VRFB technology attributes and applicability to developing countries

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Energy Storage Partnership Presentation

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Context about the presenter

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- Co-founder and Chief Executive Officer of Bushveld Energy, an energy storage solutions company, part of AIM-listed Bushveld Minerals, an integrated vanadium company
- Chairman of the South Africa Energy Storage Association (SAESA) and of the Energy Storage Committee of Vanitec, the global non-profit association of vanadium producers
- Not a representative of any specific ESS company
- Representing the vanadium-based value chain, including mining, component manufacturing, investment in BESS companies and project development across the African continent
- Based in South Africa

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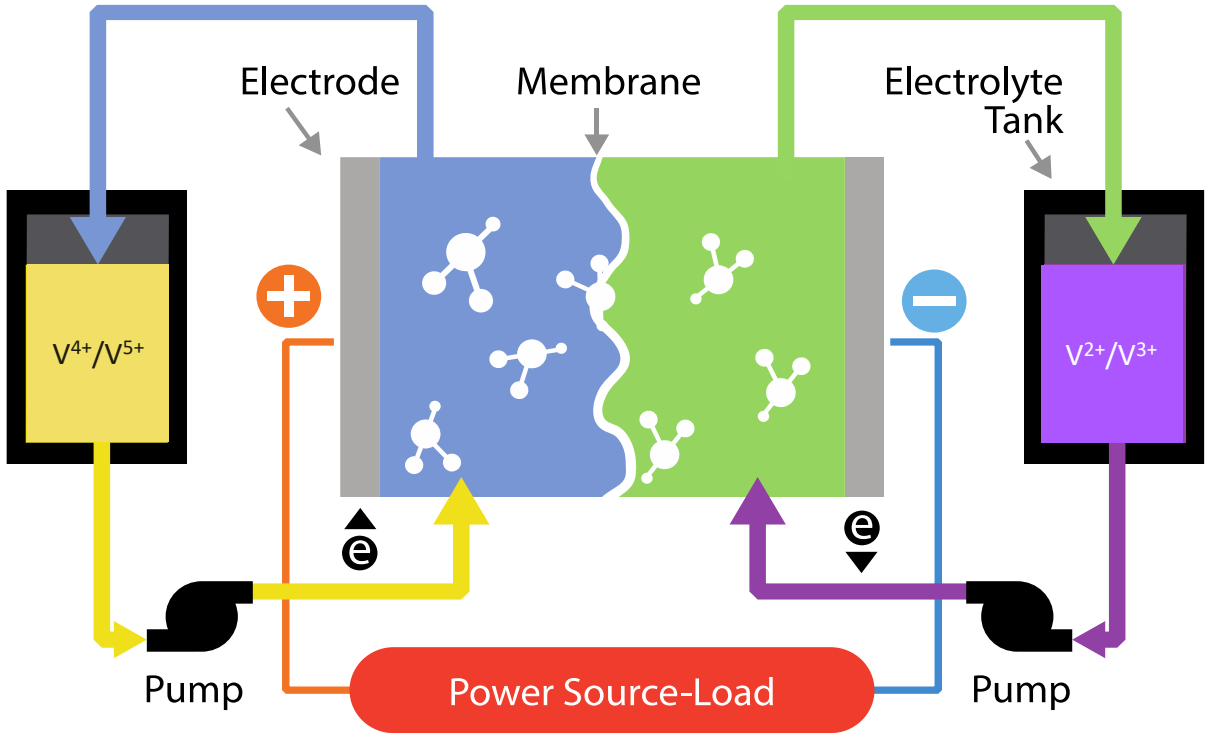
The vanadium redox flow battery, or VRFB, is the simplest and most developed flow battery in mass commercial operation

- The flow battery was first developed by NASA in the 1970s and unlike conventional batteries, the liquid 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 a reversable reduction-oxidation (“redox”) electrochemical reaction takes place, charging or discharging the battery
- Vanadium can exist in four different states, allowing for a single element to be used to store energy. Vanadium was first used in flow batteries in the mid-1980’s
- In addition to vanadium, the electrolyte consists primarily of water and additives such as sulphuric acid or hydrochloric acid



Source: IEEE Spectrum: “It’s Big and Long-Lived, and It Won’t Catch Fire: The Vanadium Redox-Flow Battery”, 26 October 2017

VRFB technology offers significant advantages

- **Long lifespan cycles:** ability to charge / discharge over 35,000 times for over 20 years, with minimal performance degradation
- **Separation of power and energy:** allowing for kWh and kW to be scaled independently, making the technology extremely cost effective for long duration use cases
- **100% depth of discharge:** allowing for the entire battery to be used all the time
- **Lowest cost per kWh:** when fully used at least once daily makes VRFBs today cheaper than Li-ion batteries
- **Safe:** with no fire risk from thermal runaway
- **Sustainable:** 100% of vanadium is re-usable upon decommissioning and the CO_2 footprint is much less than of other batteries
- **Very fast response time** of less than 70ms
- **No cross-contamination:** Only one battery element, unique among flow batteries
- **Large scale adoption in China and Japan,** including multiple 400MWh+ sites under construction in China; a 60MWh battery with 5 years performance in Japan; and many smaller systems in Europe and Americas, some operating for over 10 years

Source: IEEE Spectrum: "It's Big and Long-Lived, and It Won't Catch Fire: The Vanadium Redox-Flow Battery", 26 October 2017. IRENA

VRFB is the only BESS technology to be proven at large scale to exhibit nearly no degradation

Most Battery Energy Storage Systems ("BESS") technologies, such as lithium ion, rapidly degrade from use

Phase 1 Battery Packs – SOH Estimates from Capacity Test Results

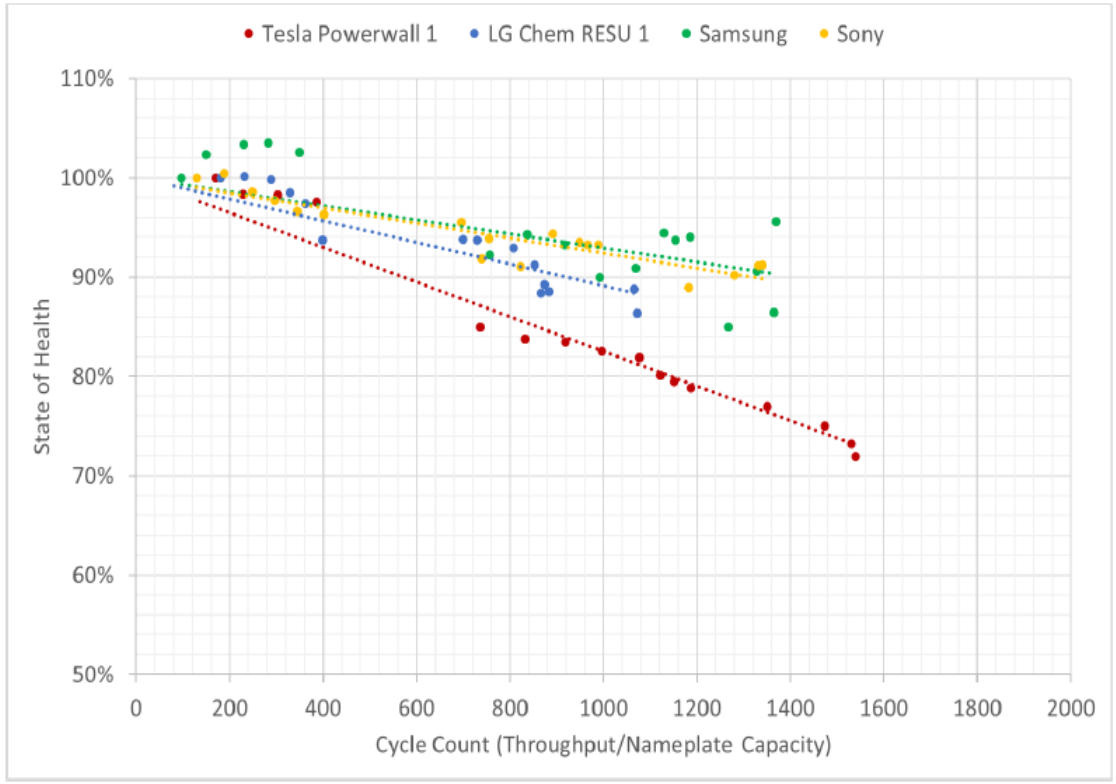
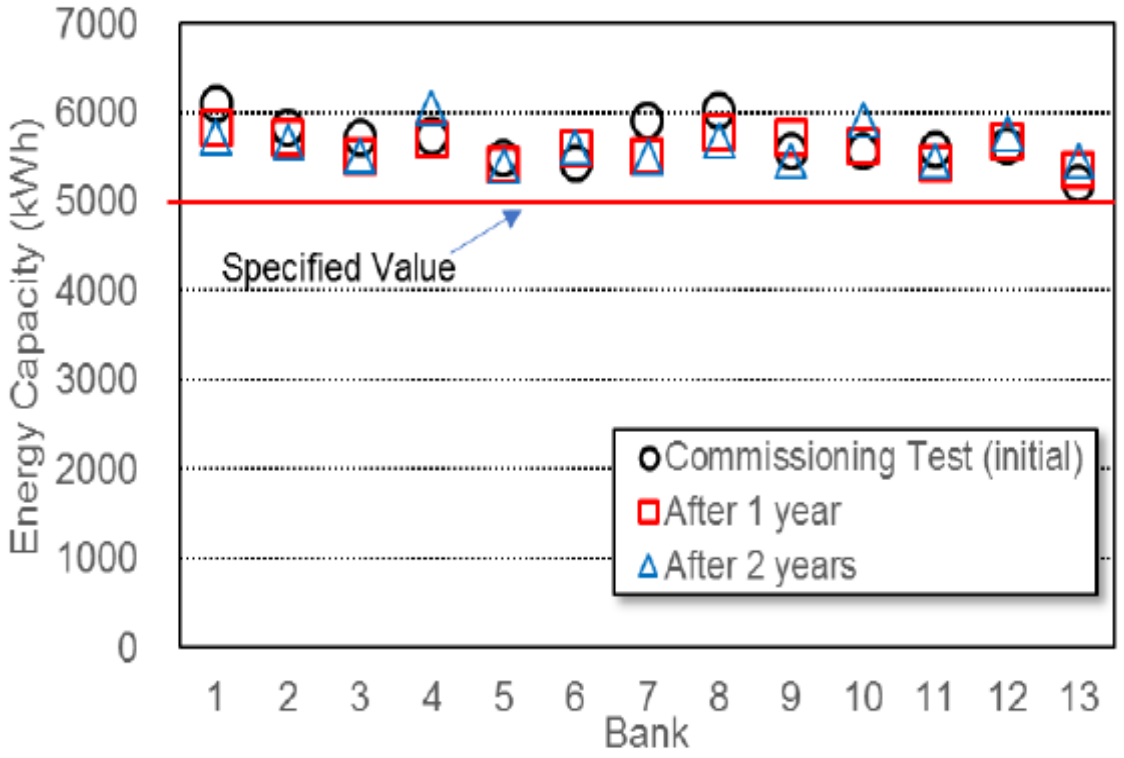


Figure 1. Capacity fade of Phase 1 battery packs based on monthly capacity tests

VRFB performance has minimal performance degradation (NEPC)

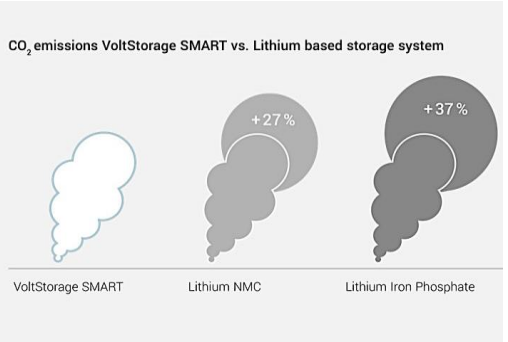


Measured capacity at HEPCO's 60MWh VRFB built by Sumitomo – data covers 2015-2018

Source: The University of New South Wales, ITP BATTERY TEST CENTRE REPORT 5, September 2018; Sumitomo Electric, April 2019

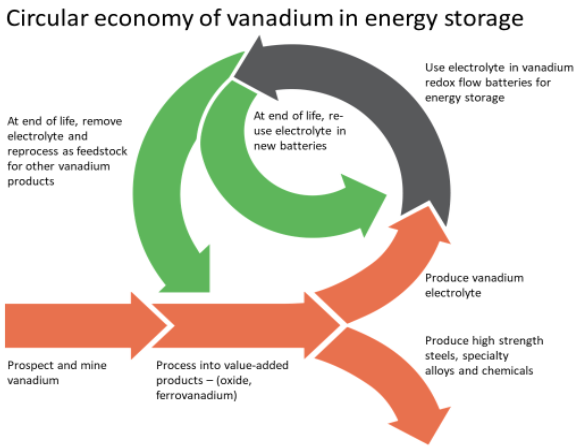
The strongest argument for a VRFB is the sustainability it offers because it uses vanadium

Low carbon intensity of VRFB technology



- According to research from the Technical University of Munich, a VRFB produces less "cradle to grave" CO_2 emissions than other technologies;
- The savings range from 27 to 37%, when compared to multiple lithium ion technologies

Circularity of vanadium in energy storage



- Vanadium is not consumed and does not degrade during operation in a VRFB
- After the battery's end of life the vanadium electrolyte can be fully redeployed into another VRFB or converted into ferrovanadium for use in steel alloys
- Conversion costs a fraction of the vanadium's market value

Source: Vanitec, Bushveld Energy, Technical University of Munich, Volterion, RMI

An entire new paradigm of mineral finance is possible

- Because the vanadium in VRFBs does not degrade, the **vanadium electrolyte can be rented** or leased to the VRFB customer rather than sold. A special purpose vehicle is used as a financial intermediary between the miner and VRFB customer.
- For energy or VRFB customers, this **reduces the upfront costs** of the battery as well as its levelized costs.
- For investors, it creates **direct exposure to the vanadium commodity**, without the management or inventory costs of most commodity funds.
- For all of us, it guarantees that the **chemistry in the battery will be recycled** and introduces a **new model for mineral wealth exploitation** and transferring mineral wealth across generations
- The model can eventually be applied to other products and other commodities, creating a new paradigm where mineral wealth has economic value both below and above ground

95% of vanadium is mined in BRICS countries, making it especially attractive for these developing countries

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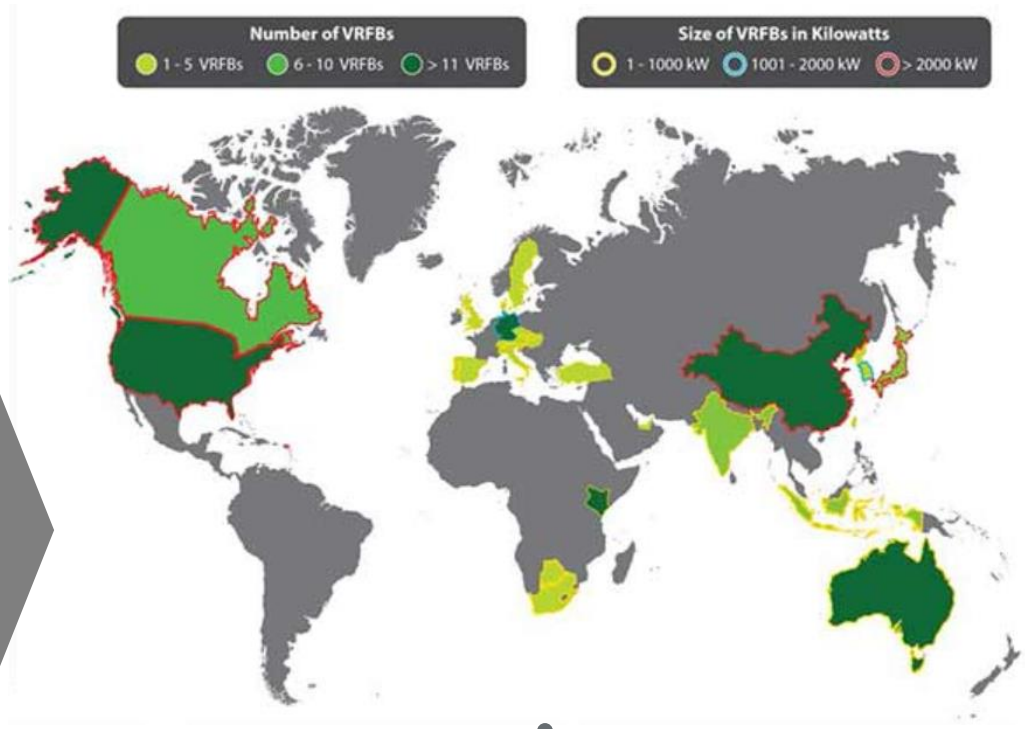
Not surprisingly, there are over two dozen VRFB manufacturers and hundreds of operating systems globally

SCHMID
INVINITY ENERGY SYSTEMS
HTR
上海电气 SHANGHAI ELECTRIC
PROTEAN ENERGY
VOLTSTORAGE
VRB ENERGY Vanadium Redox Battery Solutions
BIG PAWER 大力电工
GEFC
UET
Enerox BUILDING ENERGY STORAGE INFRASTRUCTURE
SUMITOMO
STORION
SOLIBRA SYSTEM MONTAGE GMBH
WattJoule
company that makes the world beautiful Nuriplan
volterion
H2
StorEn Technologies ENERGY YOU CAN DEPEND ON
E22
融科储能 RONGKE POWER
visblue energy in the flow
神力科技 Shen-Li High Tech



In China alone, we are tracking ~2GWh of VRFBs currently under construction

Source: Vanitec, company websites

2020 has been an especially good year for VRFB momentum

China

Shanghai Electric announced plans for another **100MW / 400MWh** VRFB in Yancheng, China

Rongke Power's **200 MW/800 MWh** is due for initial commissioning this year

Sichuan Xuteng Battery Energy Co., Ltd. is a newly introduced enterprise in Panzhihua successfully signed the R & D and industrial park projects of VRFB energy storage.

Jiangxi Yinhui New Energy Co., Ltd. plans to build a new project with an annual output **of 66,000 cubic meters** of vanadium electrolyte in Yichun

Yichun Jin Kong Group issued**)** to support the demonstration production base project of vanadium battery industrialization

Rest of the world

Joint venture established to build a VRFB facility "an annual production capacity of **3 GWh"**

51MWh VRFB system awarded to Sumitomo for a wind farm in Hokkaido, Japan

M&A activity is picking up, including a **"$70 million merger of vanadium redox flow battery start-ups".** The new company just announced 7.8MWh of orders from the California Energy Commission in the USA

Developer and maker of home VRFB energy storage systems, **raised €6 million (US$7.1 million)** in July 2020.

Large, multinational power companies are deploying VRFB technology, **including ENEL in Majorca, Spain and EDF in Oxford, UK**

Increased deployment of VRFBs and demand is likely to rise as governments focus on accelerating the transition to a zero-carbon energy future

Source: FerroAlloyNet, September 2020; press search

Closing thoughts on test beds

- Need to reduce duplication to maximise use of resource - how can existing test beds be incorporated into the WB ESP programme (e.g. Eskom's site)?
- Significant flexibility is needed from the "test bed" team, as it is impossible to future proof for possible issues and being overly prescriptive will make it less attractive.
- Need to make test beds more attractive for OEMs
  - Create a WBG-backed technology risk guarantee facility for vetted products
  - Offer partial grants, possibly success based (e.g. paying for certification)
  - Provide a path to global certification from test bed results (local is not enough)
  - Consider other services or benefits
- Important to not only test technical performance but ESS use cases – who is doing pro forma validation for new ESS use cases?

Source: Bushveld Energy