Advances in PNNL's Mixed Acid Redox Flow Battery Stack

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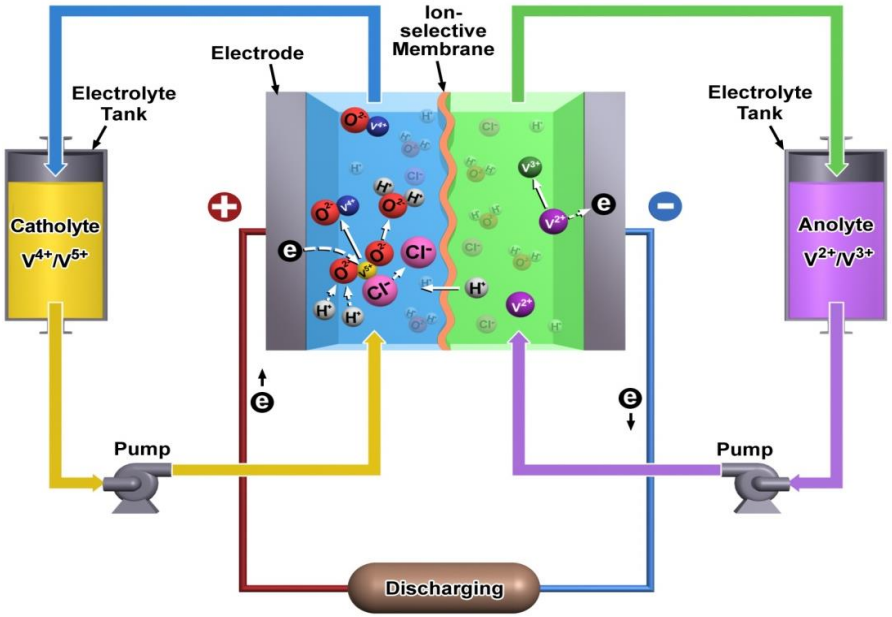
Topics

- FY 14 Objectives and Goals
- Background
- Nafion® membrane thickness development.
- Low cost interdigitated flow design
- 4 KW stack
- Conclusion and Future Work

FY14 Redox Objectives and Goal

- Operate at 240 mA/cm^2 with improved stack energy efficiency and lower stack pressure drop.
- Greater stack efficiency
  - Use of 212/211 membrane versus 115.
- Greater system efficiency
  - Use of interdigitated flow field
- Understand influence of temperature on stack efficiency

Vanadium Mixed Acid Electrolyte

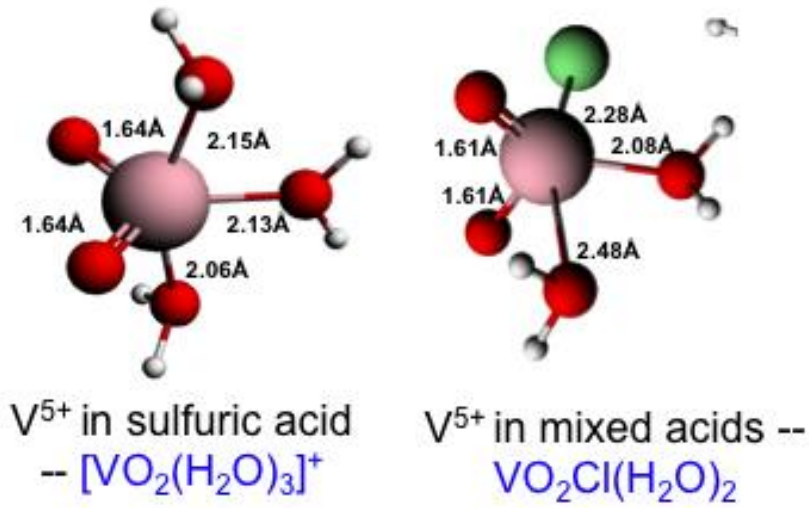


Catholyte: $VO^{2+} + Cl^- + H_2O - e \xrightleftharpoons[\text{Discharge}]{\text{Charge}} VO_2Cl + 2H^+$ ε_{co}=1.0 V

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

Overall: $VO^{2+} + Cl^- + H_2O + V^{3+} \xrightleftharpoons[\text{Discharge}]{\text{Charge}} VO_2Cl + 2H^+ + V^{2+}$ 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 -- $VO_2Cl(H_2O)_2$

- ***70% increase in capacity***
  - V^{2+}, V^{3+}, V^{4+}, V^{5+} stable >2.8M, in SO^{2-} and Cl^- mixed solutions
- ***80% increase in operating temperature window.***
  - -5 – 50°C

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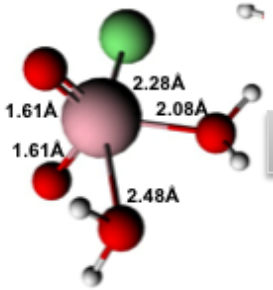
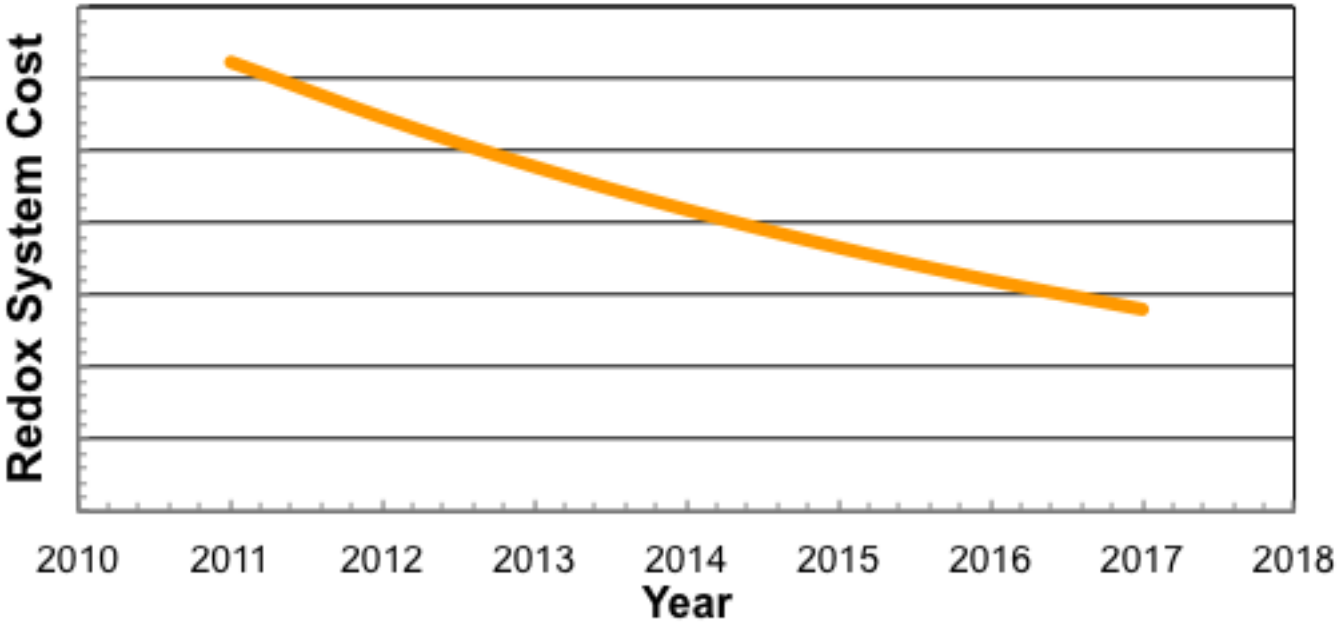
Redox Flow Battery Objectives

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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FY14 Stack Performance (Nafion® 115, 212 and 211)

VRFB System

Test Parameters

- *780 cm²*
- *3 cell stacks*
- *15-85% SOC*
- *Mixed acid electrolyte*
  - *2M V, 2M S, 2M Cl*
- *Nafion® membrane*
  - *115 (~ 5 mil)*
  - *212 (~ 2 mil)*
  - *211 (~1 mil)*
- *j = 160 and 240 mA/cm2*
- *Flow through design*

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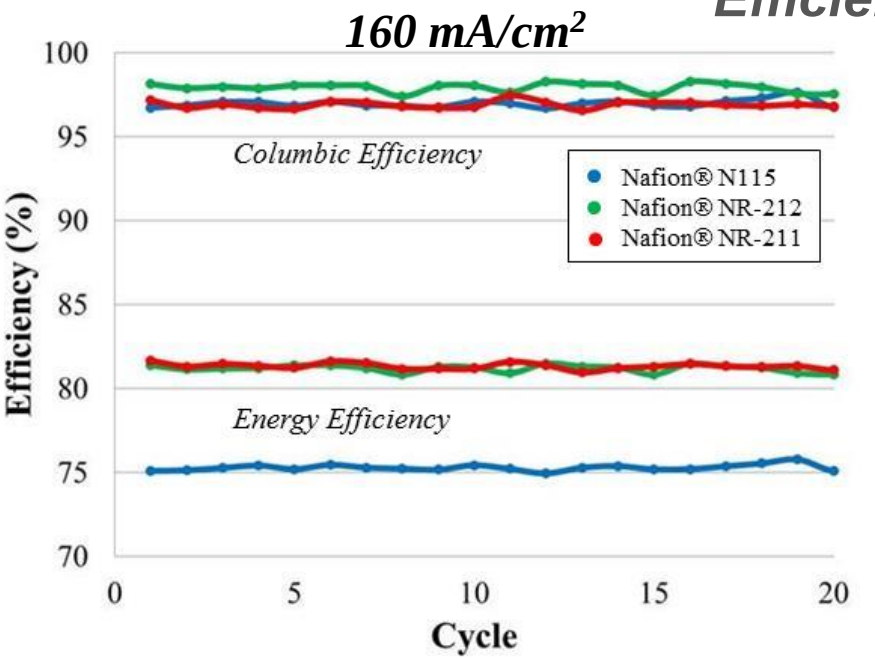
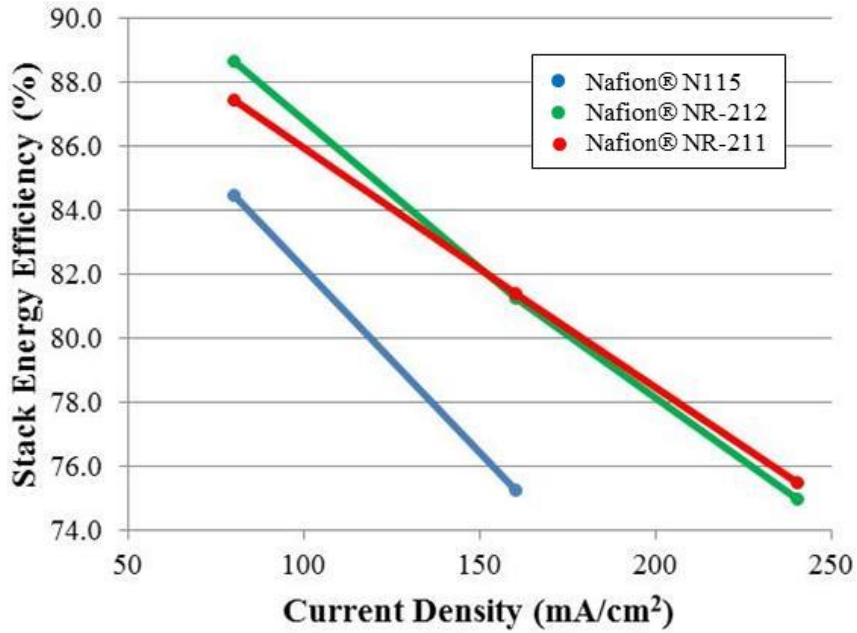
FY14 Stack Performance (Nafion® 115, 212 and 211)

Efficiencies

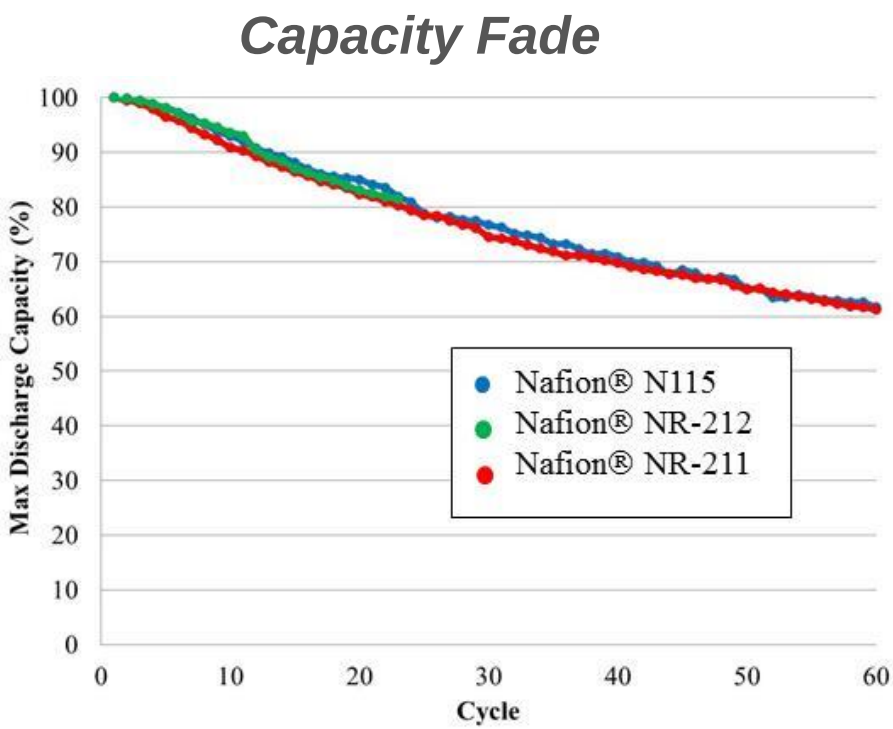


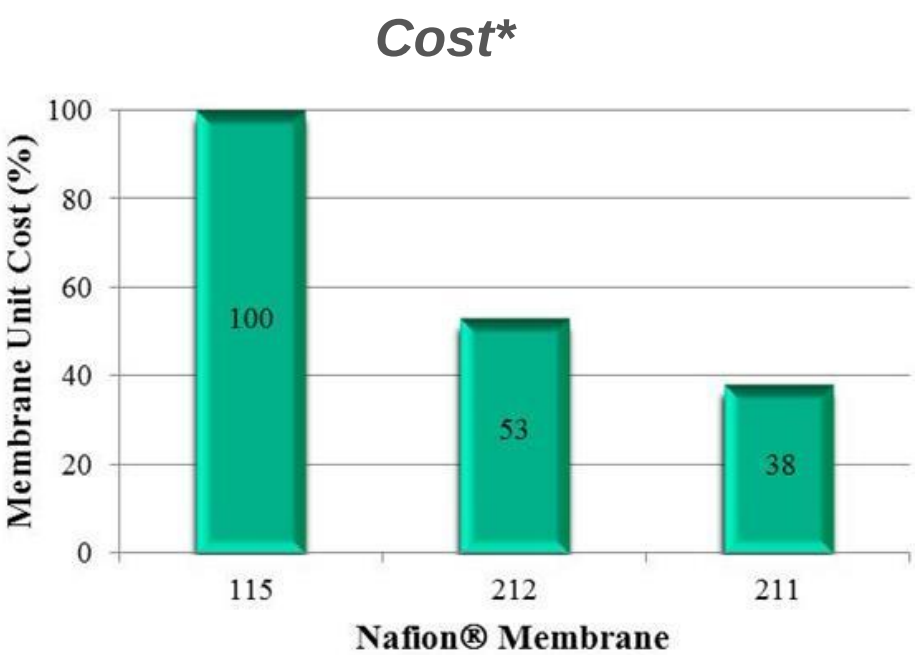


@Flow Rate = 6 lpm (400 cc/min/cell)

	Columbic Efficiency (%)	Voltage Efficiency (%)	Energy Efficiency (%)	Discharge Capacity (Ah)	Discharge Temp (°C)	Pressure (psi)
160 mA/cm²						
Nafion® 115	96.9	77.7	75.3	18.2	39.9	6.5
Nafion® 212	97.9	82.9	81.2	19.2	39.9	6.9
Nafion® 211	96.9	84.0	81.4	20.1	38.8	6.9
240 mA/cm²						
Nafion® 212	98.0	76.5	75.0	16.7	44.6	6.1
Nafion® 211	97.0	77.8	75.5	18.1	45.5	5.9

FY14 Stack Performance (Nafion® 115, 212 and 211)





* Ion Power, Inc – based on 20 m length

- Substitution of Nafion® 212 and 211 for 115 in 3-cell stack leads to
  - ~5 - 10% increase in Energy Efficiency ($\geq$ 160 mA/cm^2)
  - Similar capacity fade
  - Cost reduction
- Nafion® 211 more difficult to handle

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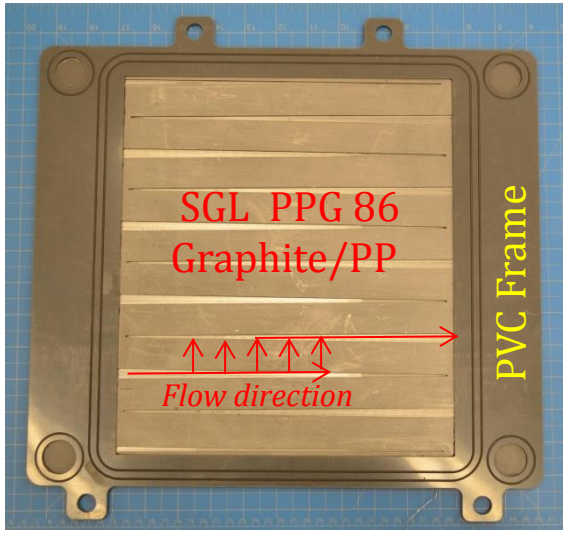
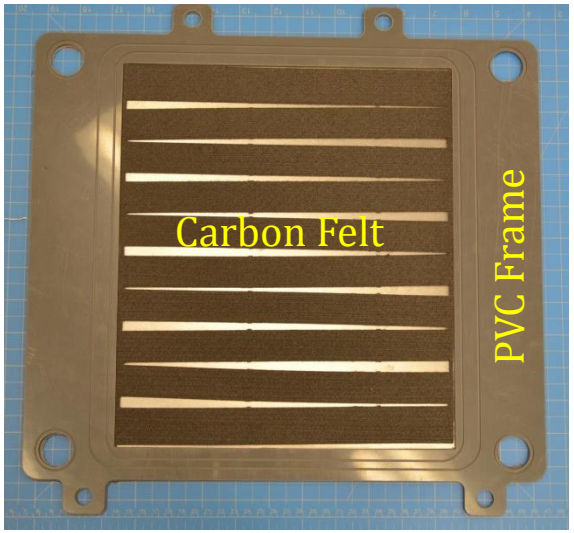
FY14 Stack Performance (Low Cost IDD Flow Design)

Flow Through Design

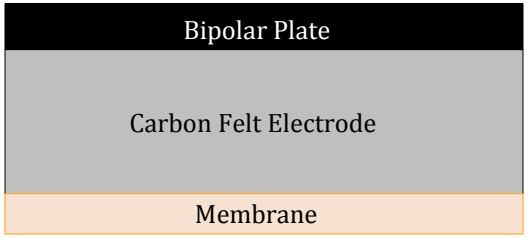
IDD Flow Design



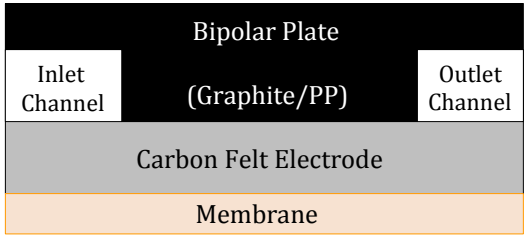
Low Cost IDD Flow Design



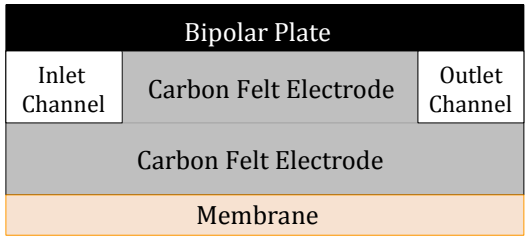
(FTD)



(IDD 1)



(IDD 2)



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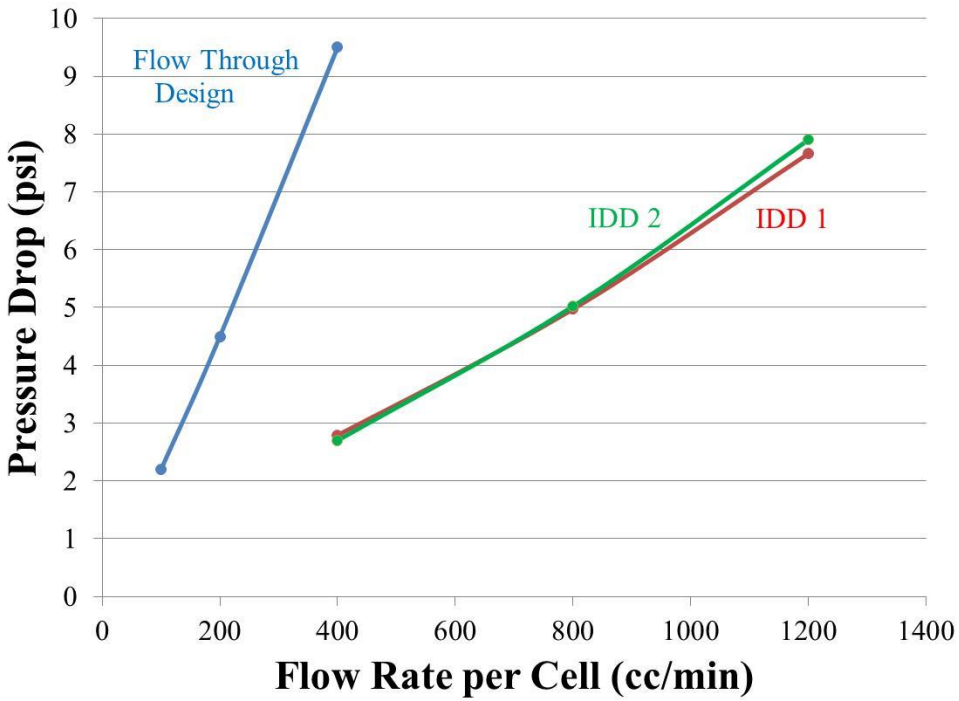
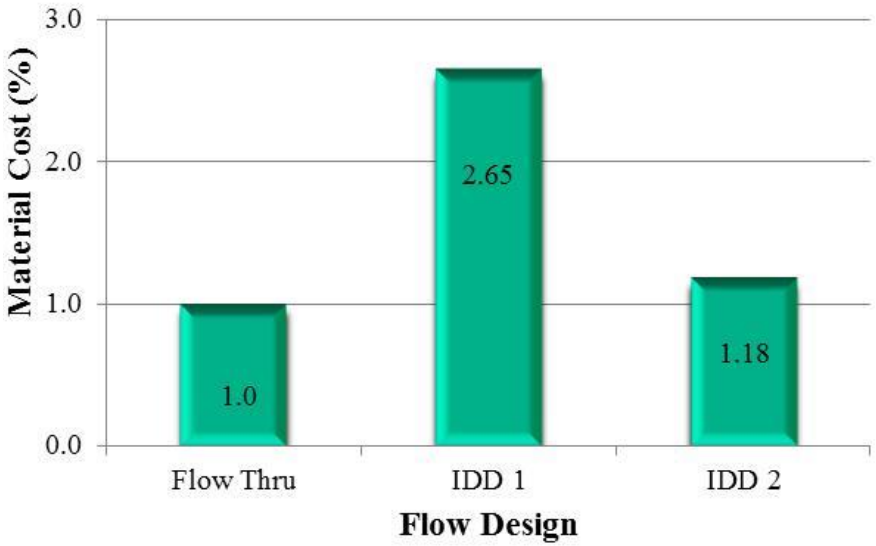
FY14 Stack Performance (Low Cost IDD Flow Design)





- Higher flow rates with IDD 1 and IDD 2
- IDD 1 approximately 3X material cost
- Sealing issues with IDD 1

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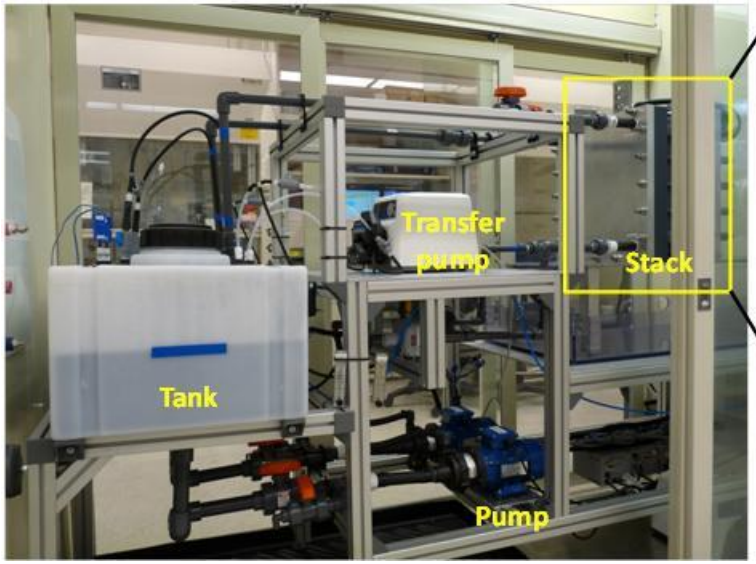
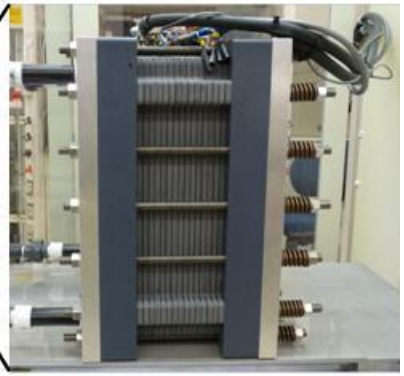
FY 14 VRFB 4KW Performance



VRFB System



Stack

Test Parameters

- 780 cm^2
- 20 cell stack
- 15-85% SOC
- Mixed acid electrolyte
  - 2M V, 2M S, 2M Cl
- Nafion® membrane
  - 212 (~ 2 mil)
  - j = 160 and 240 mA/cm^2
- Low cost interdigitated flow design
- 4 KW stack
- Chillers to control temperature

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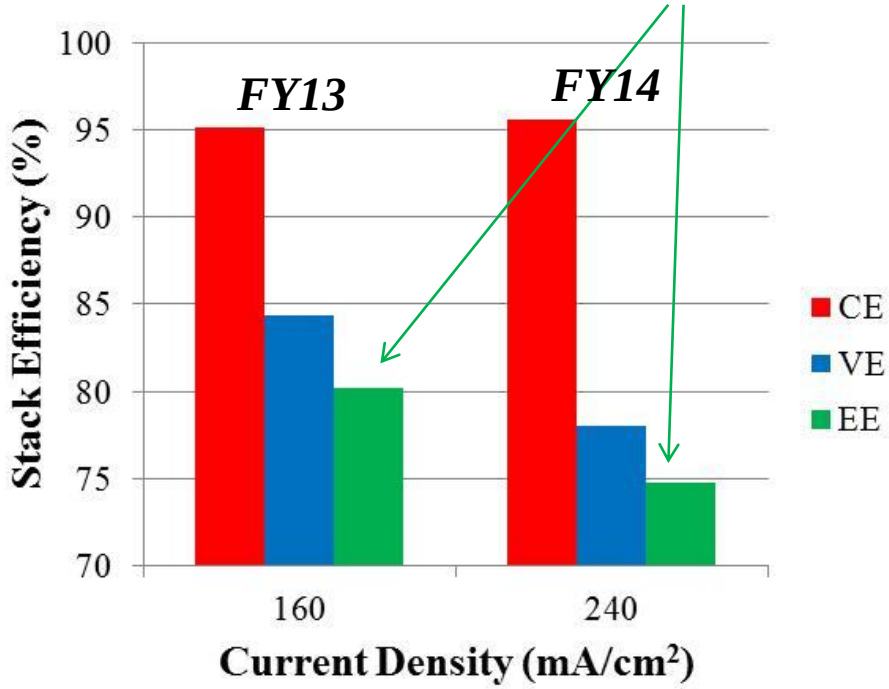
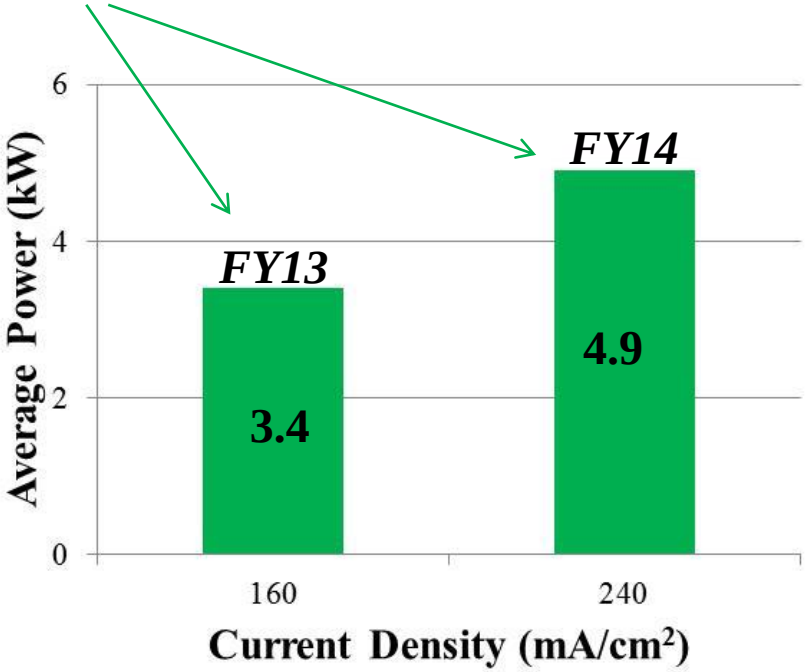
FY 14 VRFB 4KW Performance

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

5% reduction = 30% increase power





- 5% reduction in Stack Energy Efficiency
- 30% increase in Power

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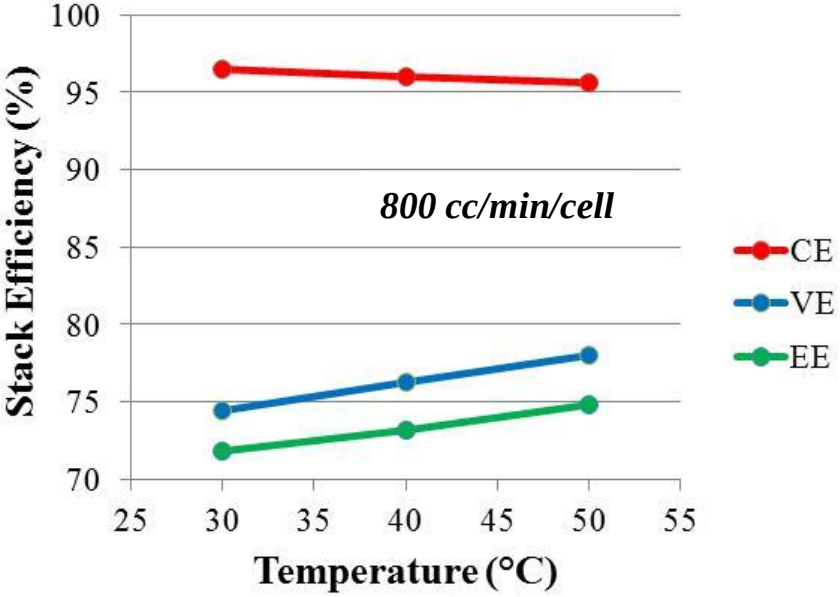
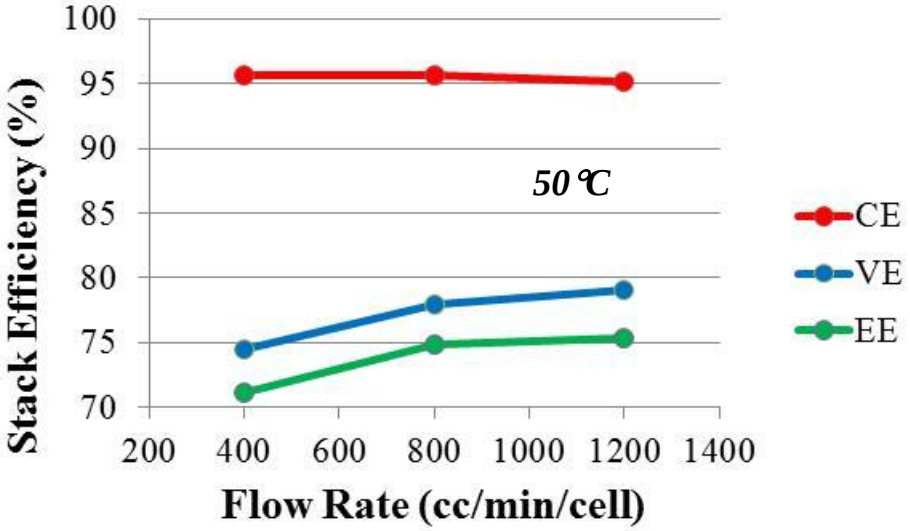
FY 14 VRFB 4KW Performance

20 Cell Stack – 240 mA/cm^2 Nafion ®212

Efficiency vs Temp



Efficiency vs Flow Rate



- Flow rate and temperature both improve stack energy efficiency

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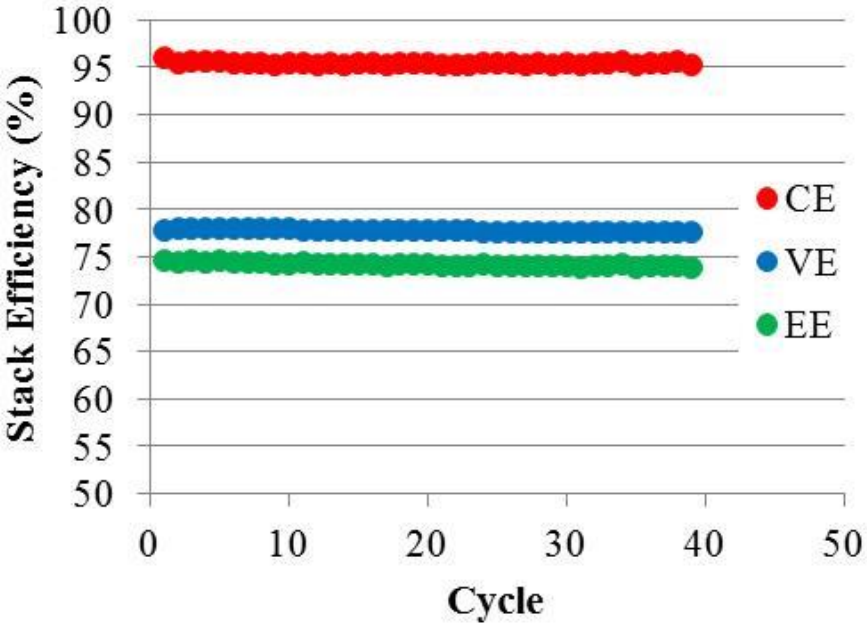
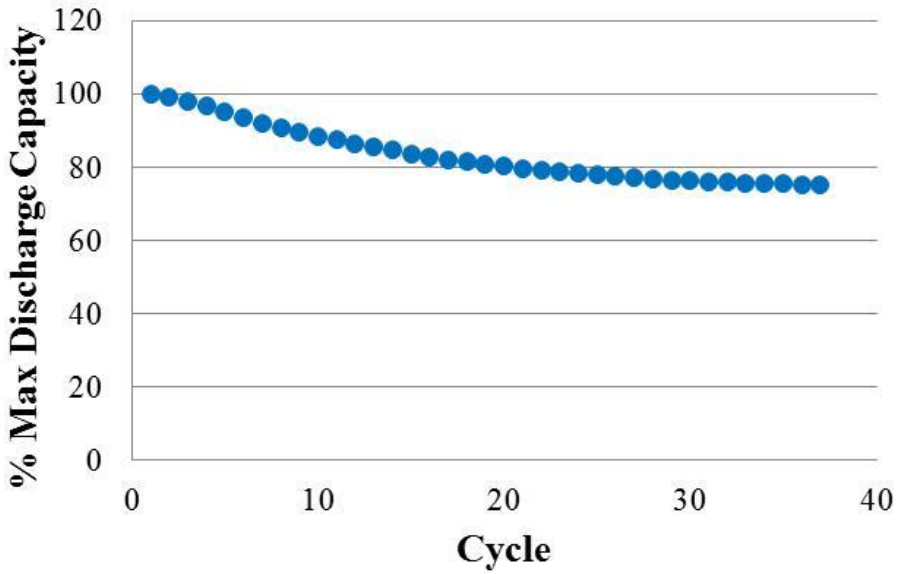
FY 14 VRFB 4KW Performance

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





- Stable performance for mixed acid electrolyte observe over a broad range of temperatures and flow rates

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Summary/Conclusions

- Substitution of Nafion® 212 or 211 for 115 in 3-cell stack leads to
  - ~5 - 10% increase in Energy Efficiency ($\geq$ 160 mA/cm^2)
  - ~ 50% cost reduction

- Low cost IDD had similar performance to original IDD but has a substantial reduction in material cost

- The 4kW class – 20 cell stack operated at 240 mA/cm^2 resulted in
  - ~ 30% increase in power
  - 5% reduction in energy efficiency (75%)
  - Stable performance over a range of temperatures and flow rates using the mixed acid electrolyte

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Acknowledgements

- DOE-OE Energy Storage Program, Dr. Imre Gyuk

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