New Generation VRFB: Field Experience and Value Propositions

John DeBoever and Z. Gary Yang

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UniEnergy Technologies (UET)

A Leading Systems and Service Provider in the multi-hour energy storage market

Technologies:

- VO₂Cl(H₂O)₂

EcoPartners:

- Rongke Power

Innovation + Quality + Partnerships

Investments:

- BNM
- ORIX

10 years stack field experience, ramping up GW production capacity

Electrolyte production: 1.5 GWh/yr capacity
New generation vanadium redox flow battery (VRFB)

Developed at PNNL and optimized at UET. Won the highest US Government Award for Excellence in Technology Transfer and 2017 Green Chemistry Award

- More stable electrolyte chemistry:
  - 2x energy density
  - Up to 50°C or higher

- Optimized electrochemistry:
  - Inhibiting oxygen activity, mitigating electrode degradation
  - Easing electrochemical balancing

- Higher chemical activity:
  - Less sensitive to impurities
  - More corrosive, high chloride activity
Advancing new gen VRFB products meeting market demands

- Scaling up
- Field demonstration
- Optimization through value engineering
- Building a chain through partnerships

2012, 2013, 2014
**IP DEVELOPMENT**
- Electrochemical, Mechanical, Power & Controls Engineering

2015, 2016, 2017
**PRICELESS FIELD EXPERIENCE**
- Understanding Customers
- Contract Manufacturing

2018
**PIVOT TO REFLEX™**
- Customer Driven Design
- Flexible, Modular, Resilient

2019
**100kW String Configurations**
- High System Availability
- Industrial Design

2020
**ELECTRICITY WAREHOUSING**
- E’lyte Leasing
- Storage-as-a-Service
Up to MW scale deployments around the globe

From C&I, Microgrid to T&D, plus renewable integration

Great learnings from early deployments!!!
Highly modulized, plug-play system products

✓ Compact foot print
✓ Short & long duration
✓ Zero degradation
✓ Unlimited cycles
✓ 20+ Year lifetime
✓ Non-flammable
✓ No thermal runaway
✓ Shipped ready to run
✓ Highly recyclable
VRFB’ developed and built specifically for utility applications

- Simple for big, each stack, from kWs to 10’ kWs
- kW & kWh decoupled, longer durations by adding only electrolytes, self-discharge limited to only volumes in stacks
- “Inert” electrodes – no structural changes or strain/stress buildup
VRFB becoming the leader among emerging technologies

Over 100 projects, >1GWh deployed; more under construction
Meeting demands covering longer *duration* to better value propositions

Where Are We Headed?
U.S. Energy Storage Deployments (MWh) and Average Duration (hrs)

<table>
<thead>
<tr>
<th>Year</th>
<th>MWh</th>
<th>Average Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>167</td>
<td></td>
</tr>
<tr>
<td>2016E</td>
<td>475</td>
<td></td>
</tr>
<tr>
<td>2017E</td>
<td>1,101</td>
<td></td>
</tr>
<tr>
<td>2018E</td>
<td>1,635</td>
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<td>2019E</td>
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<tr>
<td>2020E</td>
<td>4,044</td>
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<tr>
<td>2021E</td>
<td>5,879</td>
<td></td>
</tr>
</tbody>
</table>

Source: GTM Research

Kann - U.S. Solar Market Insight 2016
No or negligible degradation over life

UET exhibits 0% fade over 3,400 cycles and counting

Extreme cycles characterization, Including short circuited testing

... 100% access to rated capacity

Li-ion, Pb-acid degrading in capacity, even under developer’ recommended SOC range

Typically 70~80% of rated at the end of life, partial access to rated capacity


ARENA ITP Report: Ongoing Battery Testing
Unlimited cyclability and a long life

➢ Over 12,000 cycles achieved over a 6 yrs test at 100% SOC; 275,000 cycles in the field at varied SOC
➢ Life limited by shelf life, ≥20years
No thermal runaway

- Shorted cell stack produces no lasting damage
- No spontaneous reactions when shorted
- Limited temperature increase
- Justified simplified cooling, e.g. with heat exchanger

- 9.1 °C increase in surface temperature was measured after 29 minutes during an intentional short-circuit at full charge
- At fully charged, mixing of electrolytes would raise temperature less than 20°C.
No fire accident reported for VRFB’ !!!

A number of fire accidents reported for Li-ion

No thermal runaway
Non-flammable aqueous electrolytes
As thus without danger of releasing exposed to a sustained external fire

New gen VRFB approved by NY Fire Dept, after only Pd-acid

After a fire was contained, this photo captures the initial explosive re-ignition of a 2.5MWh lithium battery, severely injuring 3 experienced firefighters in Hilden, Germany

In Nov 2017, this lithium battery with state-of-the-art fire protection technology failed during commissioning, resulting in release of toxic fumes, closing freeways and evacuating citizens
Vanadium flow battery systems offer significant safety advantages relative to lithium-ion in the areas of short-circuit fault, arc-flash/blast, “stranded” energy, fire suppression, and deflagration. This can lead to a streamlined review and approval process for all stakeholders involved.

When comparing available ESS technologies, many factors will affect the final system choice. From a safety perspective, significant questions remain unanswered when it comes to protecting Li-ion batteries from thermal runaway, even more so in an occupied structure. If codes continue developing along their current trajectory, many structures may not be suitable without significant modifications. As one designer of naval-based ESS explained, “A submarine must have a significantly higher level of safety than a land based structure, as escape is impossible.” However, when looking at ESS installations inside high-rise apartment dwellings, these structures may be compared to submarines standing on end in terms of life hazard profiles.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Lithium</th>
<th>Lead Acid</th>
<th>NaS</th>
<th>Vanadium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arc-Flash/Blast</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Toxicity</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Fire</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Thermal Runaway</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Stranded Energy</td>
<td>X</td>
<td>X</td>
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</tbody>
</table>
Advancement in integration

Successful Implementation of Islanding, realizing smooth transition
High Residual Value supports 100% Recycling

Electrolyte (2 options)
1. 100% reusable (no decay) for next ReFlex™
2. 100% Vanadium recycling & reused for other purposes

Plastics
- Tanks
- Piping
- Other

Stacks (separate components)
- Painted Steel & Copper
- Plastics
- Carbon

Steel Shell & BOP
- Steel shell
- Coated Metal frames
- Pumps
- Air Handler
- Electronics
Case Study: xxx
Location: CA
Tariff: PG&E E-20
System Size: 125 kW / 450 kW ESS
Incentives: SGIP + MACRS
System Installed Cost: $550/kWh
Replacement: Yr. 10 @ 70% original CAPEX

Economic return very sensitive to degradation

20-Year IRR vs. Degradation
Competitive value propositions

Economic return less sensitive to efficiency

VRFB: 80~85% stack efficiency
70~75 AC system efficiency
Need to establish a full industry chain

- Billions invested and well established industry chains in Li-ion, though most for vehicle and electronics applications;
- Leading dramatic cost reduction in the past decade.
- But as emerging technologies, RFB’ have yet established a full industry chain that is critical to further technology maturation and cost reduction.

**Raw materials** ➔ **Electrolytes** ➔ **Stacks** ➔ **Modules** ➔ **System**
Further improvement in value engineering

➢ **Shunt current** — parasitic current flowing through liquid-connected circuit, leading to potential materials and structural failures in stacks and pipes

![Shunt current diagram](https://wernerantweiler.ca/blog.php?item=2014-09-28)

Kim, et al., J Power Sources, 237, 1, 300.

➢ **Mass balancing** during operation – driven by electrochemical potential difference, mass (H\(^+\), other ions too) transports through the membrane leading to mass-imbalance across anode and cathode and potential gassing and other damages, if not well managed during operation.

![Mass balancing diagram](https://wernerantweiler.ca/blog.php?item=2014-09-28)
Streamlining deployments and conformance with utilities

➢ Lack of standardization, as an emerging industry

Some standards on batteries, power connection, integration, etc., BUT limited

➢ Not only batteries, but power conversion, integration including software all important to the applications

Details will be added