Advances in PNNL’s Mixed Acid Redox Flow Battery Stack

David Reed, Ed Thomsen, Wei Wang, Zimin Nie, Bin Li, Brian Koeppel, Kurt Recknagle, and Vincent Sprenkle.
Pacific Northwest National Laboratory
Electrochemical Materials and Systems

DOE Office of Electricity Energy Storage Program – Imre Gyuk Program Manager.

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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/cm² 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

- **70% increase in capacity**
  - $V^{2+}$, $V^{3+}$, $V^{4+}$, $V^{5+}$ stable $>2.8$M, in $SO_2^-$ and $Cl^-$ mixed solutions

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

- 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

Catholyte: $VO^{2+} + Cl^- + H_2O - e \rightarrow VO_2Cl + 2H^+$  
$\varepsilon_{co}=1.0$ V

Anolyte: $V^{3+} + e \rightarrow V^{2+}$  
$\varepsilon_{ao}=-0.25$

Overall: $VO^{2+} + Cl^- + H_2O + V^{3+} \rightarrow VO_2Cl + 2H^+ + V^{2+}$  
$E_o=1.25$ V
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.
FY14 Stack Performance (Nafion® 115, 212 and 211)

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

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

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

<table>
<thead>
<tr>
<th></th>
<th>Columbic Efficiency (%)</th>
<th>Voltage Efficiency (%)</th>
<th>Energy Efficiency (%)</th>
<th>Discharge Capacity (Ah)</th>
<th>Discharge Temp (°C)</th>
<th>Pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>160 mA/cm²</strong></td>
<td></td>
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<tr>
<td>Nafion® 115</td>
<td>96.9</td>
<td>77.7</td>
<td>75.3</td>
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<tr>
<td>Nafion® 211</td>
<td>96.9</td>
<td>84.0</td>
<td>81.4</td>
<td>20.1</td>
<td>38.8</td>
<td>6.9</td>
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<td><strong>240 mA/cm²</strong></td>
<td></td>
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<tr>
<td>Nafion® 212</td>
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<tr>
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</table>
Substitution of Nafion® 212 and 211 for 115 in 3-cell stack leads to

- ~5 - 10% increase in Energy Efficiency (> 160 mA/cm²)
- Similar capacity fade
- Cost reduction

Nafion® 211 more difficult to handle
FY14 Stack Performance (Low Cost IDD Flow Design)

**Flow Through Design**
- SGL TF6 Graphite sheet
- PVC Frame

**IDD Flow Design**
- SGL PPG 86 Graphite/PP
- Flow direction
- PVC Frame

**Low Cost IDD Flow Design**
- Carbon Felt
- PVC Frame

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**FTD**
- Bipolar Plate
- Carbon Felt Electrode
- Membrane

**IDD 1**
- Bipolar Plate (Graphite/PP)
- Inlet Channel
- Outlet Channel
- Carbon Felt Electrode
- Membrane

**IDD 2**
- Bipolar Plate
- Inlet Channel
- Carbon Felt Electrode
- Outlet Channel
- Membrane

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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
FY 14 VRFB 4KW Performance

Test Parameters

- 780 cm²
- 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/cm²
- Low cost interdigitated flow design
- 4 KW stack
- Chillers to control temperature

VRFB System
FY 14 VRFB 4KW Performance

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

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

5% reduction = 30% increase power

FY13 FY14

Stack Efficiency (%)

Current Density (mA/cm²)

<table>
<thead>
<tr>
<th>Current Density (mA/cm²)</th>
<th>FY13</th>
<th>FY14</th>
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<tbody>
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<td>240</td>
<td>80</td>
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Average Power (kW)

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<th>Current Density (mA/cm²)</th>
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FY 14 VRFB 4KW Performance

20 Cell Stack – 240 mA/cm² Nafion® 212

Efficiency vs Temp

Efficiency vs Flow Rate

- Flow rate and temperature both improve stack energy efficiency
Stable performance for mixed acid electrolyte observe over a broad range of temperatures and flow rates
Summary/Conclusions

► Substitution of Nafion® 212 or 211 for 115 in 3-cell stack leads to
  ■ ~5 - 10% increase in Energy Efficiency (≥ 160 mA/cm²)
  ■ ~ 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/cm² 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
Acknowledgements

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