Advances in PNNL's Mixed Acid Redox Flow Battery Stack

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Pacific Northwest National Laboratory

Support from DOE Office of Electricity Delivery & Energy Reliability
Energy Storage Program

OE Energy Storage Systems Program Review
Washington DC
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Project Overview

Project Objective

- Develop a lower cost stack with improved performance to enable broader market penetration.
- Increase the current density by 20% over FY15 targets.
- Maintain a similar Stack Energy Efficiency (EE) to FY15 results (~75%).

Accomplishments

- Demonstrated >1 kW stack (3 cells) with ~74% energy efficiency at 400 mA/cm^2. 20 cell stack ~ 7.4 kW
- Cost model indicates Vanadium cost is primary driver
- 2 publications, 1 patent application in FY 16.

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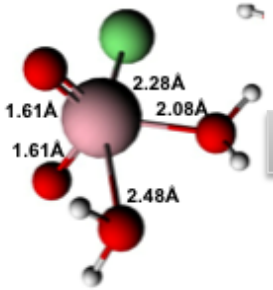
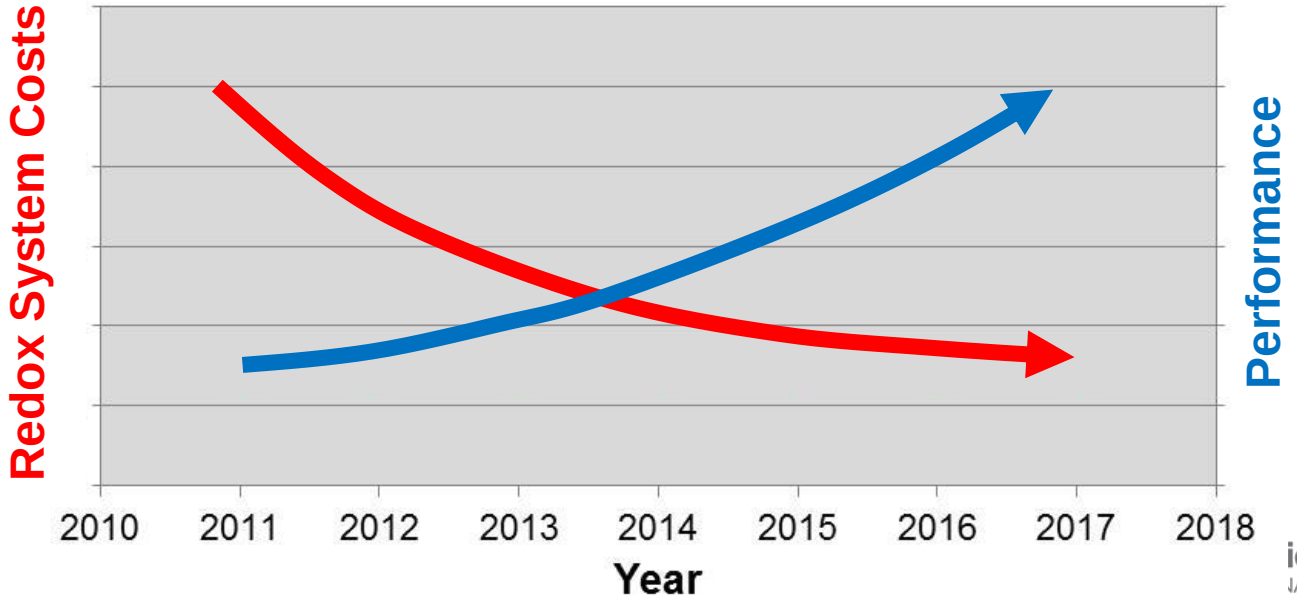
Redox Flow Battery Objectives

Develop the technologies, tools, and system understanding required to move the mixed acid electrolyte chemistry from basic chemistry to cost effective system solution.



Basic Chemistry

Applied Systems



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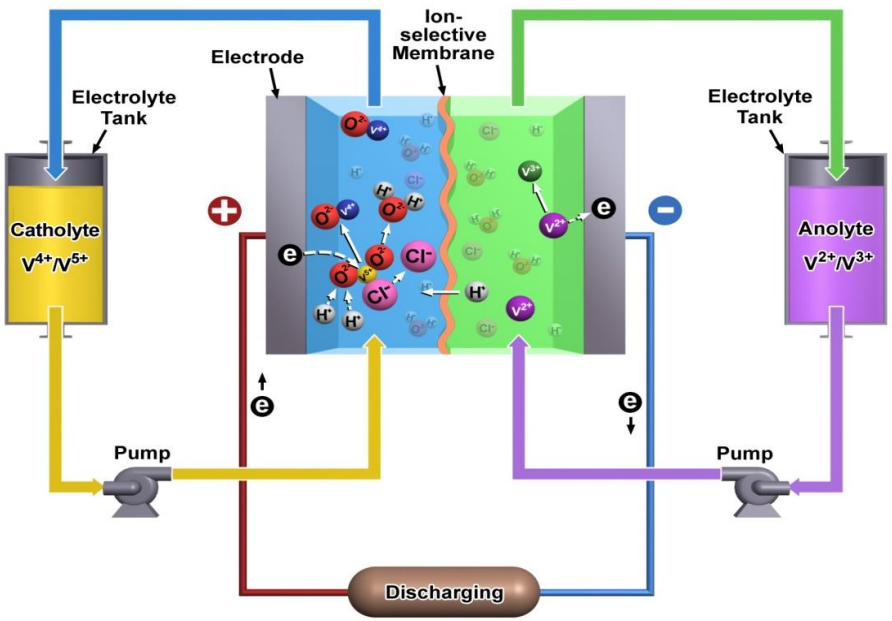
Vanadium Mixed Acid Electrolyte

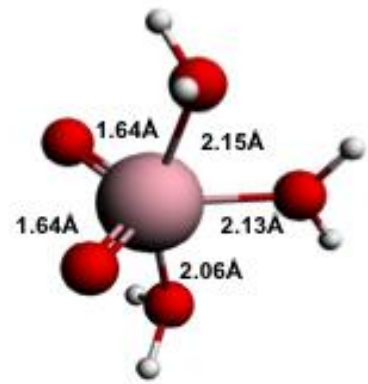


Catholyte: $VO^{2+} + Cl^- + H_2O - e \xleftrightarrow[\text{Discharge}]{\text{Charge}} VO_2Cl + 2H^+$ ε_{co}=1.0 V

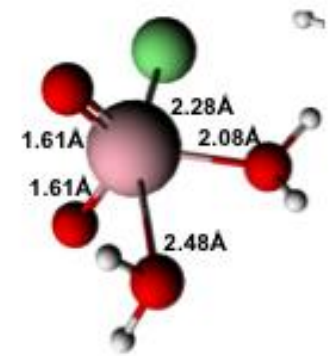
Anolyte: $V^{3+} + e \xleftrightarrow[\text{Discharge}]{\text{Charge}} V^{2+}$ ε_{ao}=-0.25

Overall: $VO^{2+} + Cl^- + H_2O + V^{3+} \xleftrightarrow[\text{Discharge}]{\text{Charge}} VO_2Cl + 2H^+ + V^{2+}$ E_0=1.25 V

- Power and Energy are separate enabling greater flexibility and safety.
- Suitable for wide range of applications 10's MW to ~ 5 kw
- Wide range of chemistries available.
- Low energy density ~ 30 Whr/kg



V^{5+} in sulfuric acid -- $[VO_2(H_2O)_3]^+$



V^{5+} in mixed acids -- $VO_2Cl(H_2O)_2$

Benefits

- ***70% increase in capacity***
- ***80% increase in operating temperature window.***
  - -5 – 50°C

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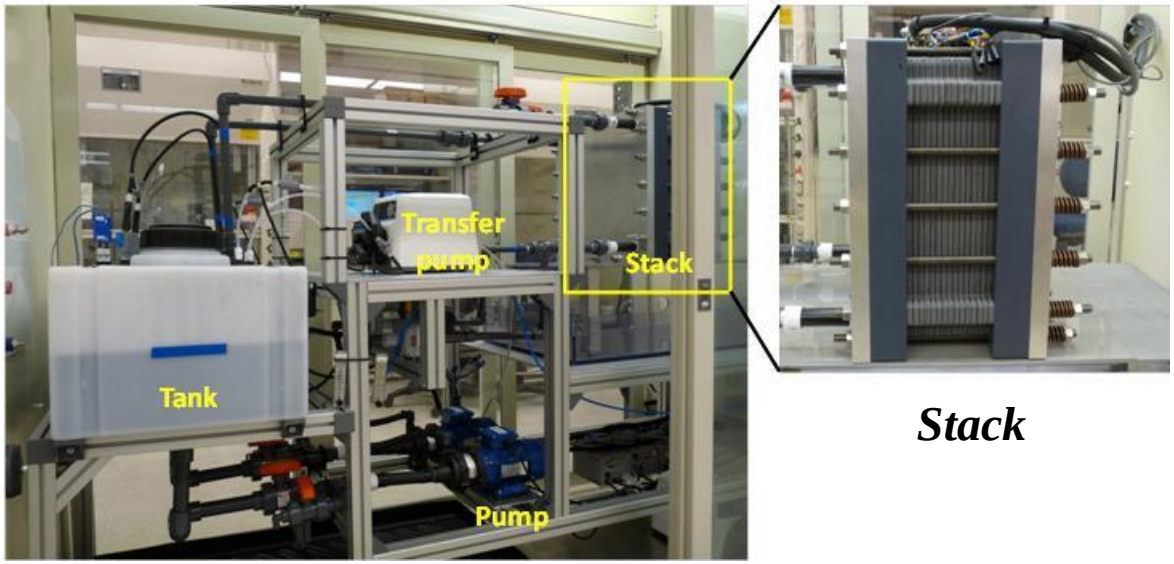
FY 16 VRFB Performance – Stack Testing



Stack

Test Parameters

- *780 cm²*
- *1-20 cell stacks*
- *15-85% SOC*
- *Mixed acid electrolyte*
  - *2M V, 2M S, 5M Cl*
- *Nafion® membrane*
  - *211 (~ 1 mil)*
  - *j = 160-400 mA/cm²*
- *Interdigitated flow design (IDD)*
- *Chillers to control temperature*

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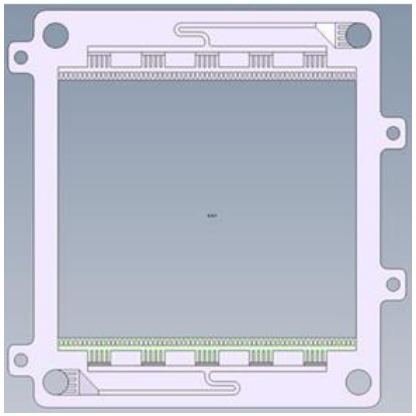
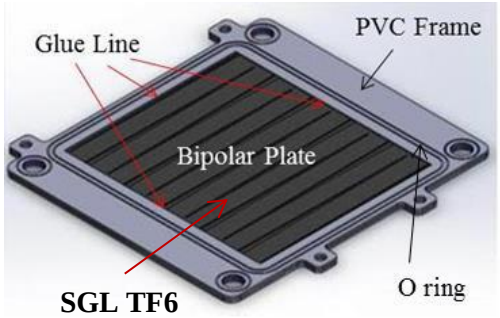
FY15 design at 400 mA/cm^2

PVC frame

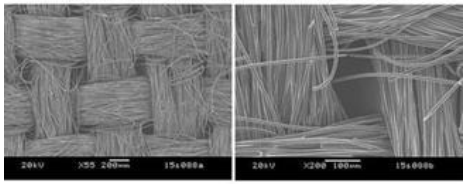


FY15 IDD laminated

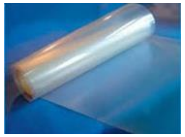


SGL TF6 Graphite Sheets

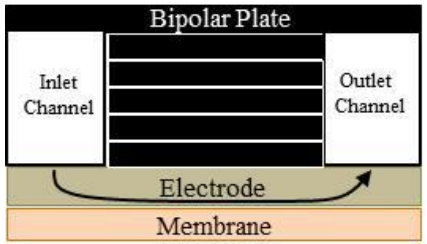
Electrode microstructure

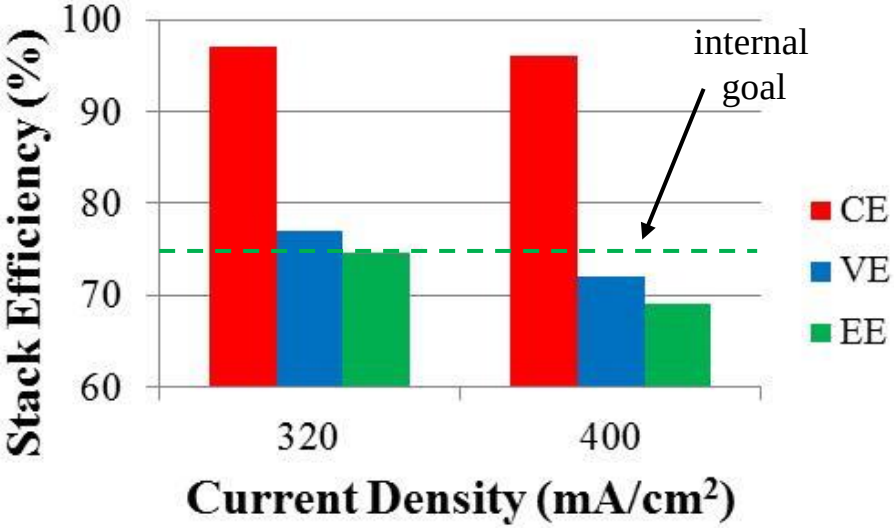


Nafion® 212



Side View of FY15 IDD laminated





- ~ 5% reduction in stack EE from 320 mA/cm^2 to 400 mA/cm^2

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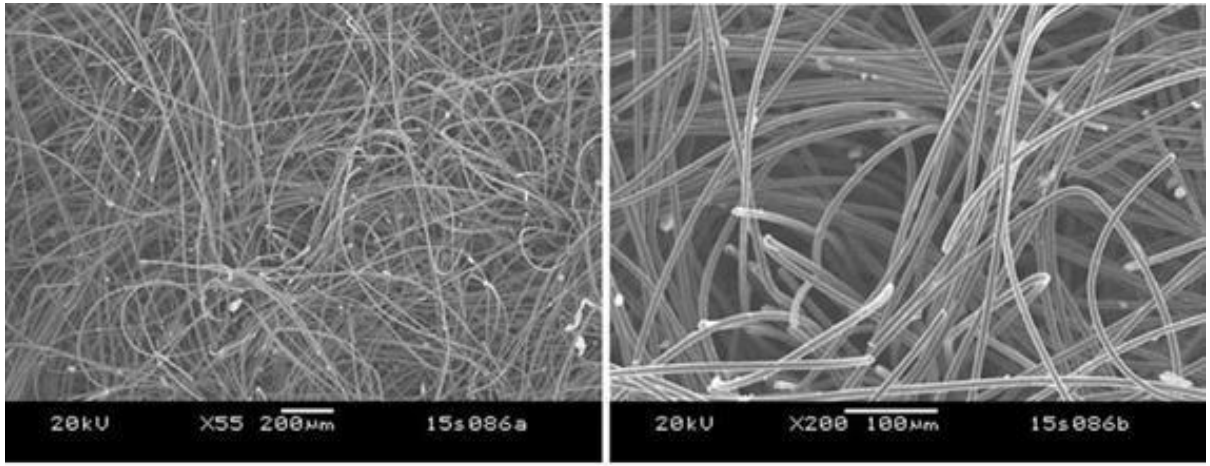
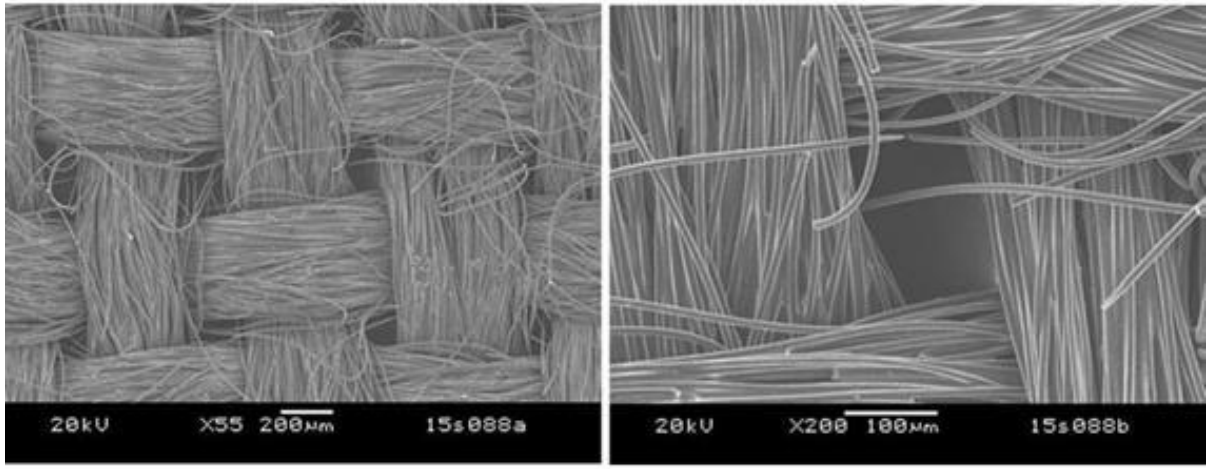
FY16 Stack Performance - Electrodes

	Surface Area (m^2/g)	Thickness (mm)	Porosity (%)	Conductivity (S/cm)
SGL GFD 2.5	0.1	2.5	95	1.7
ELAT- H	3	0.4	80	2.7

SGL GFD 2.5



ELAT-H



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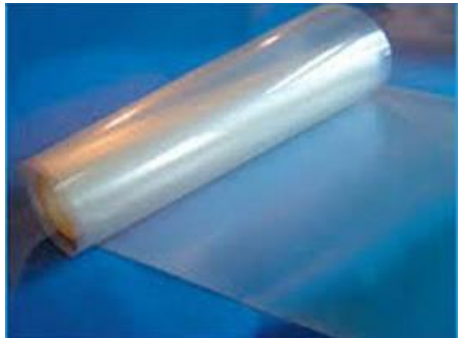
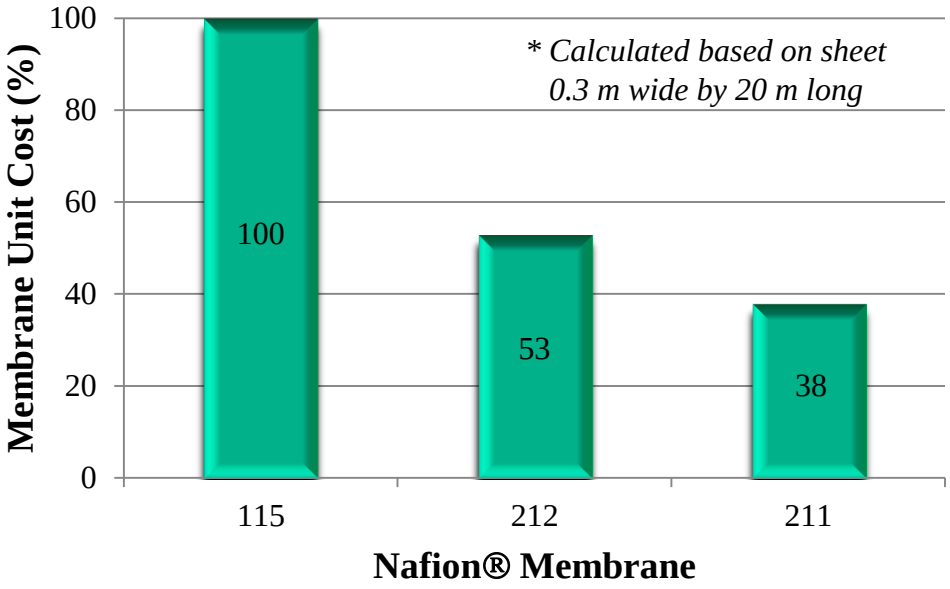
FY16 Stack Performance – Nafion® Membrane

	Nafion® Membrane		
	115	212	211
Prep Technique	extruded	cast	cast
Conductivity (S/cm)	~0.1	~0.1	~0.1
Thickness (mils)	5	2	1
Year Utilized	FY 13	FY 14 -FY 15	FY 16





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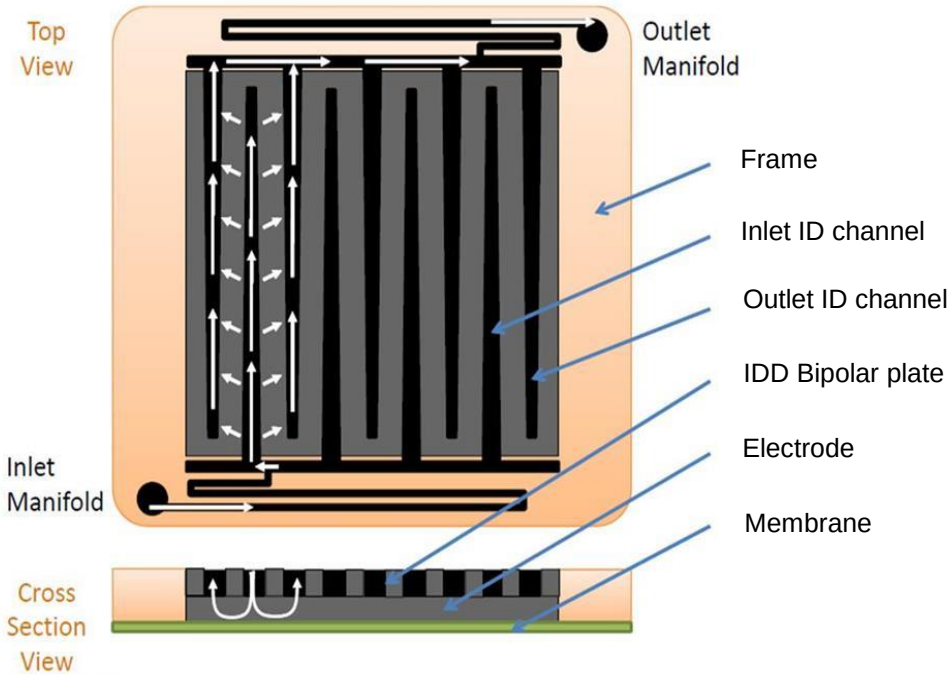
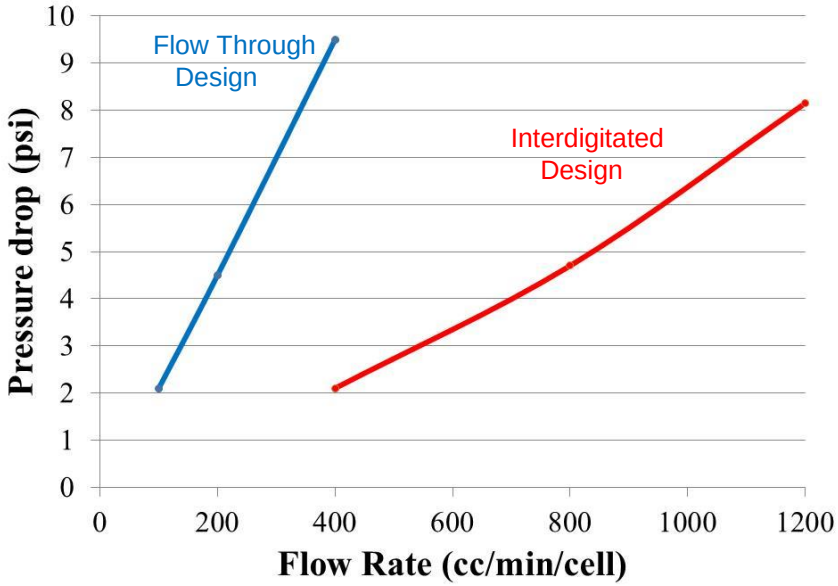
FY16 Stack Performance

Interdigitated Flow Design





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- ~ 3-4X decrease in pressure using interdigitated flow design

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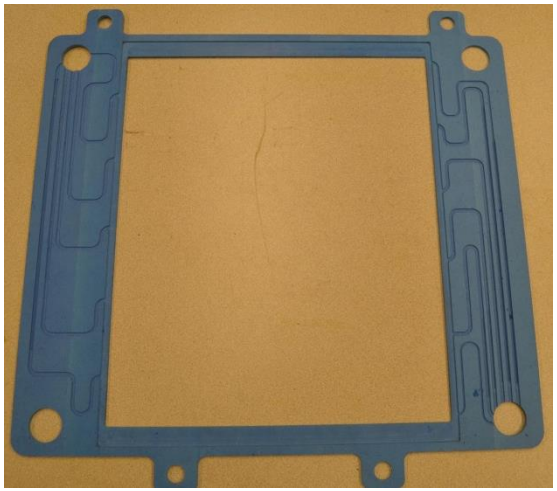
FY16 Stack Performance – Bipolar/IDD Monolith

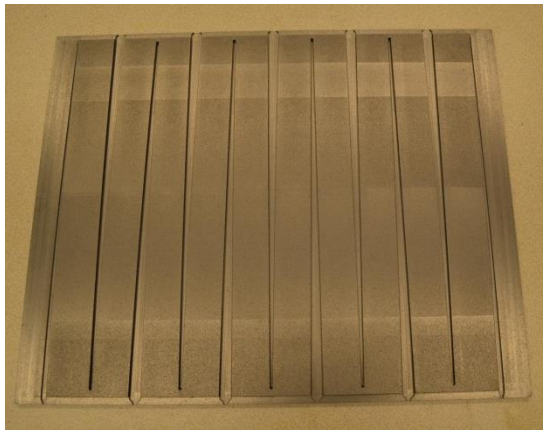
Flow Frame

*Glass fiber loaded vinyl ester**



IDD Monolith

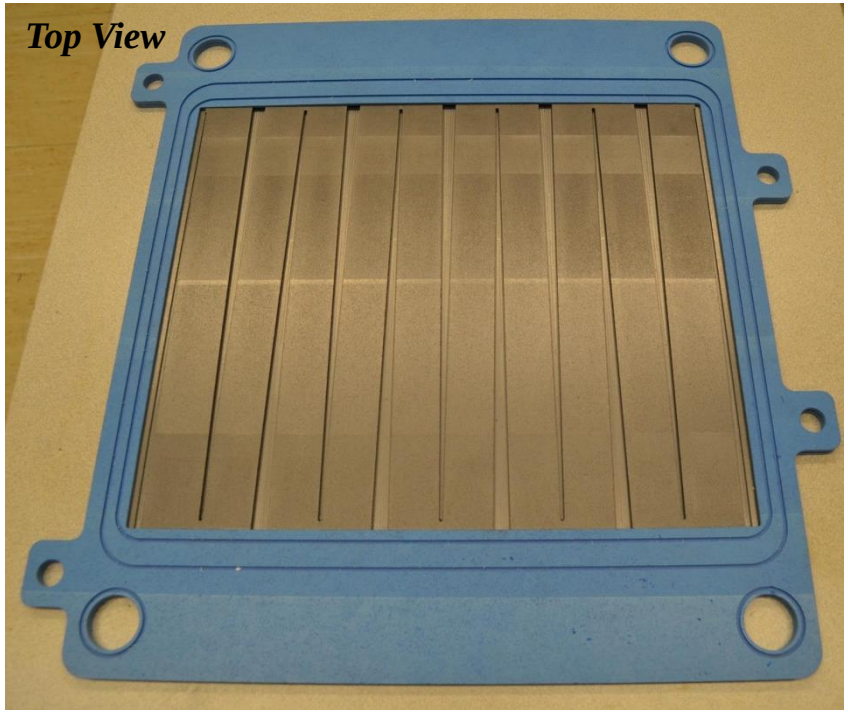
*Graphite loaded vinyl ester**



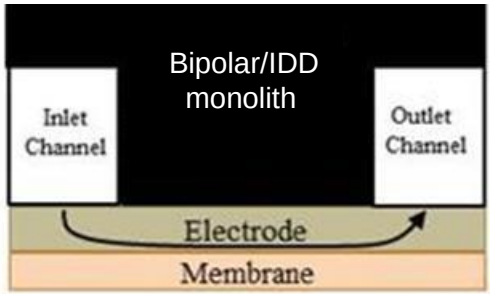
* Bulk Molding Compounds, Inc.

Assembled Cell

Top View



Side View



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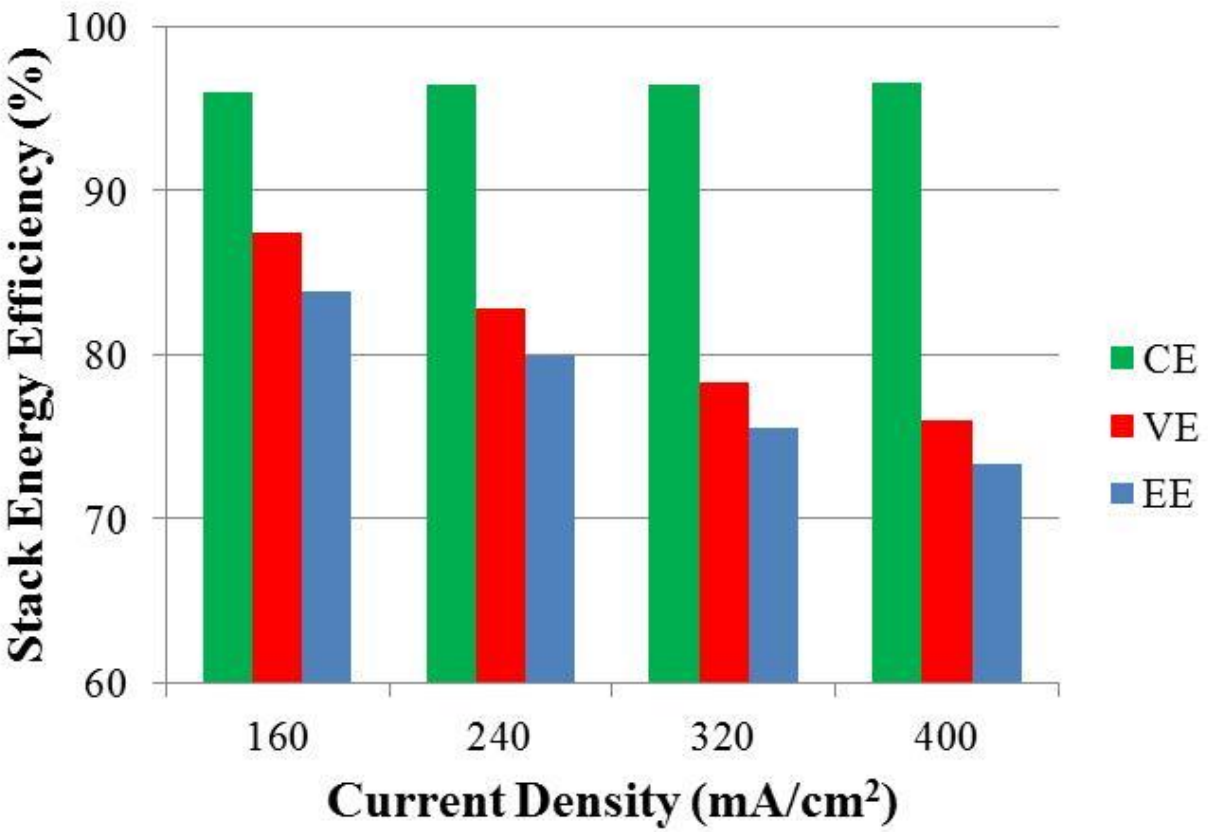
FY16 Stack Performance

3 Cell Stack, Nafion 211, ELAT Electrodes, IDD monolith



- Using monolith IDD and Nafion 211, the stack EE is ~74%

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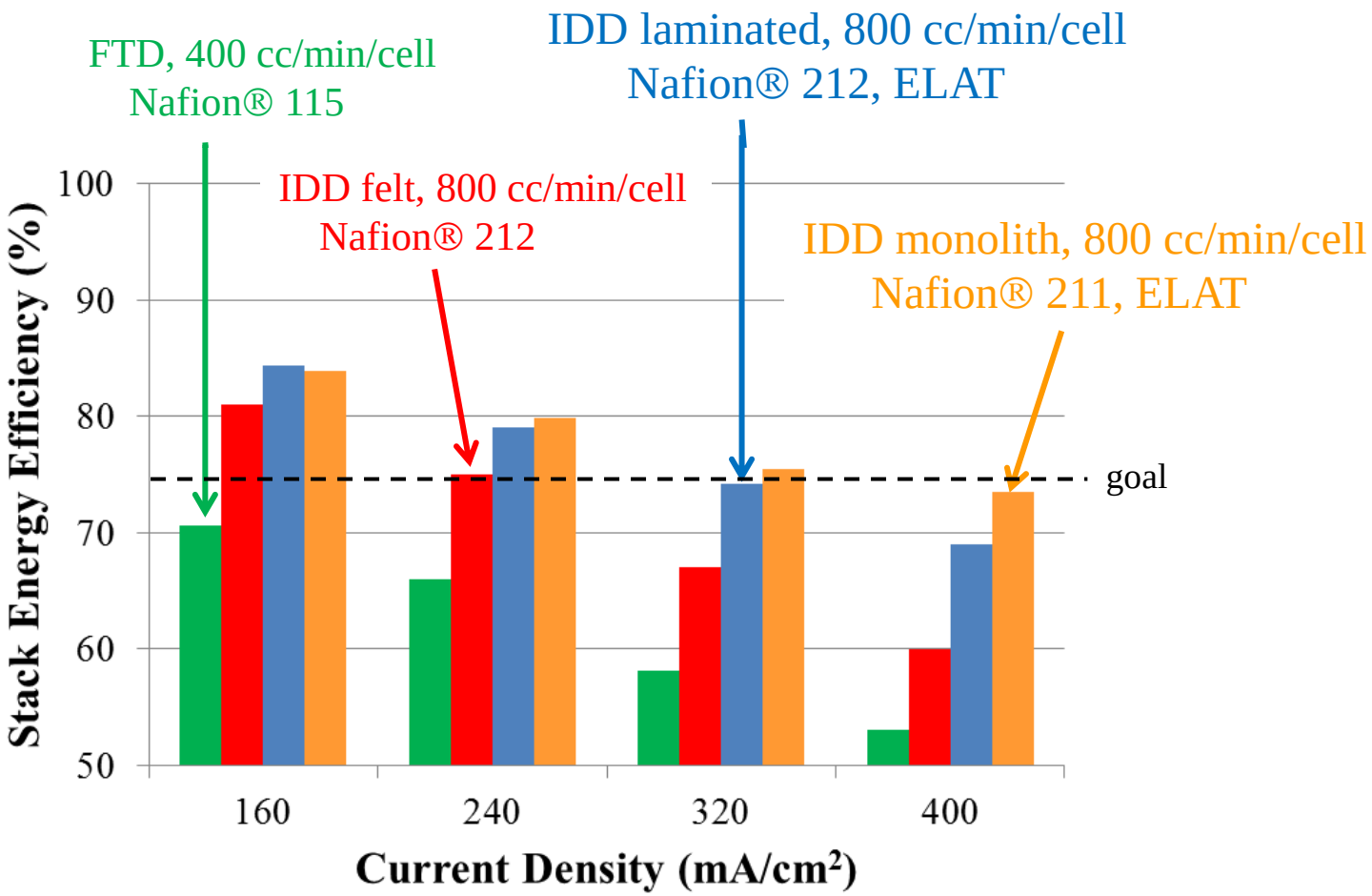
FY16 Stack Performance



- The stack EE has been held relatively constant as the current density has been increased from 160 to 400 mA/cm^2.

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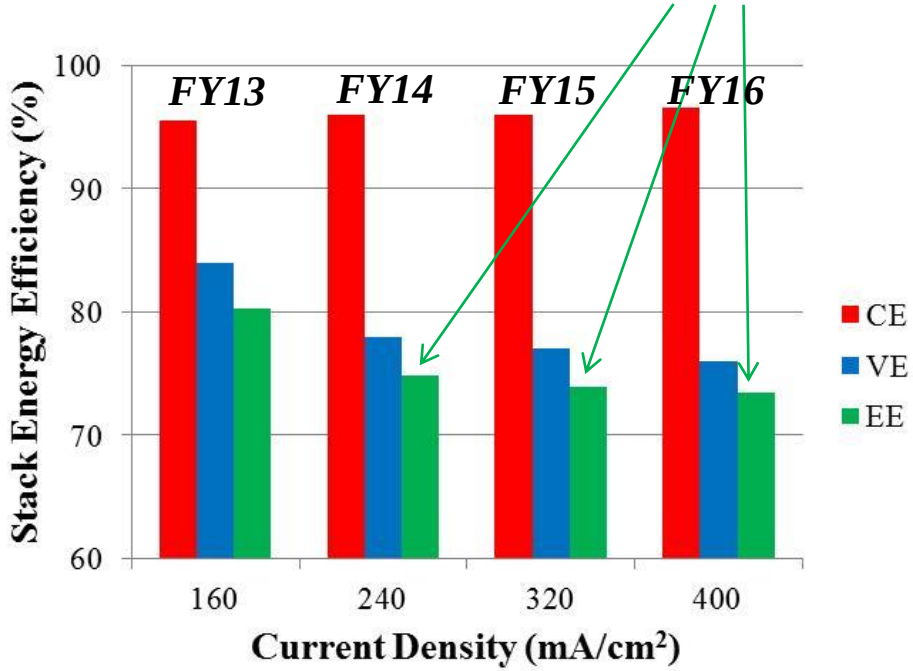
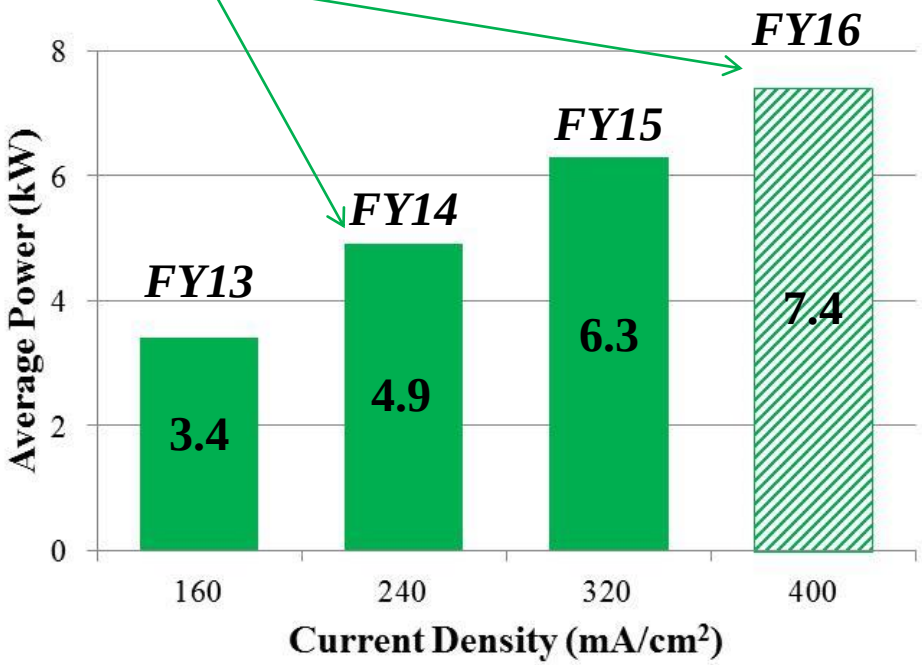
FY 16 VRFB 8kW Performance

20 Cell Stacks

Similar EE with 35% increase in power





- Similar stack EE in comparison to FY14 & FY15
- ~35% increase in Power

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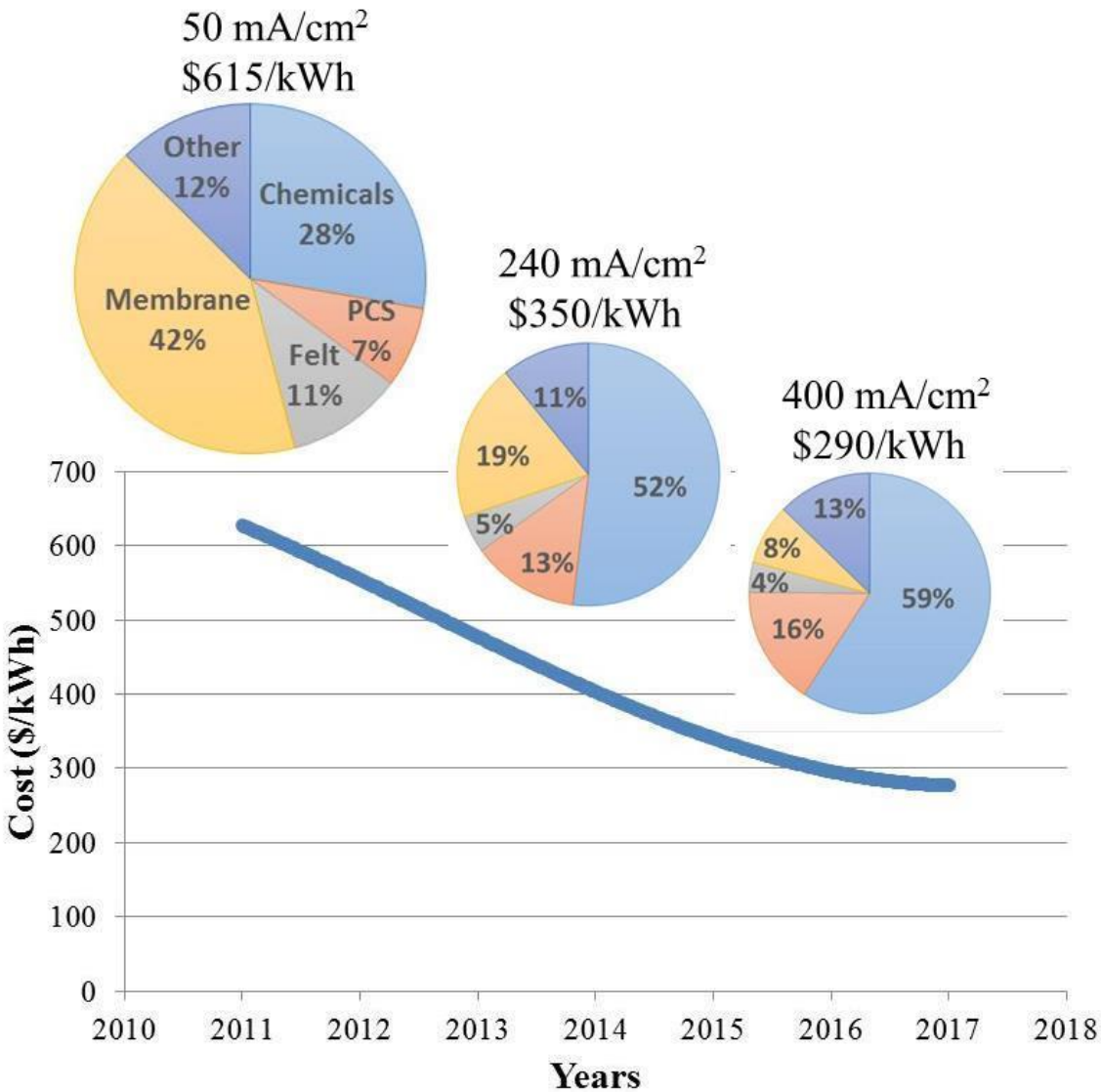
FY 16 VRFB Stack Performance – System Costs



- Membrane cost has been significantly reduced
- Primary driver is cost of vanadium

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Summary/Conclusions

- The 3 cell stack operated at 400 mA/cm^2 with a monolith IDD and thinner Nafion® 211 membrane resulted in:
  - Stack EE ~ 74% (similar EE to FY14 and FY 15 designs operated at 240 and 320 mA/cm^2)
  - ~ 35% increase in power over FY14/FY15
  - Stable performance over a range of temperatures and flow rates using the mixed acid electrolyte
  - Cost model indicates Vanadium cost is primary driver

Acknowledgements

- Support from US DOE Office of Electricity Delivery & Energy Reliability - Dr. Imre Gyuk, Energy Storage Program Manager

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