenylene)-based Anion Exchange Membrane." Originator(s): HIBBS, MICHAEL; CORNELIUS, CHRISTOPHER J; FUJIMOTO, CY H. Patent no. 7,888,397

Acidic Membranes

SD13592.0/S139911 Number: FUNCTIONALIZATION OF DIELS-ALDER POLYPHENYLENE POLYMERS Application no.: 62/274569, filed January 4, 2016 (FUJIMOTO, CY).

SD12691.1/S132308: “High performance, durable polymers including poly(phenylene),” application no. 14/933,981, filed November 5, 2015 (FUJIMOTO, CY; PRATT, HARRY: ANDERSON, TRAVIS MARK)

SD-12299.0/S-129594: "Functionalization of Poly(phenylene) by the Attachment of Sidechains." Originator(s): HIBBS, MICHAEL; Patent no. 8,809,483

SD-11085/S-114236: " Multi-block sulfonated poly(phenylene) copolymer proton exchange membranes." Originator(s): FUJIMOTO, CY H.; HIBBS, MICHAEL; AMBROSINI, ANDREA. Patent No. 8,110,636

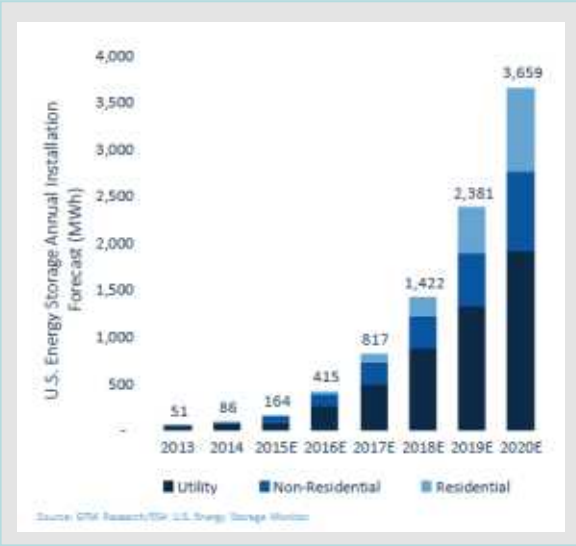
SD-7565.1/S-103422: "Sulfonated Polyphenylene Polymers." Originator(s): CORNELIUS, CHRISTOPHER J; FUJIMOTO, CY H.; HICKNER, MICHAEL A Patent No. 7,301,002.

SD-11210.0/S-116111: "Epoxy-crosslinked sulfonated poly (phenylene) copolymer proton exchange membranes." Originator(s): HIBBS, MICHAEL; FUJIMOTO, CY H.; NORMAN, KIRSTEN; HICKNER, MICHAEL A Patent No. 7,816,482.

Market Size/Impact

Much more "professional-level" market research required

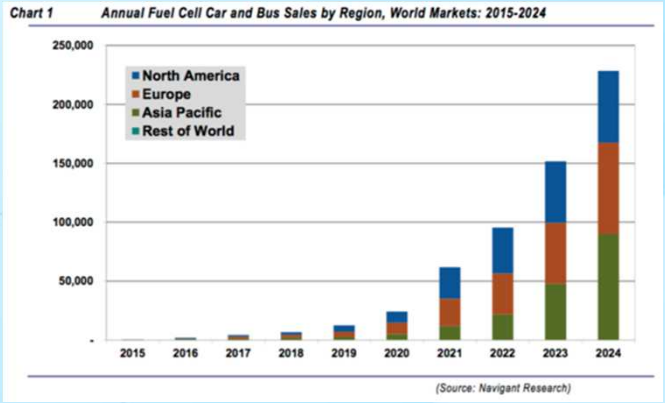
Energy Storage FB Membranes Market Forecast

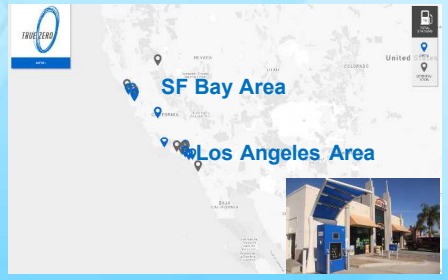


Assumptions:
$50/m^2
192 m^2/(4MWhr)
70% utility/commercial
40% GR (like early solar)

TAM FB
2020 ~ $4M
2025 ~ $20M
2030 ~ $106M

Transportation FC Membrane Market Forecast





Assumptions:
$50/m^2
15 m^2/(vehicle)
50,000 Vehicles

TAM FC
2025 ~ $38M

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