Advances in PNNL's Mixed Acid Redox Flow Battery Stack

David Reed, Ed Thomsen, Wei Wang, Zimin Nie, Bin Li, James Kizewski, and Vincent Sprenkle.

Pacific Northwest National Laboratory

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Energy Storage Program

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Topics

- Project Overview
- Background
- FY 15 Stack performance
  - Improved electrodes
  - Modified interdigitated design
- Conclusion and Future Work

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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 33% over FY14 targets.
- Maintain a similar Stack Energy Efficiency (EE) to FY14 results (~75%).

Accomplishments

- Demonstrated 5kW stack with ~75% energy efficiency at 320 mA/cm^2.
- Stack energy efficiency is less flow rate dependent than previous stack designs.
- 4 publications specific to kW class stack advances (to date).

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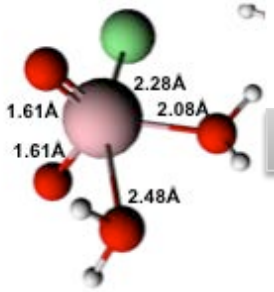
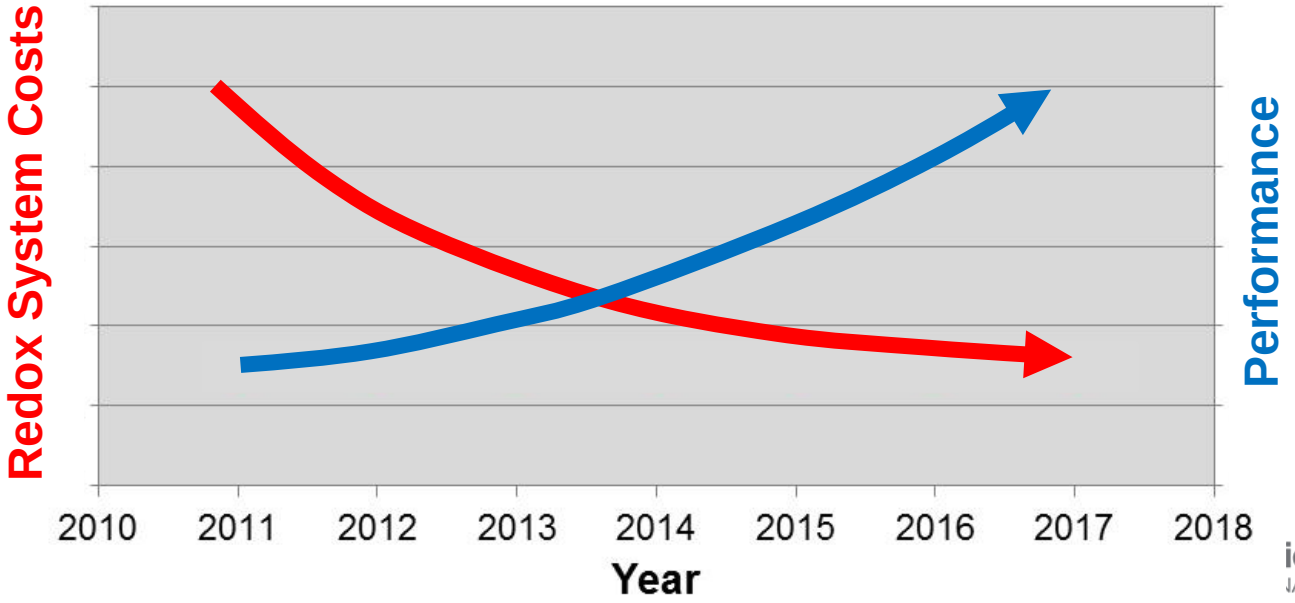
Redox Flow Battery Objectives

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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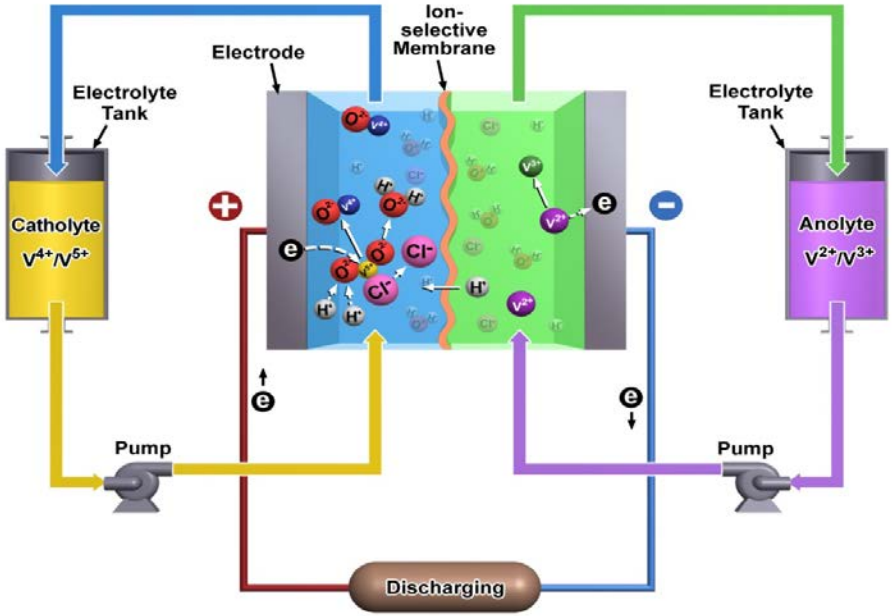
Vanadium Mixed Acid Electrolyte

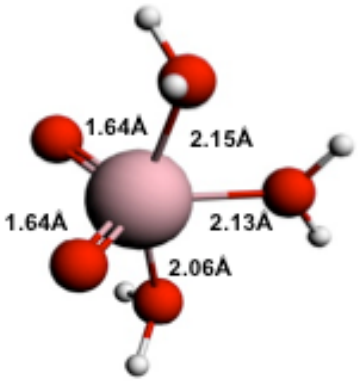


Catholyte: $VO^{2+} + Cl^- + H_2O - e \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} VO_2Cl + 2H^+$ ε_{co}=1.0 V

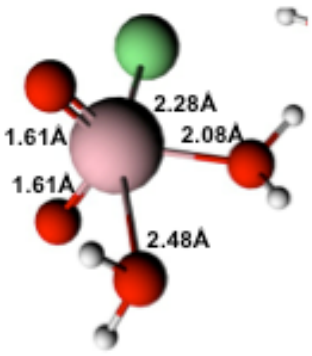
Anolyte: $V^{3+} + e \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} V^{2+}$ ε_{ao}=-0.25

Overall: $VO^{2+} + Cl^- + H_2O + V^{3+} \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} VO_2Cl + 2H^+ + V^{2+}$ 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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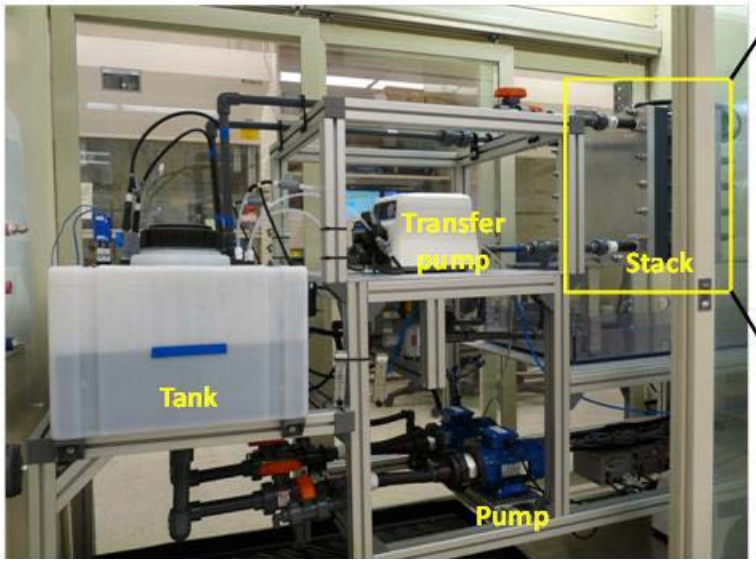
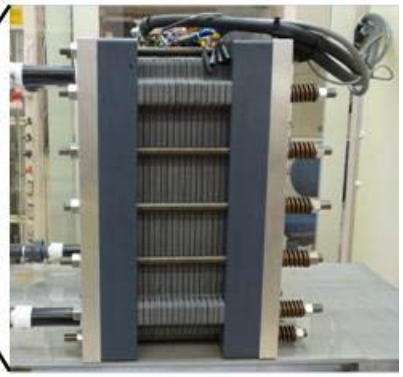
FY 15 VRFB 5kW Performance





Stack

Test Parameters

- *780 cm²*
- *1-20 cell stacks*
- *15-85% SOC*
- *Mixed acid electrolyte*
  - *2M V, 2M S, 2M Cl*
- *Nafion® membrane*
  - *212 (~ 2 mil)*
  - *j = 160-320 mA/cm²*
- *Modified interdigitated flow design*
- *6 kW stack*
- *Chillers to control temperature*

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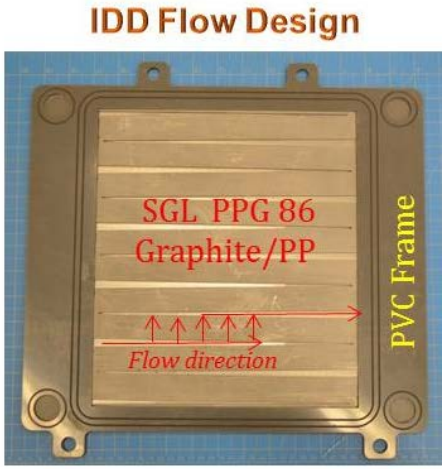
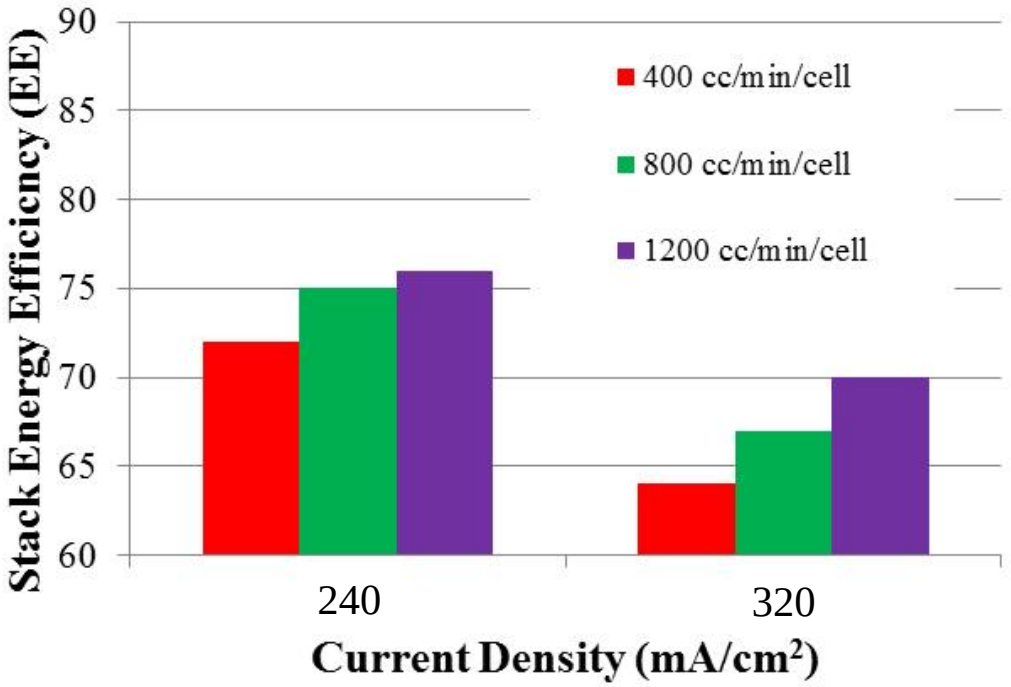
FY15 Stack Performance

FY14 design at 320 mA/cm²





- ~ 6-8% reduction in stack EE from 240 mA/cm² to 320 mA/cm²

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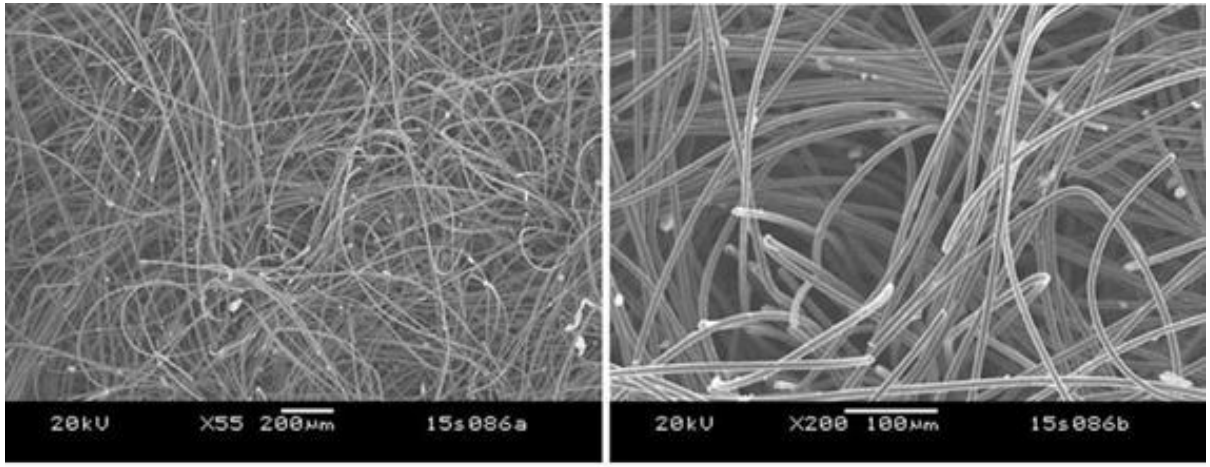
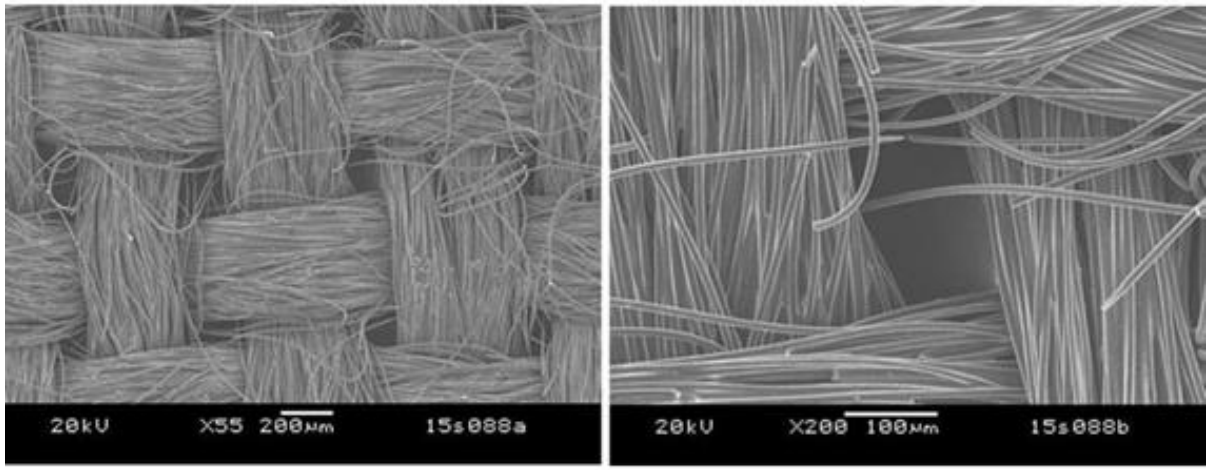
FY15 Stack Performance - Electrodes

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

SGL GFD 2.5



ELAT-H



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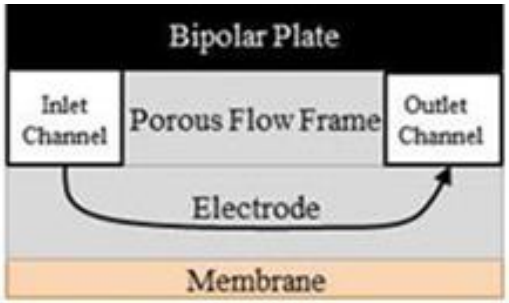
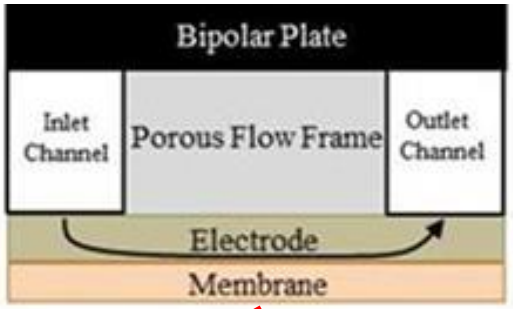
FY15 Stack Performance – Modified IDD

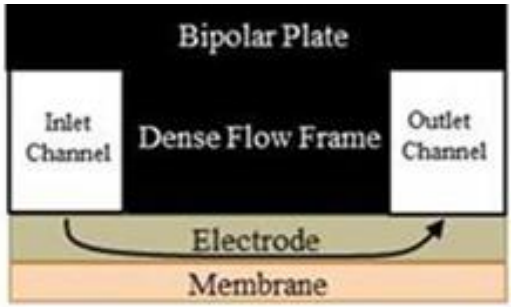
IDD 1

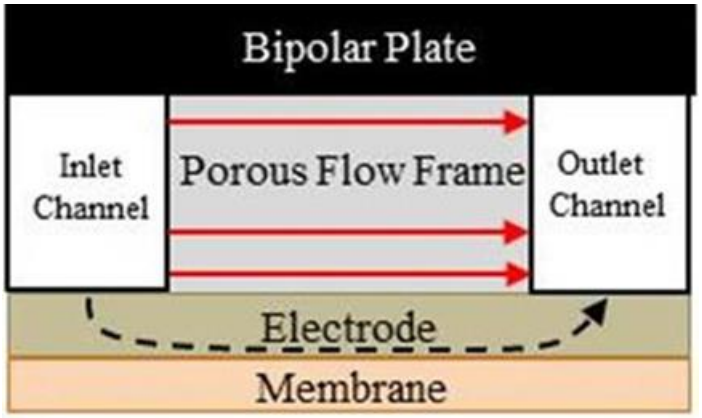


IDD 2p



IDD 2s





- Lower performance than IDD 1
- Low resistance path through the porous flow frame rather than electrode
- Eliminated from investigation

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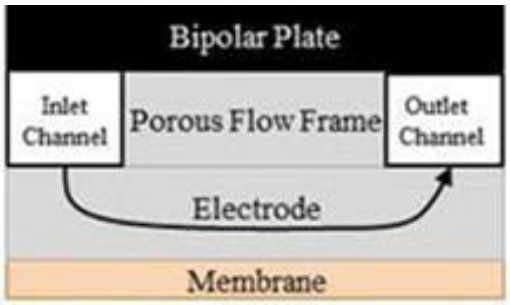
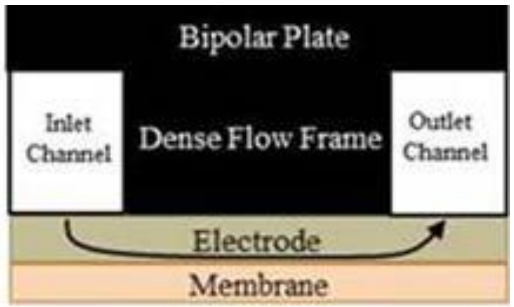
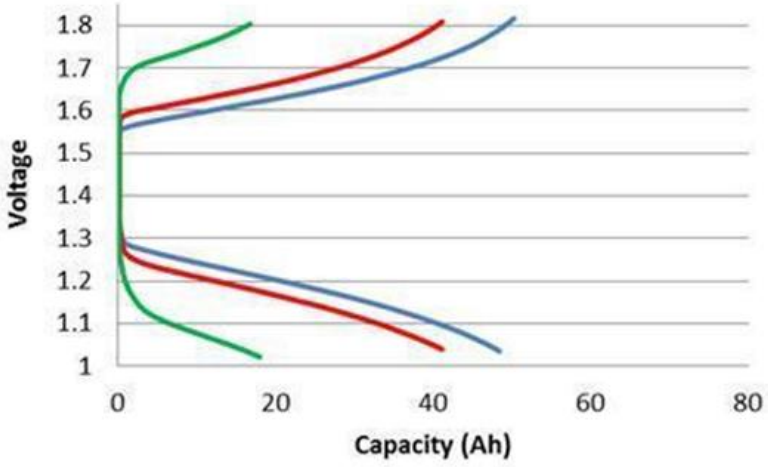
FY15 Stack Performance – 320 mA/cm²

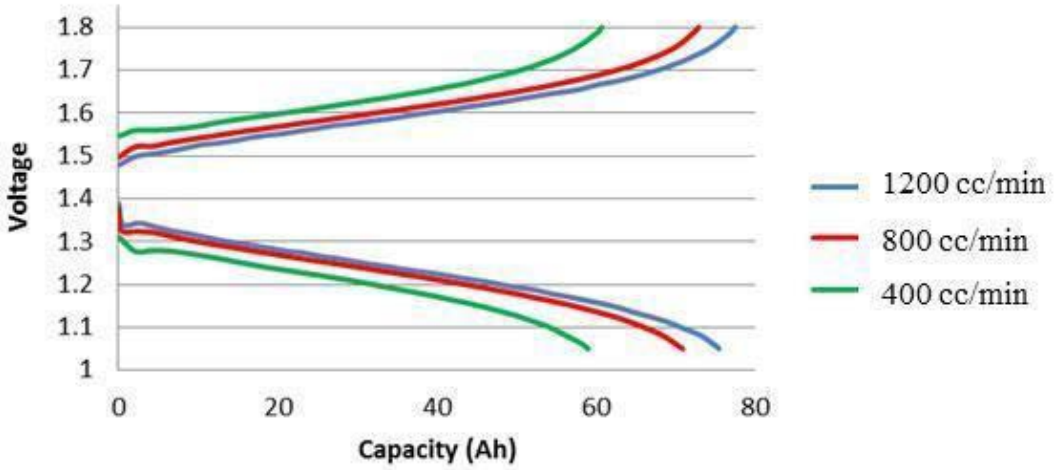
IDD 1



IDD 2s







- IDD 2s design attains a higher capacity at a given cut off window.
- IDD 1 has a much higher charge/discharge overpotential at a lower capacity

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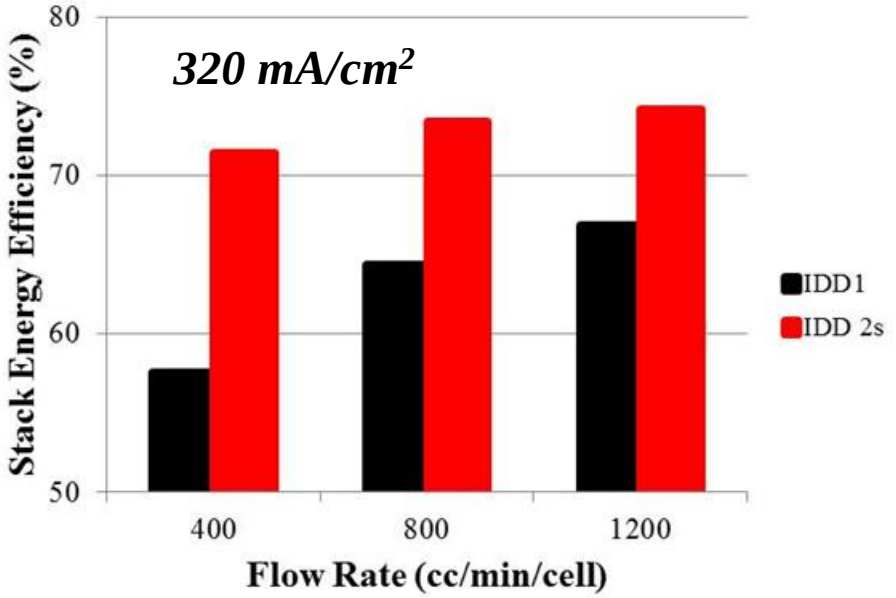
FY15 Stack Performance

	Flow Rate (cc/min/cell)	160 mA/cm²		240 mA/cm²		320 mA/cm²	
		VE	EE	VE	EE	VE	EE
IDD 1	400	76.3	73.3	67.3	65.3	59.5	57.5
IDD 2s	400	84.2	82.2	78.4	76.5	73.3	71.4
IDD 1	800	81.2	77.6	74.3	71.8	67.3	64.3
IDD 2s	800	85.9	83.6	80.5	78.5	75.3	73.4
IDD 1	1200	82.2	78.3	75.7	72.1	69.2	66.8
IDD 2s	1200	86.8	84.4	81.4	79	76.4	74.2



- IDD 2s has ~ 9-15% improvement in stack EE with highest increase at low flow rates
- IDD 2s is less flow rate dependent which could improve overall system efficiency (pressure drop, pumping power)

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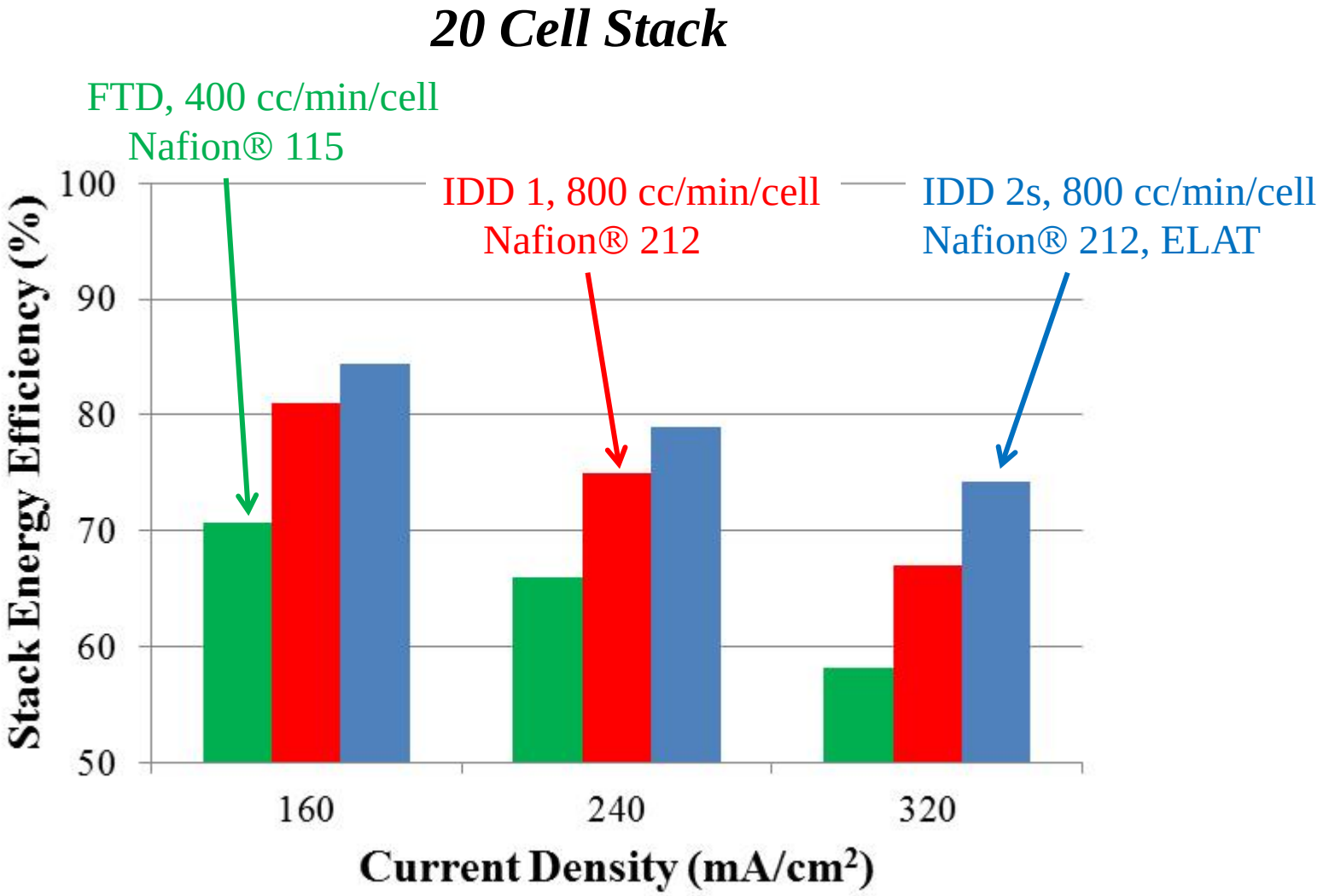
FY15 Stack Performance



- With modifications to the cell, the current density has been doubled with ~ 4% increase in stack EE

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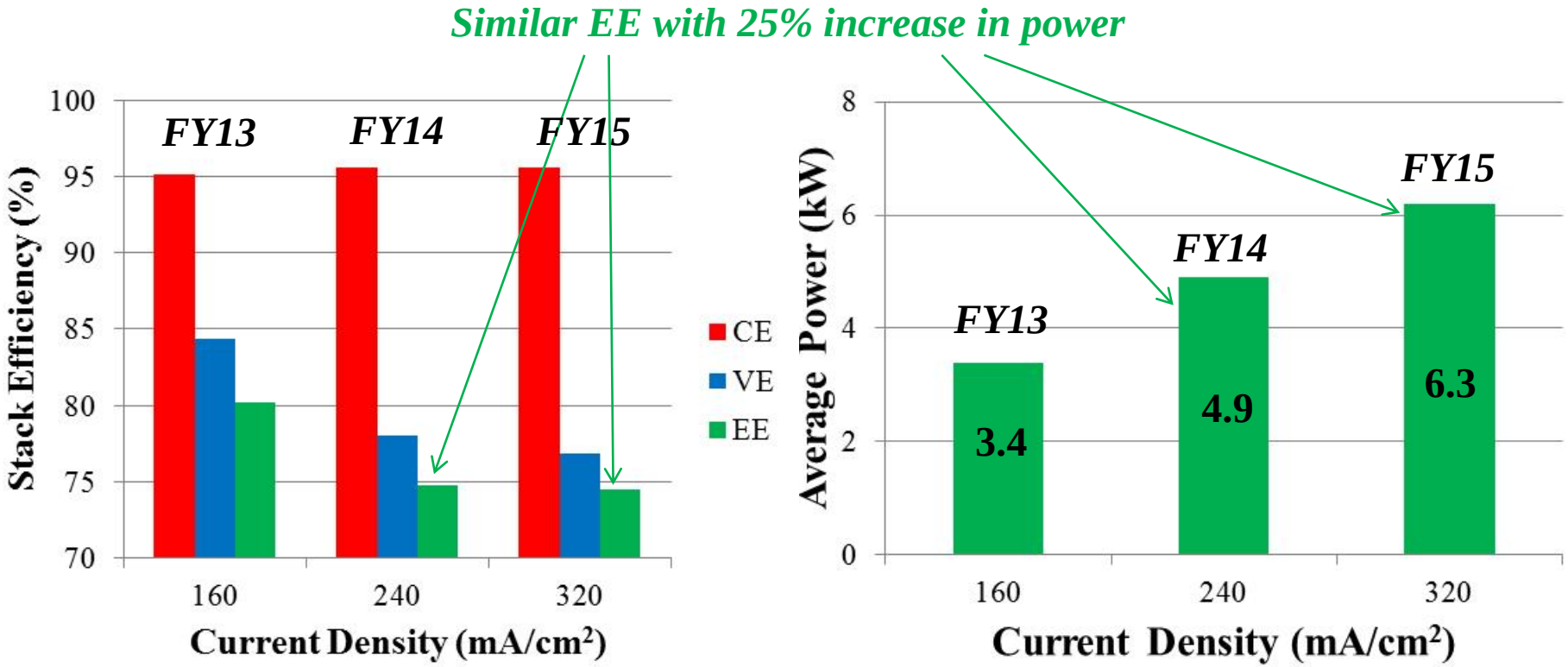
FY 15 VRFB 6kW Performance

20 Cell Stack – 50℃ , 800 cc/min/cell, Nafion® 212



- Similar stack EE in comparison to FY14
- 25% increase in Power

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Summary/Conclusions

- The 6kW class – 20 cell stack operated at 320 mA/cm^2 with a modified IDD and improved electrode microstructure resulted in
  - ~ 25% increase in power
  - Stack EE ~ 75% (similar EE to FY14 design operated at 240 mA/cm^2)
  - EE found to be less flow rate dependent
  - With modifications to the cell, the current density has been doubled with ~ 4% increase in stack EE
  - Stable performance over a range of temperatures and flow rates using the mixed acid electrolyte

Acknowledgements

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