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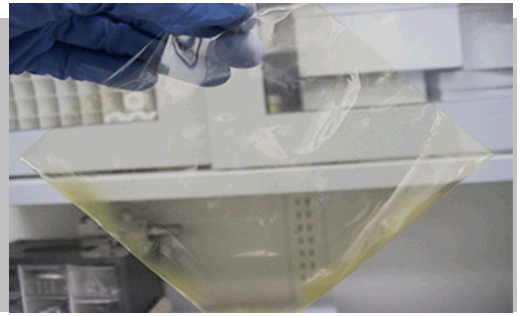

Ion selective membranes for electrochemical systems

Cy Fujimoto

May 13, 2017

Sandia No. 600060

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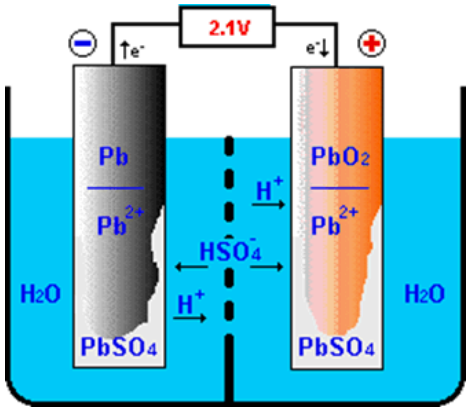
Role of membrane in electrochemical devices

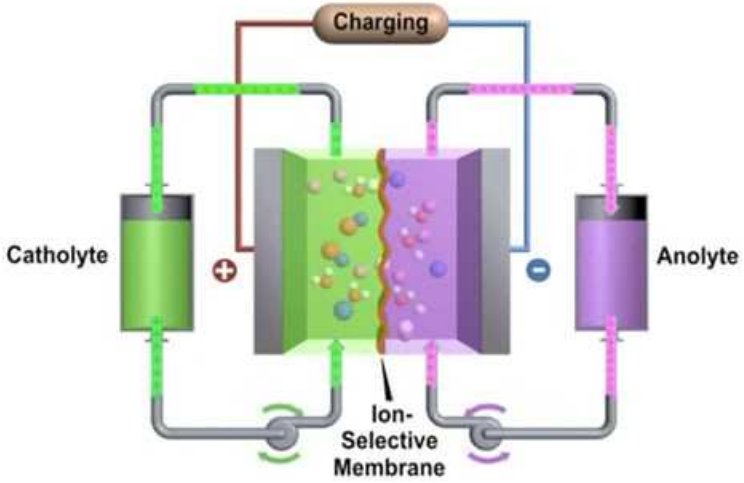
"Traditional" battery



Membrane is porous PE or PP

Purchased by Asahi
approx. $1B 2015

"Non traditional" battery



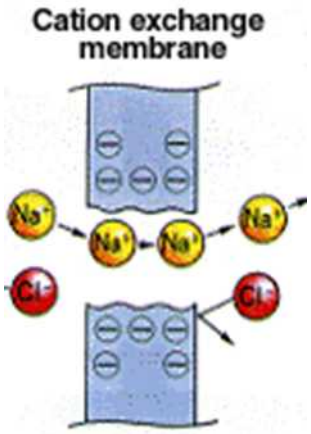
Membrane in "non traditional" battery requirements:

1) Allow for selective ion transport
2) Stable, mechanically robust
3) LOW COST

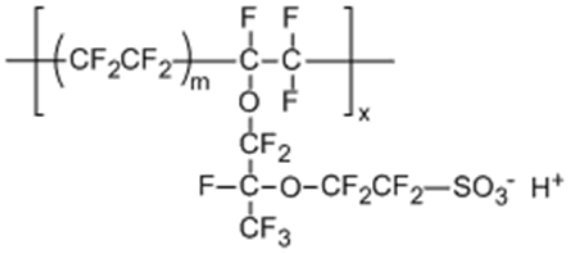
What are ion selective membranes

1. **Two types of fixed ions (tethered negative or positive charge)**

Acidic (H^+)

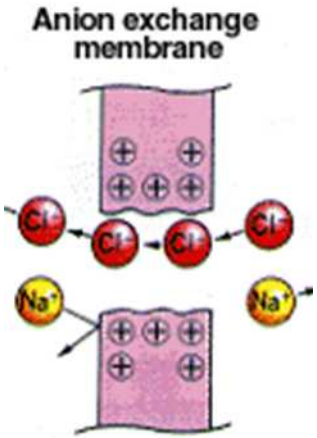


State of the art

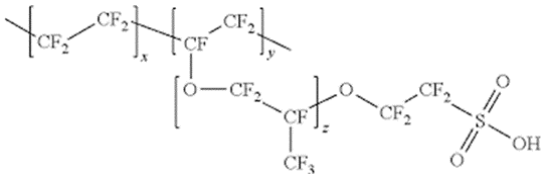


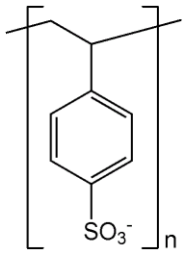
Nafion (has fixed SO_3^-)

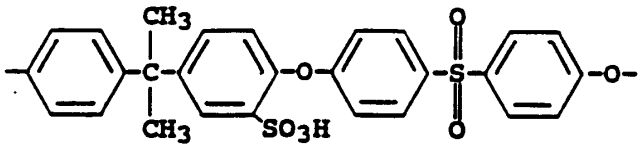
Alkaline (HO^-)



2. **Different types of polymer backbones**

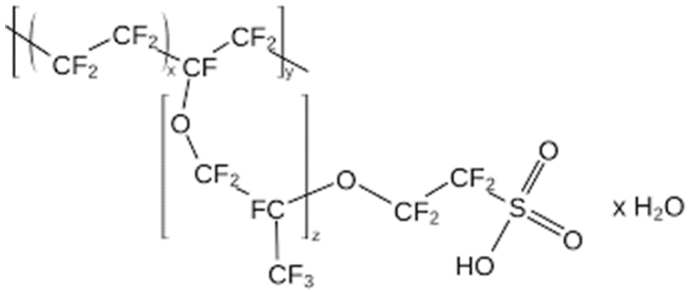






Polymer backbone stability important for cell durability

Cation exchange membrane State of the art



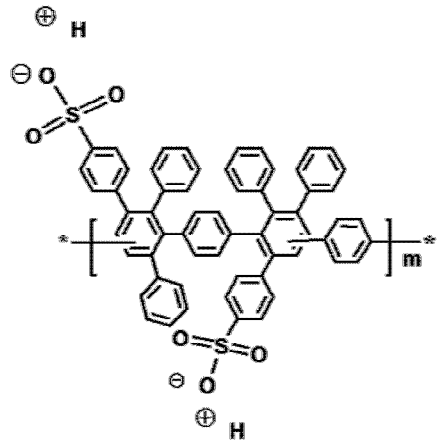
Perfluorosulfonic acid membranes (PFSA)s

Company	Product type	Trade name
DuPont now Chemours	Perfluorosulfonic acid membrane	Nafion
Asahi Chemical	Perfluorosulfonic acid membrane	Aciplex
Asahi Glass	Perfluorosulfonic acid membrane	Flemion
3M	Perfluorosulfonic acid membrane	3M MEA
Fumatech	Perfluorosulfonic acid	F-series
Gore	Reinforced perfluorosulfonic acid membrane	GoreSelect
DSM Solutech	Reinforced perfluorosulfonic acid membrane	Solupor

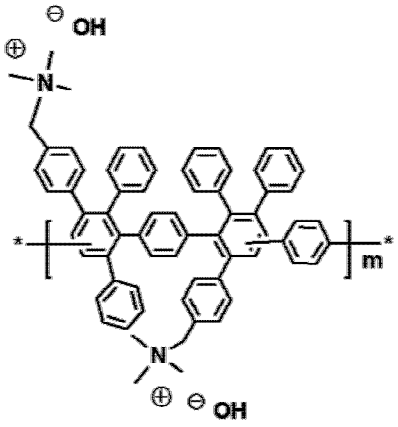
- Various suppliers for perfluorosulfonic acid membranes (PFSA)s
- Primary application chloro-alkali industry
- High cost \$250-500/m^2 associated to high capital costs

Sandia's ion exchange membranes

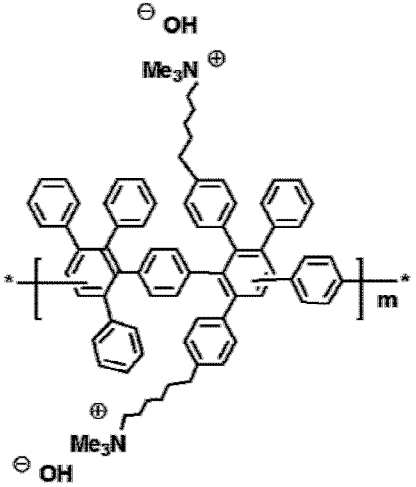
At SNL we are developing and engineering poly(phenylene) ion conductive m



US Patent 7,301,002

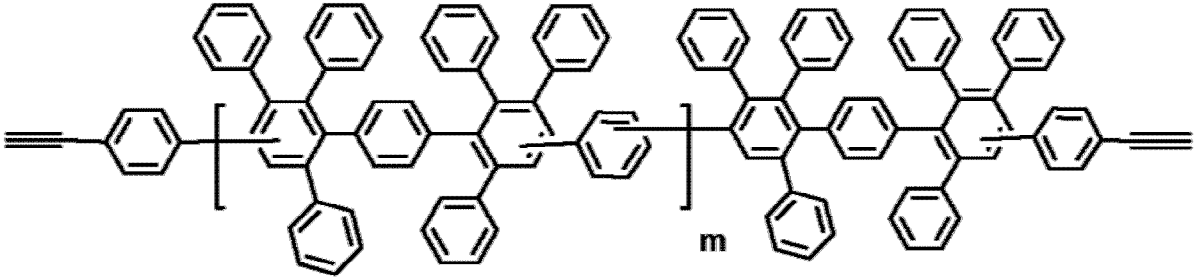


US Patent 7,888,397



US Patent 8,809,483

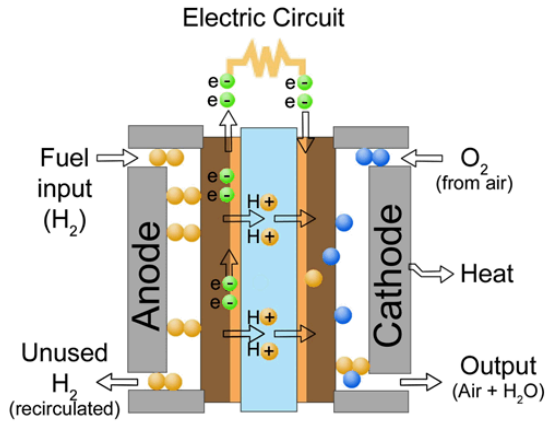
Materials based on chemistry that Dow commercialized as low k dielectric



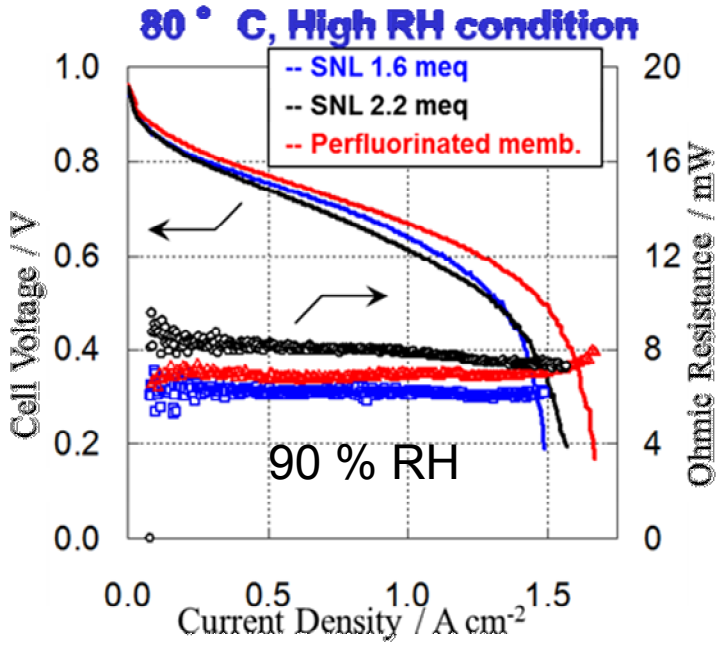
Low cost at low production volumes: DOE < $50/m²

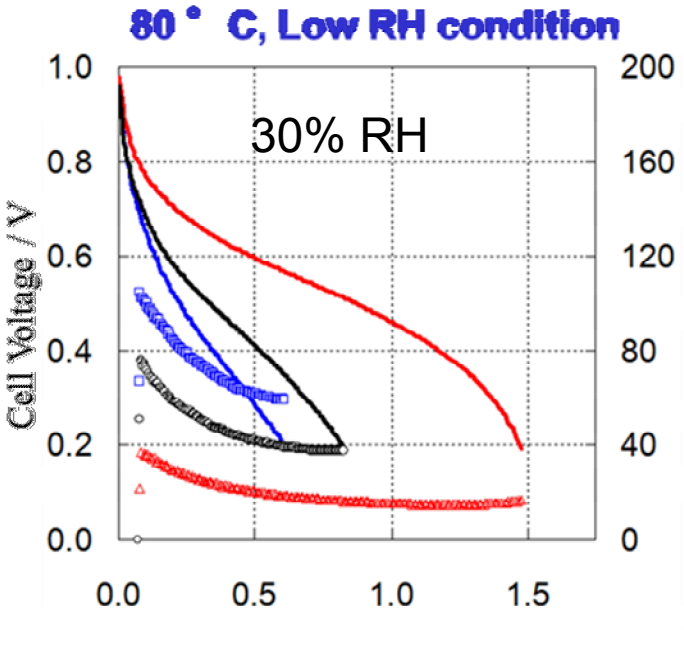
PEM Fuel Cell

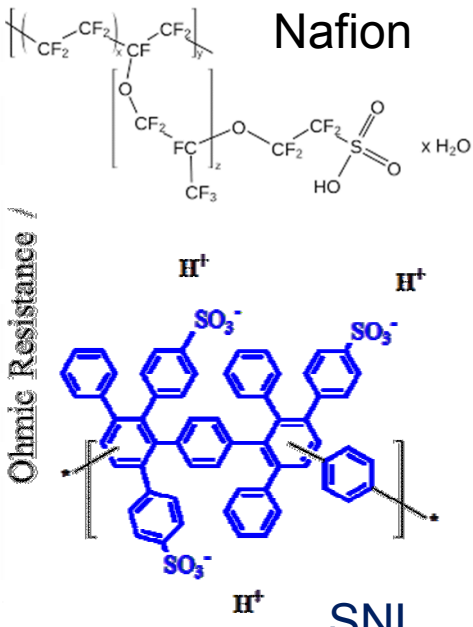
- Challenge of membranes in PEMFC is maintaining high proton conductivities at both high and low RH.
- PFSAs have best performance and durability



2004 WFO with Toyota Motor Company



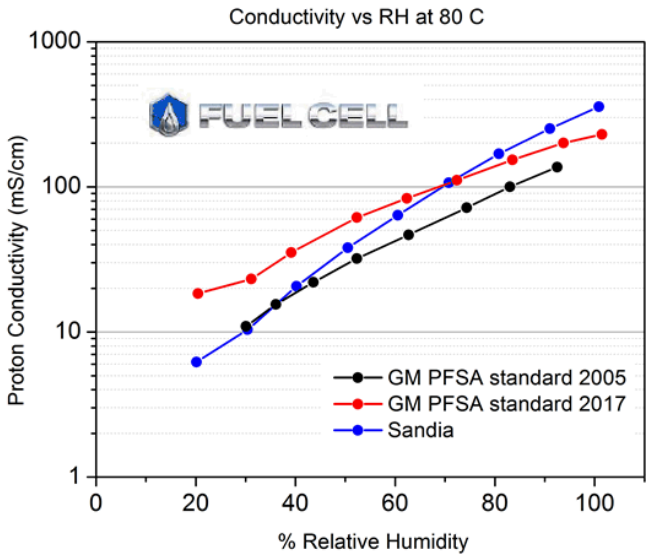


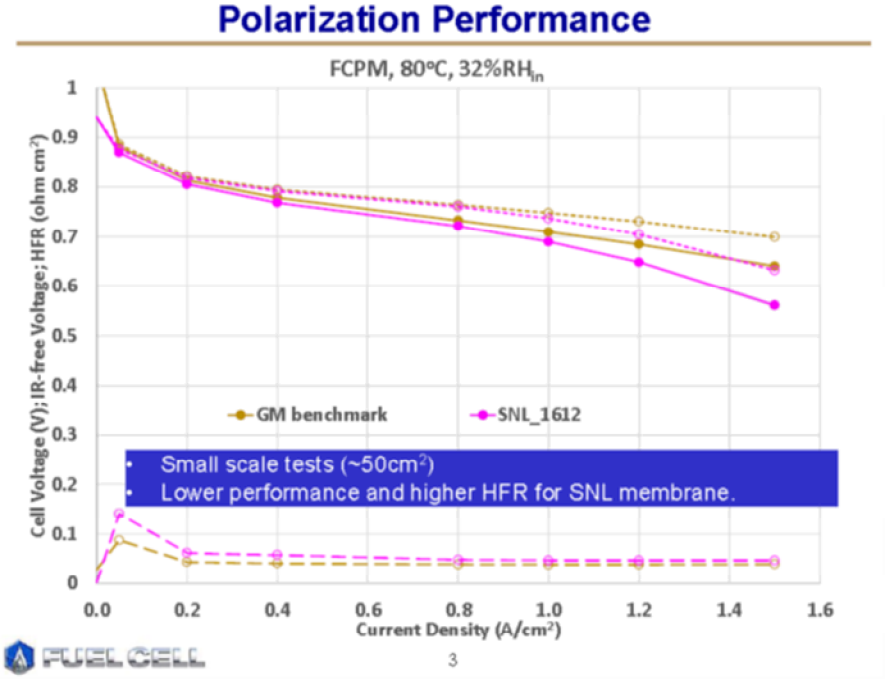


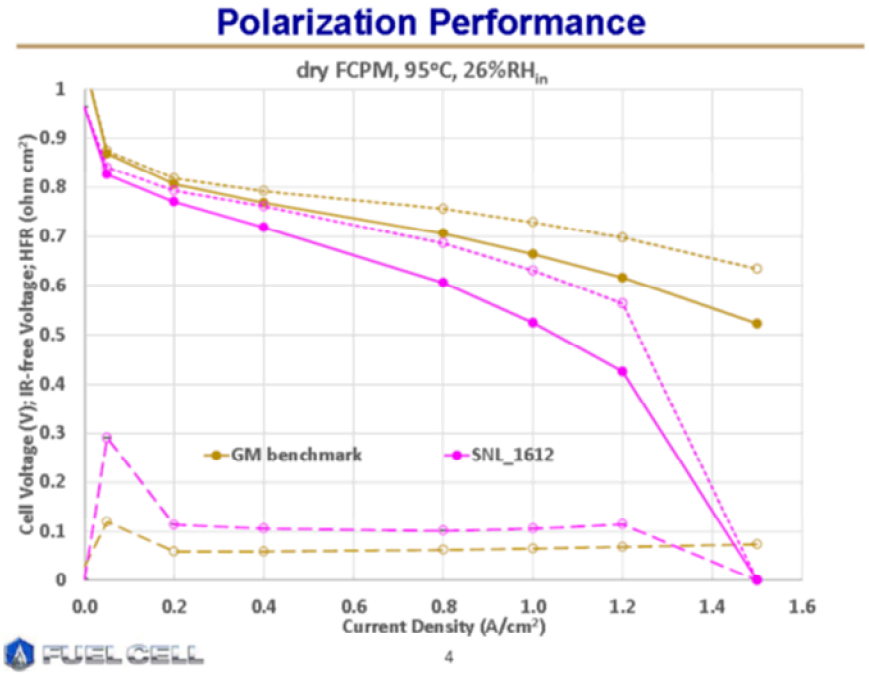
Highly durable as a HC membrane, but desired to improve durability

PEM Fuel Cell

- Conductivity compares well with 2005 GM PFSA standard, but slightly below 2017 standard
- MEA testing shows that SNL almost equivalent at low RH [32% RH and 80 °C]
- Under hotter (95 °C) and drier (26% RH) conditions performance difference more pronounced



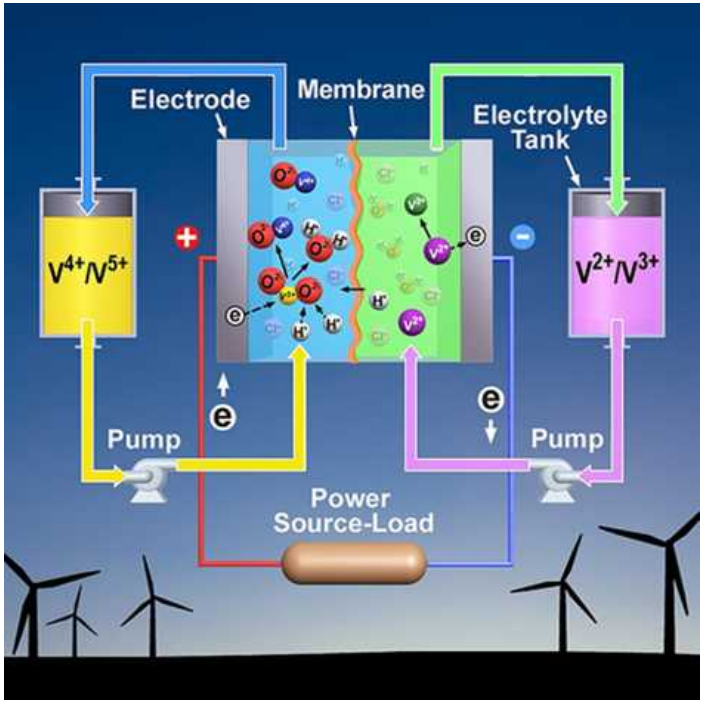




SNL-GM is working together to further improve performance

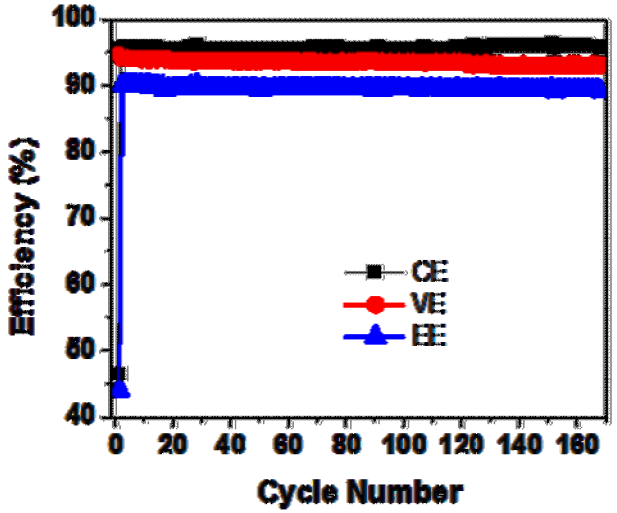
Vanadium Redox Flow Batteries (VRFB)

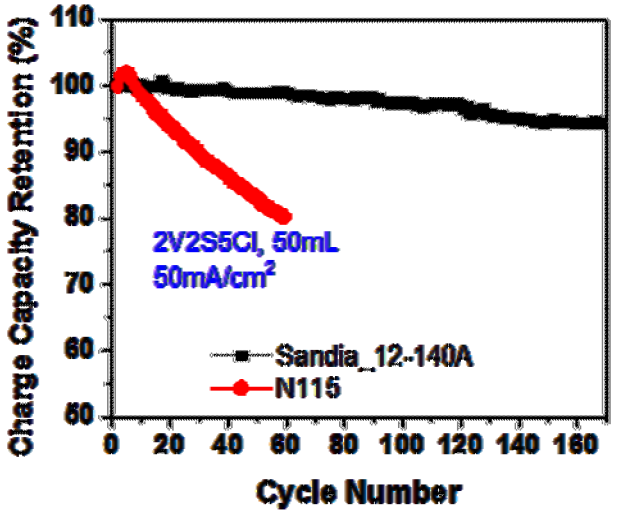
- Separation of energy and power
- Robust battery. Allows for deep discharge and long life cycles
- Several US companies looking to commercialize this technology: Demonstration project 1 MW 4MW/hr UET, largest 6MW/hr on a 32 MW wind farm in Japan Sumitomo.



According to a CEO of a VRFB company, membranes account for 1/3 of the overall system cost

Superior VRFB Performance





Data by PNNL, SNL membrane has high efficiencies (90% EE, PFSA 75%) and high capacity retention; PFSA 75% EE

	Pmax, mW/cm^2	Specific Resistance, Ωcm^2
Sandia	1159	0.505
Fluorinated	946	0.610

Membrane	Efficiency, Round Trip	Efficiency, Coulombic	Efficiency, Voltaic
Sandia	82.2%	96.2%	85.4%
Fluorinated	72.3%	92.5%	78.2%

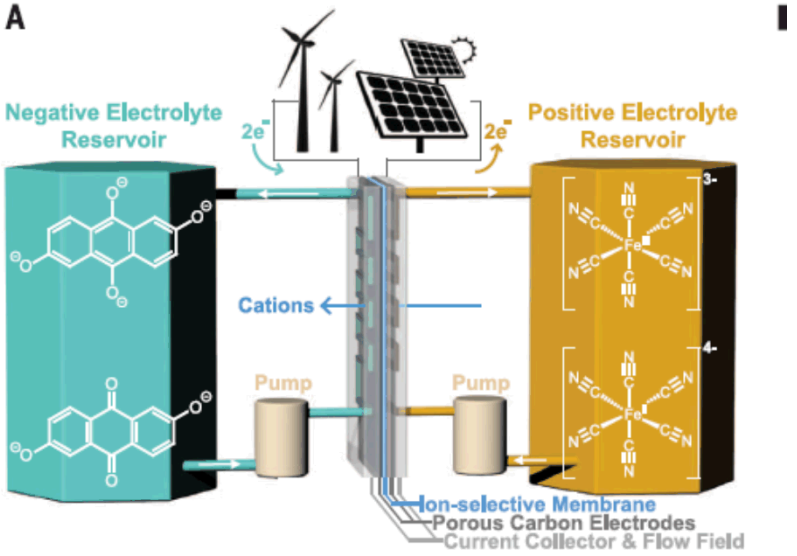
WattJoule

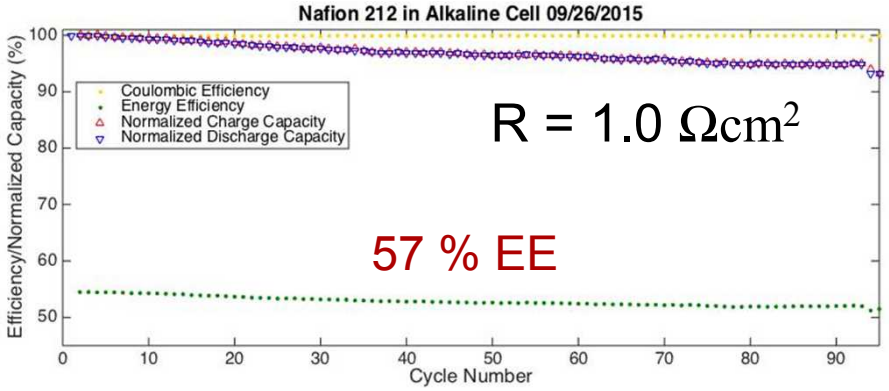
VRFB results from both NL and industry show superior performance

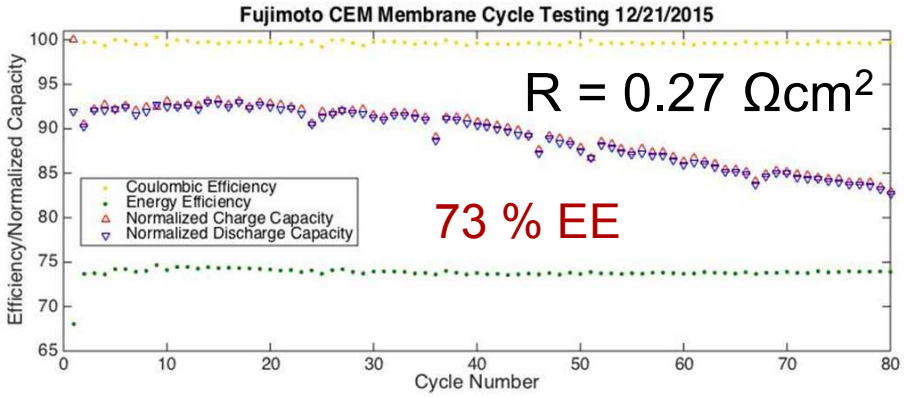
Beyond Vanadium

Harvard professor, Michael Aziz developing aqueous flow battery with earth abundant materials

Using alkaline environment helps improve solubility quinone (increase energy density)







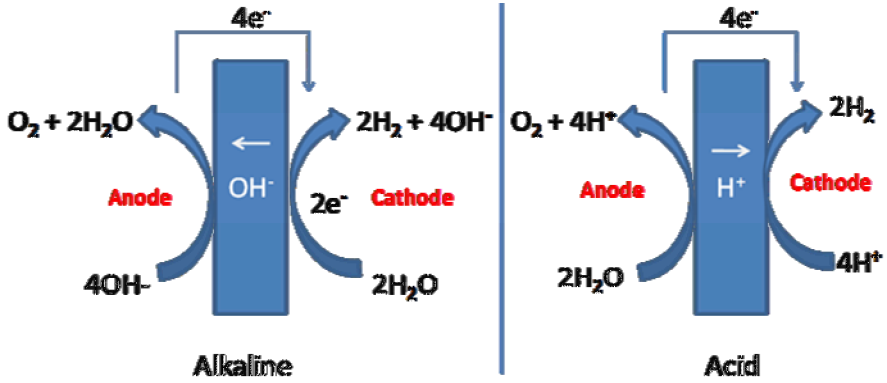
SNL polymer shows ¼ of the resistance of Nafion. Higher energy efficiencies than Nafion (+20%)

Hydrogen from water (alkaline electrolysis)

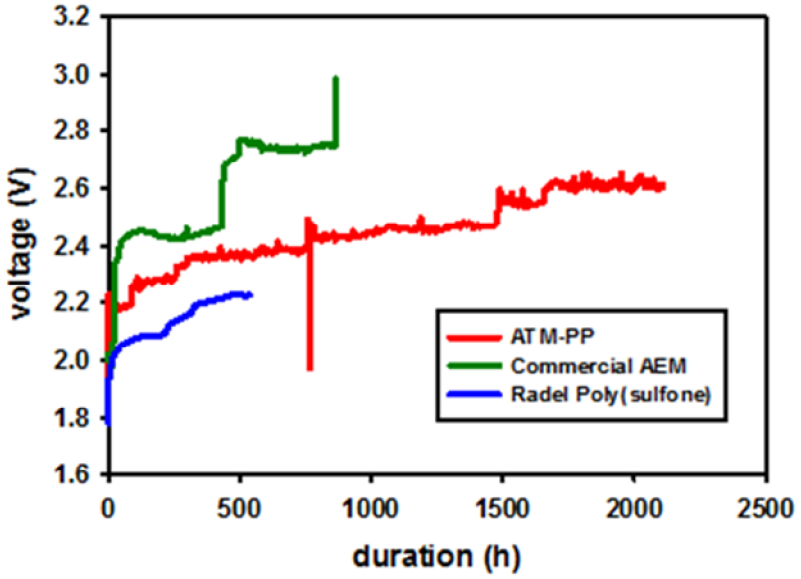
Sandia National Laboratories

arpa·e U.S. DEPARTMENT OF ENERGY

PROTON ON SITE



- Desired lowest voltage for hydrogen production and no catastrophic failure
- Radel failed after 500 hrs, commercial AEM failed near 1000 hrs, Sandia (ATM-PP) over 2000 hrs (never failed, test halted)



SNL membrane only durable membrane in alkaline water electrolysis

Technology to Market

Sandia National Laboratories

A spin off company is currently being put together to scale and commercialize two membrane products (one acid and one alkaline membrane). Current name of company is ***Energy Abler***.

Proceeding through a start up incubator

SolAero TECHNOLOGIES

SolAero is a leader in solar cells and panels in the aerospace industry is looking to expand their business space. Energy and energy related technology market extremely large.

Target is to start producing membranes for sale sometime fall/winter 2017

Summary & Impact

- SNL membranes can be functionalized for a multitude of electrochemical applications
- The applications discussed today: PEMFC: GM; VRFB: WattJoule, PNNL, ORNL; AEM: LANL and unnamed industrial partner looking at materials
- Membranes development was initially seeded internally (SNL) but has progressed greatly through DOE EERE/OE funding [Thank you!]
- Ready to move towards commercialization

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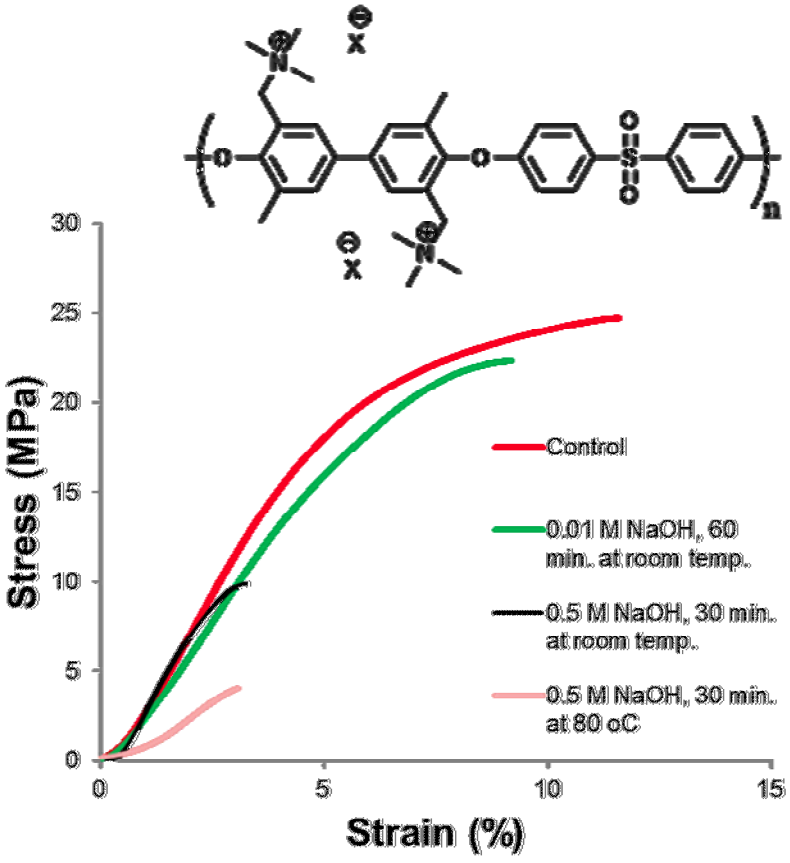
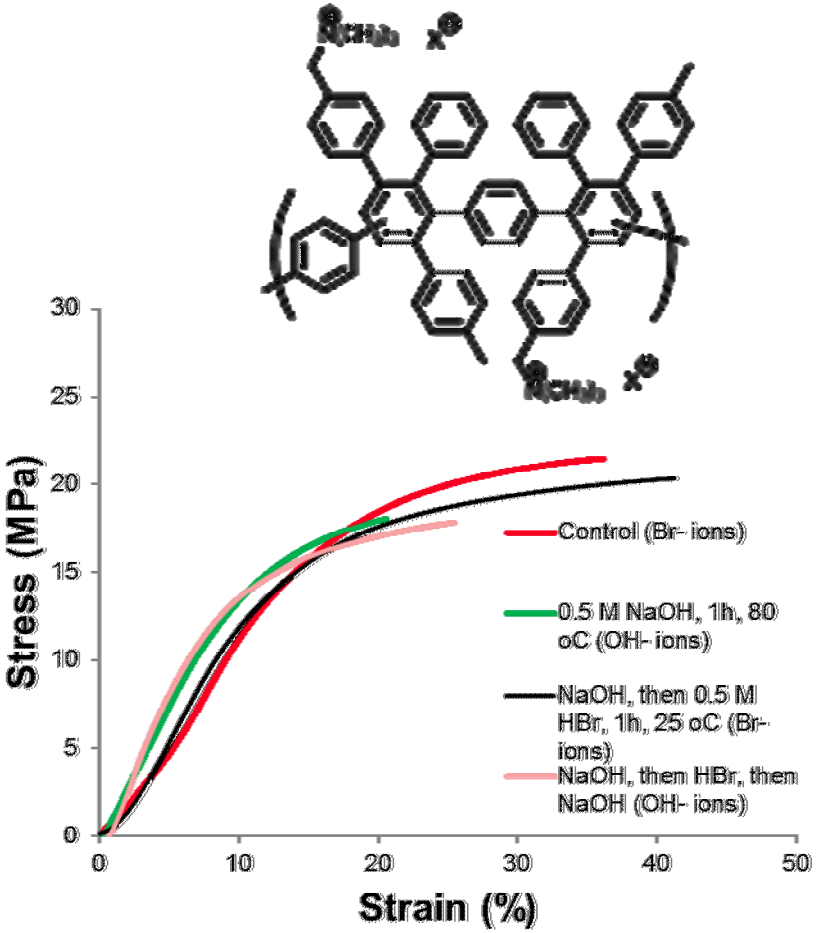
Contributors & Collaborators- SNL: Jeff Nelson and Michael Hibbs; LANL: Yu Seung Kim, Kwan-Soo Lee and Sandipkumar Maurya; PNNL: Vince Sprenkle, Wei Wang, and Xiaoliang Wei; ORNL: Tom Zawodzinski and Zhijiang Tang

Alkaline exchange membrane (AEM)





Anion exchange poly(phenylene) stable in alkaline environments, while poly (arylene ether)s develop mechanical issues