The Vanadium Redox Flow battery and South Africa's export opportunity

by Mikhail Nikomarov, Bushveld Energy
Introduction and objectives

• Mikhail Nikomarov, co-founder
• An energy storage solutions company, part of Bushveld Minerals, a R1.5bil vanadium minerals company, producing ~4% of global vanadium here in SA;
• Exclusively focusing on vanadium redox flow battery technology, including marketing and project development;
• In process of delivering a 450kWh into Eskom’s RT&D facility;
• Objective is to establish a global VRFB supply chain in SA, starting with vanadium electrolyte.

Objectives of presentation

• Overview the VRFB technology, including deployment, design, benefits and downsides in battery performance, safety and sustainability and the technology-specific business cases;
• Present an argument for why South Africa is uniquely positioned to benefit in the global success of VRFBs;
• Discuss questions and answers at end of presentation.

SOURCE: www.bushveldenergy.com
Some trivia:
What battery technology was used in the largest stationary energy storage battery installed in 2015? (Measured in watt-hour capacity)

Possible answers

A. Lithium ion technology (Li-ion)

B. Vanadium redox flow battery technology (VRFB)

C. Sodium Sulphur technology (NaS)
Answer: VRFB

60 megawatt hour VRFB from Sumitomo in Hokkaido, Japan

HEPCO PJ (online @Dec., 2015)
- Size: 15 MW / 60 MWh (max. capacity: 30 MW)
- Application: Multi-purpose
  - Renewable generation mitigation
  - Frequency control, etc
- Funded by Japanese government

SOURCE: Sumitomo
What battery technology was used in the largest stationary energy storage battery installed in 2016?

Possible answers

A. Lithium ion technology (Li-ion)

B. Vanadium redox flow battery technology (VRFB)

C. Zinc bromide flow technology (ZBFB)
120 megawatt hour lithium ion battery from AES and LG in Escondido, California, USA

The largest lithium ion energy storage system in the world.

Size: 30 MW
Online date: Q1 2017
Service: The Advancion energy storage arrays provide flexible peaking capacity to enhance regional energy reliability while maximizing renewable energy use in Southern California. The 30 megawatt (MW) energy storage facility is capable of storing up to 120 megawatt hours of energy, the energy equivalent of serving 20,000 customers for four hours.

SOURCE: www.aesenergystorage.com
What battery technology is used in the largest stationary energy storage battery being installed right now?

Possible answers

A. Lithium ion technology (Li-ion)

B. Vanadium redox flow battery technology (VRFB)

C. Zinc Metal Air battery technology
800 megawatt hour VRFB by Rongke Power in Dalian, China
(400MWh for 2017 deployment)

Location: Dalian City, CHINA

The first floor: Electrolyte tank
The second floor: Power unit + control unit
The third floor: PCS + Transformer

Specification:
Rated power: 200MW
Rated capacity: 800MWh
AC Efficiency: >70%

Components:
Battery: 500kW/2MWh×400
PCS: 550kVA×400
Transformer: 2500kVA×100
EMS: 1 unit
SCADA: 1 unit

Source: Rongke Power
Vanadium is the simplest and most developed flow battery

How does a vanadium redox flow battery (VRFB) work?

- A flow battery was first developed by NASA in the 1970s and is charged and discharged by a reversible reduction-oxidation reaction between the battery’s two liquid vanadium electrolytes.
- Unlike conventional batteries, electrolytes are stored in separated storage tanks, not in the power cell of the battery.
- During operation these electrolytes are pumped through a stack of power cells, or membrane, where an electrochemical reaction takes place and electricity is produced.

Vanadium can exist in four different states, allowing for a single element to be used.

Benefits include simplicity and no cross-contamination.

In 2010, US DoE funded research at PNNL yielded an improved electrolyte formula.

SOURCE: IEEE Spectrum: It’s Big and Long-Lived, and It Won’t Catch Fire: The Vanadium Redox-Flow Battery, 26 October 2017
VRFB systems provide long life and flexible performance

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
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<tbody>
<tr>
<td>Long cycle life (10,000+ full cycles, with 10 to 20 times this possible)</td>
</tr>
<tr>
<td>Relative high energy efficiency (up to 85%), but lower than Li-ion</td>
</tr>
<tr>
<td>One of the most mature flow batteries with multiple demonstration and deployed at MW scale</td>
</tr>
<tr>
<td>Design E/P ratio can be optimised to suit specific application</td>
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<td>Long duration (1-20 hours) continuous discharge and high discharge rate possible</td>
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<td>Quick response times</td>
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<tr>
<td>Same element in active materials on electrolyte tanks limits ion cross-contamination</td>
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<tr>
<td>The electrolyte can be recovered at end of project life</td>
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<tr>
<td>Heat extraction due to electrolyte prevents thermal runaway</td>
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VRFB’s are an excellent fit for **daily, multi-hour, deep cycle storage** (e.g. with solar PV), **grid support** (e.g. peak shaving, system balancing, capital deferral) and **off-grid or minigrid** installations.

SOURCE: IRENA: ELECTRICITY STORAGE AND RENEWABLES: COSTS AND MARKETS TO 2030
Technically, a VRFB is intrinsically safer than solid state batteries because it has no “thermal runaway”

Unsurprisingly, VRFBs are safer across a broad range of factors, when compared to lithium-ion (or other technologies)

<table>
<thead>
<tr>
<th>Risk</th>
<th>Lithium-ion</th>
<th>Flooded Cell</th>
<th>Sodium Sulfur</th>
<th>VRB Flow Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>X</td>
<td>X</td>
<td>X</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>X</td>
<td></td>
</tr>
<tr>
<td>Deflagration</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Stranded Energy</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

“It is clear that Vanadium flow battery systems offer significant safety advantages to li-ion”

- Fire Captain Matthew Paiss

1 Captain Paiss is a 21-year veteran of the San Jose Fire Department and the primary representative of the International Association of Fire Fighters (IAFF) to NFPA 70 (NEC) and NFPA 855 ESS standards.

For many applications, VRFBs yield the lowest levelised cost of energy storage.

Lazard’s analysis shows that VRFBs already have the lowest costs in the industry.

**USD / kWh, 2017, levelised costs**

- **Peaker replacement**: -26%
- **Distribution**: -32%
- **Micro-grid**: -29%

**SOURCE:** Lazard’s Levelised Cost of Energy Storage Analysis – Version 3.0 (November 2017); Bushveld Energy analysis
The technology is especially suited to the unique challenges of South African electricity

**Improved regional and municipal integration of renewables** (where the battery can improve the power quality and allow for more renewable energy connection)

**Higher load factor of the existing base-load fleet** (i.e. power plants can be run at their best utilisation levels at night, while batteries are charged, and coal does not need to be used as back-up power / spinning reserve)

**Transmission and distribution lines can be run at a constant load**, which will increase system utilisation, reduce losses and defer costly new infrastructure investment

**Electricity consumers can reduce peak time energy costs** (i.e. the dual-peak demand and tariff structure in South Africa, would allow for a VRFB to run two cycles per day to reduce peak time grid demand)

"VRFB represents a mature and well understood energy storage technology that is well suited for energy intensive energy storage applications. The relative ease of vanadium electrolyte production and the availability of vanadium in South Africa further enhances the attractiveness of this specific flow technology."

– SA South Africa Energy Storage Technology and Market Assessment

Source: Bushveld Energy; Parsons Engineering
South Africa is naturally positioned for vanadium-based industry but has not used this competitive advantage

Vanadium forms one of SA’s largest mineral resources…

<table>
<thead>
<tr>
<th>% of global supply reserve base located in SA, 2003¹</th>
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<tbody>
<tr>
<td>Platinum-group...</td>
</tr>
<tr>
<td>Manganese</td>
</tr>
<tr>
<td>Chromium</td>
</tr>
<tr>
<td>Vermiculite</td>
</tr>
<tr>
<td>Alumino-silicates</td>
</tr>
<tr>
<td>Gold</td>
</tr>
<tr>
<td>Titanium</td>
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<tr>
<td>Vanadium</td>
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</table>

...but production of vanadium in SA has fallen by nearly half

Annual South African vanadium production

<table>
<thead>
<tr>
<th>Metric Tons of Vanadium (MTV)</th>
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<tbody>
<tr>
<td>2013</td>
</tr>
<tr>
<td>13400</td>
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<tr>
<td>2016</td>
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<tr>
<td>7600</td>
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Bushveld Minerals and Glencore are the only two remaining companies, currently producing vanadium in South Africa

¹ 2008 data for Gold and 2014 data for Vanadium

Vanadium electrolyte contributes ~30% to the overall cost of the VRFB system, allowing SA to participate in a large global value chain.

**VRFB cost breakdown**

- **Vanadium electrolyte**: 31%
- **Cell Stack**: 9%
- **Electrical (PCS, inverter)**: 12%
- **Assembly**: 8%
- **BOP (tanks, pumps, pipes)**: 3%
- **Engineering**: 3%

- Larger VRFB systems have a higher relative contribution of Vanadium and local content of up to 80% is possible for SA-installed systems;
- It is more important to consider export potential, when evaluating “the creation of jobs and localisation.”

Cooperating jointly with the IDC and international partners, Bushveld Energy is already progressing toward establishing a local VRFB supply chain.

SOURCE: IRENA: ELECTRICITY STORAGE AND RENEWABLES: COSTS AND MARKETS TO 2030; Bushveld Energy
Thank you for your attention.

Any questions?