



# Vanadium value chain innovation to reduce energy storage costs

Peter Oldacre, Bushveld Energy (Pty) Ltd

# Bushveld Minerals is an integrated vanadium-based platform which spans from extraction to manufacturing to deployment



Integrated vanadium minerals company with a R6 billion market capitalisation, listed in London<sup>1</sup>



## VANADIUM

A growing, low cost, vertically integrated vanadium mining and processing platform

- Operating the Vametco vanadium mine and processing plant in Brits, SA and producing more than 3% of world's vanadium
- Controlling multiple large, open cast deposits with a 439.6Mt combined resource (including ~55 Mt combined reserves) in South Africa, host to the world's largest high-grade primary vanadium resources



## ENERGY STORAGE

An energy storage project developer and component manufacturer

- Exclusively focused on vanadium redox flow battery (VRFB) technology with US-based technical partner UniEnergy Technologies (UET)
- Markets and develops projects using VRFB solutions across Africa
- Works with the Industrial Development Corporation (IDC) to establish VRFB and electrolyte production in SA



## COAL & POWER

Developing an integrated thermal coal and IPP asset in Madagascar

- Developing an integrated thermal coal asset and Independent Power Producer (IPP) in Madagascar

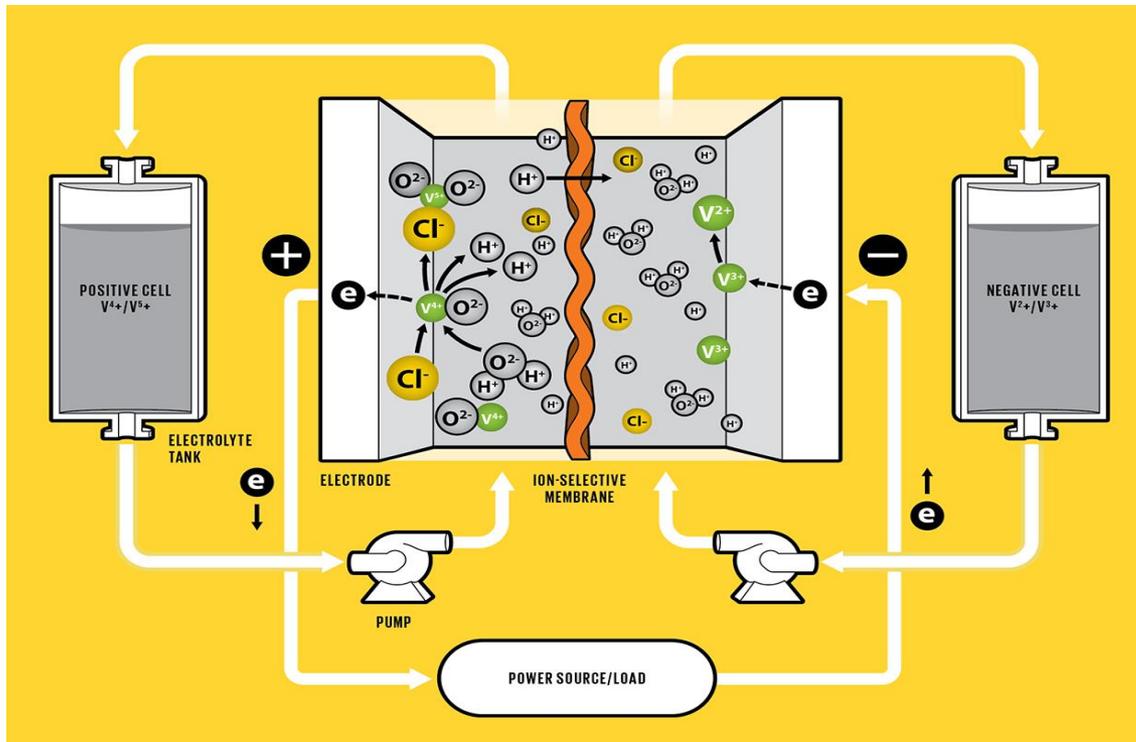
### Flagship platform

1. The Company holds a 10% shareholding in AIM-listed AfriTin Mining Limited

# 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 two liquid vanadium electrolytes of the battery
- 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

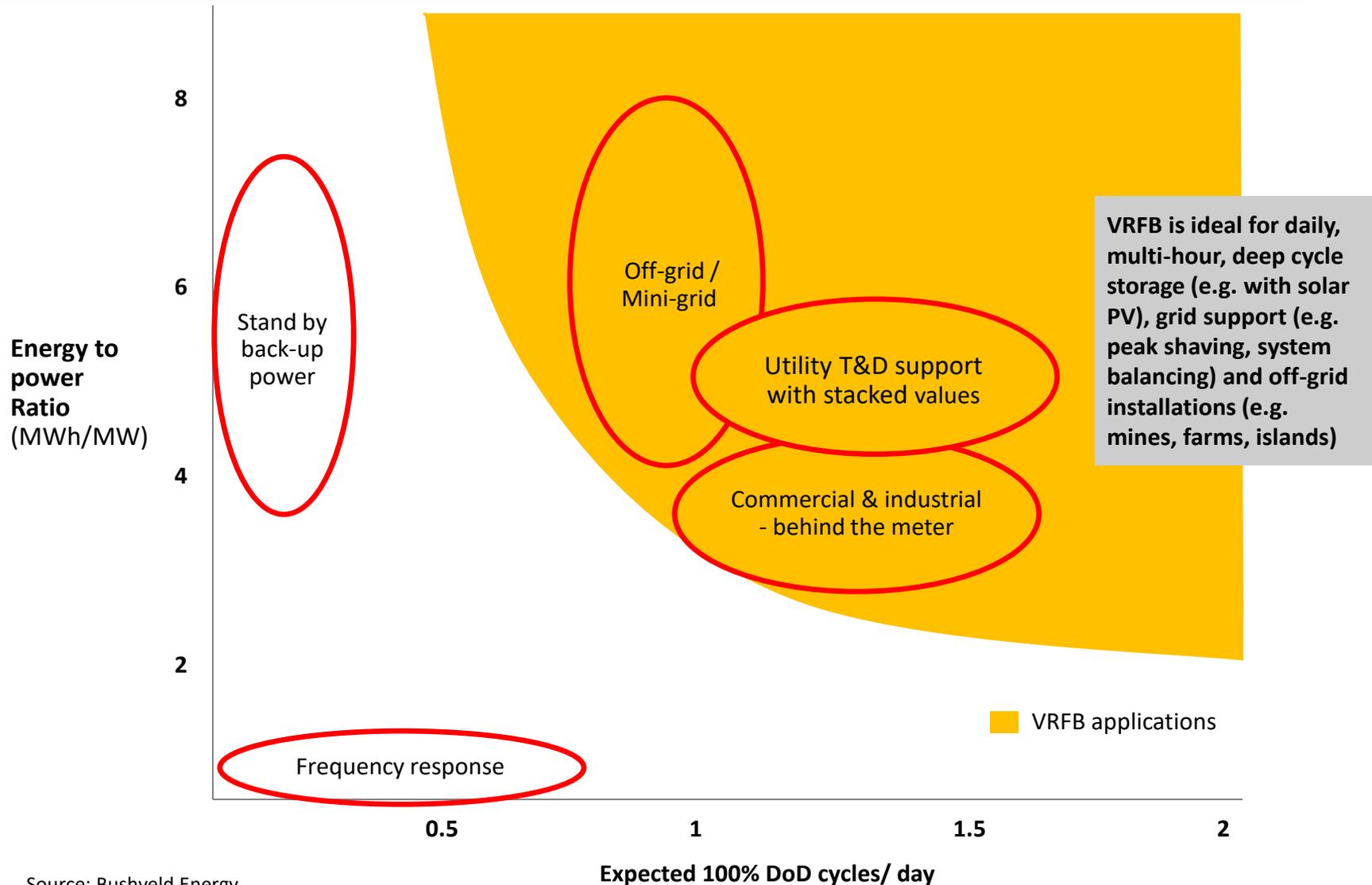
# VRFB technology has significant benefits

- + Long life and minimal reduction in performance during its life
  - + 100% depth of discharge
  - + Nearly unlimited number of cycles
- + Lowest cost per kWh when fully used once daily (or more frequently)
- + Easily scalable, as energy and power ratings are independent
- + Safety (no fire) and sustainability (100% of vanadium is reused at end of life)
- + The Vanadium is usable at the end of the lifespan of the battery.



# VRFB's value proposition is to equalise power distribution and bridges gaps in power generation over longer durations

## Stacking storage applications based on daily usage and storage requirements



# Technically, a VRFB is intrinsically safer than solid state batteries because it has no “thermal runaway”

Fire safety is an inherent risk of solid state batteries



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

## Analysis of typical hazards by ESS Type

Risk	Lithium-ion	Flooded Cell	Sodium Sulfur	VRB Flow Battery
Voltage	X	X	X	
Arc-Flash/Blast	X	X	X	
Toxicity	X	X	X	X
Fire	X	X	X	
Deflagration	X	X		
Stranded Energy	X	X	X	

***“VRFB along with lead acid is the only battery chemistry to receive a letter of no objection from the New York Fire Department.”***

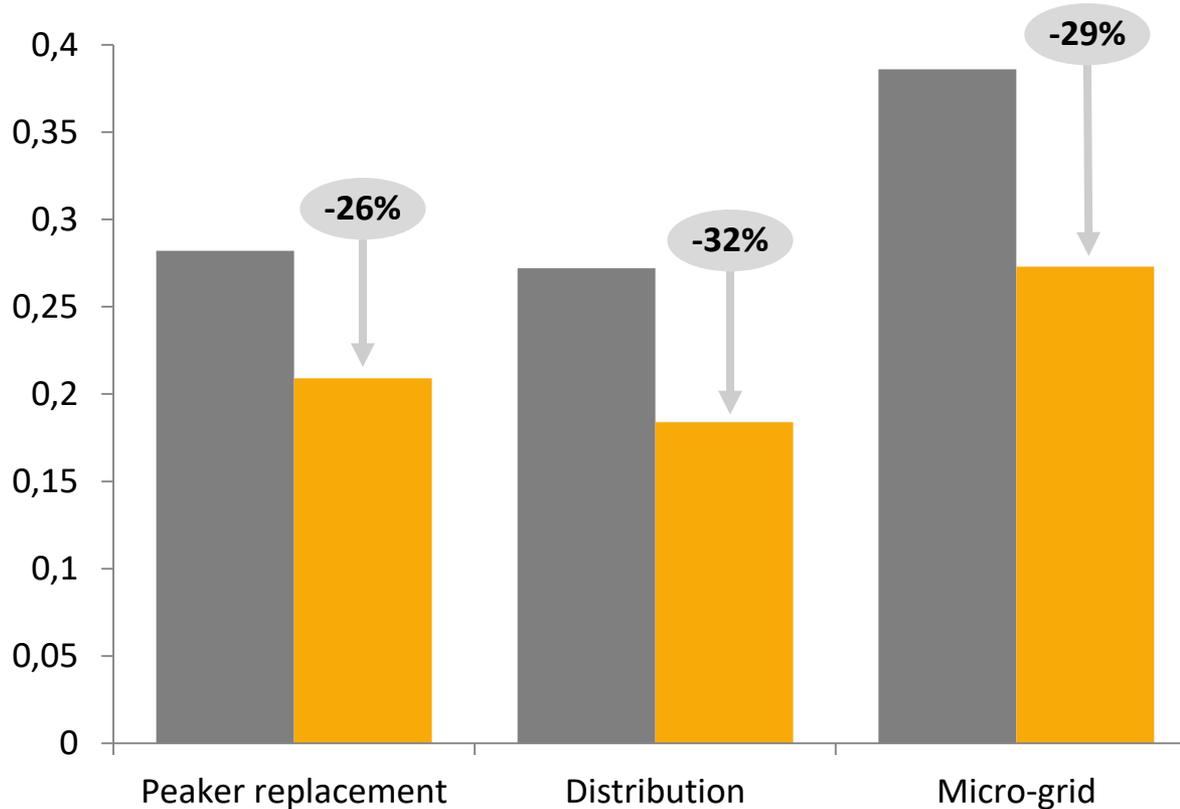
- ESJ (Energy Storage Journal) 14.11.16

# VRFBs can be cheaper on life-time ownership (or levelised) cost, but costs are still high

Investment bank Lazard analysis shows that VRFBs already have the lowest costs in the industry

USD / kWh,<sup>1</sup> 2017, levelised costs

■ Lithium-Ion ■ VRFB

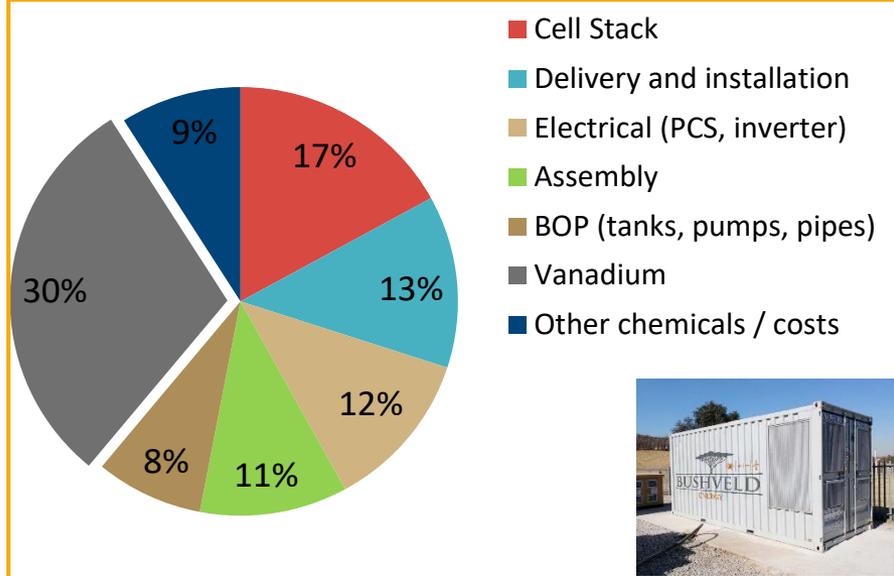


- Lithium-ion manufacturers have focused on driving down upfront costs by expanding manufacturing capacity through multi-billion dollar giga-factories and using less cobalt and lithium
- VRFB technical design offers a uniquely different means to reduce costs, even before massive capacity expansion

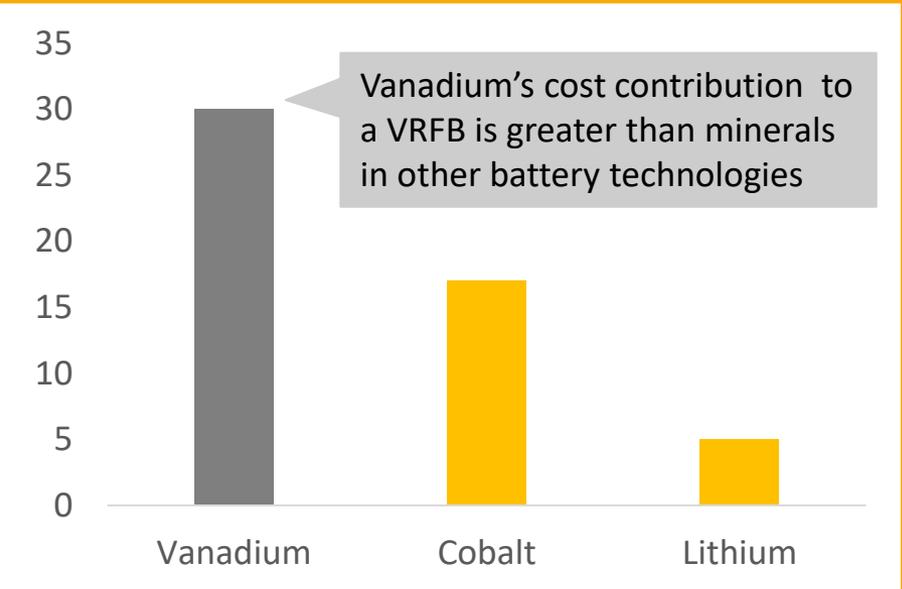
LAZARD

# Vanadium is a more significant contributor to the cost of VRFBs than key minerals in comparative battery technologies

## Vanadium redox flow battery's cost breakdown %



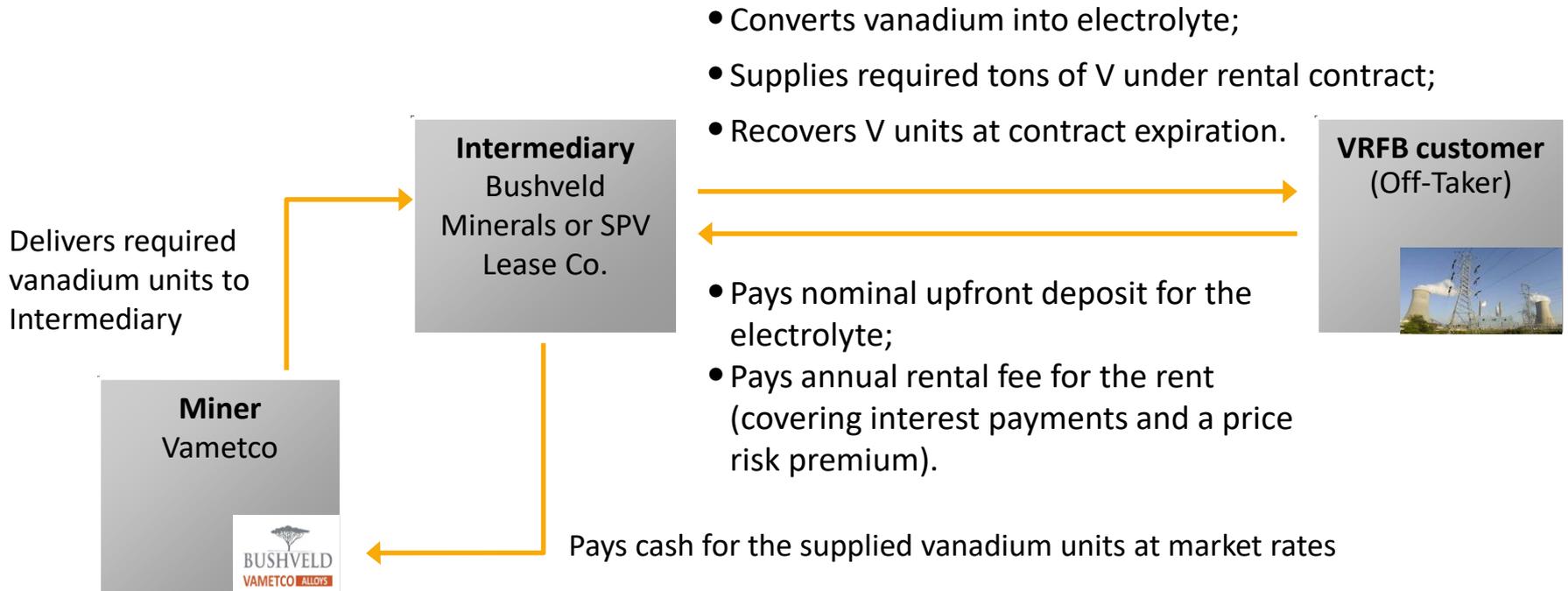
## Mineral cost contribution<sup>1</sup> to respective battery %



- High dependence on one mineral presents a challenge for the technology but an opportunity for vanadium suppliers
- Strategies for countering high vanadium prices will be key to VRFBs' sustained success

<sup>1</sup> Exact cost contributions of each mineral will vary and are a function of underlying prices and other factors. Roskill utilises an average of multiple lithium ion technologies to derive a typical cost contribution for 2018

# Bushveld Energy's vanadium rental product takes advantage of the unique properties of vanadium and VRFB technology



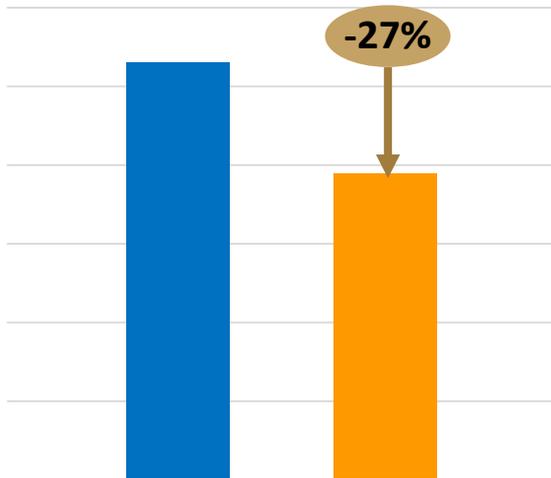
## Benefits of the product to VRFB customers include:

- Significantly lower and predictable CAPEX for the battery that could make it cheaper than lithium ion
- A manageable and predictable annual fee that is added to the battery's maintenance costs
- Lower overall total cost of ownership / levelized cost for a VRFB than an outright purchase

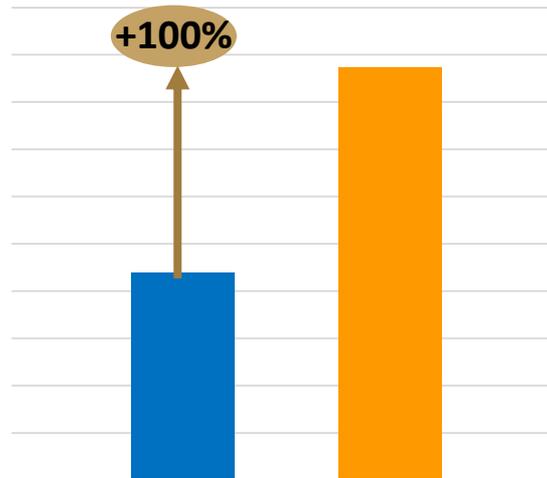
# The Vanadium Electrolyte Rental Product has significant positive impact on energy storage projects

■ 100% CAPEX ■ Electrolyte rental

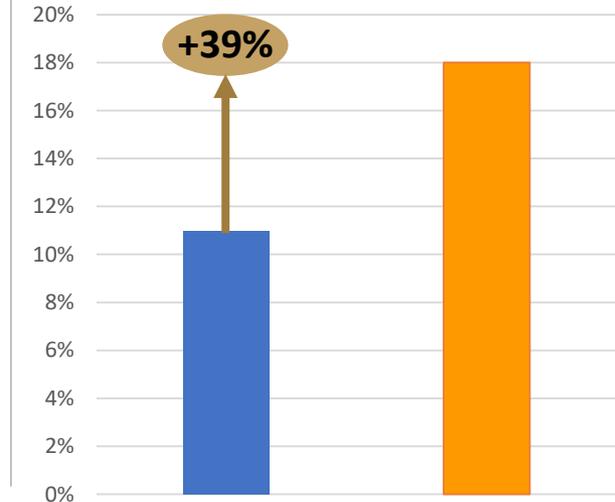
Capital Outlay



Annual Operating Cost



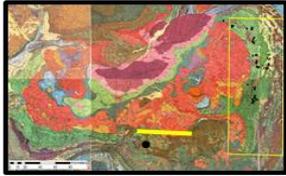
Project IRR



- Under the VRFB electrolyte rental model, the customer trades off upfront capital costs for an increase in the annual operating costs (to cover the cost of the rental payment)
- The tradeoff is a significant net gain for the end user, however, and reduces the impact of vanadium pricing in the project
- In future, as the model is proven and risk lowered, the upfront capital and/or the annual rent cost could be decreased further

# This innovation is supported by the forward looking business model for the integrated vanadium-based platform

## Key activities in the vanadium value chain



- Large high grade ore for primary vanadium mining
- Significant resource base in choice locations in South Africa's Bushveld complex



- Large, low cost vanadium processing
- Focus on expansion and enhancement of brownfield operations in South Africa



- Local electrolyte manufacturing for SA and export markets
- Scope to co-locate with ore processing to lower costs significantly



- VRFB assembly and manufacturing
- Research and development in cooperation with local and international institutes



- Large scale energy storage projects development
- Innovative business models and products, such as electrolyte leasing, energy storage capacity sales, ESS as a service

- **Integration over the entire vanadium value chain, positions the Bushveld group of companies uniquely to create value from vanadium resources all the way through VRFB projects**
- **The model also allows for greater beneficiation potential in South Africa for vanadium than nearly any other mineral resource**

# Thank you for your attention



Contact details:

[www.bushveldenergy.com](http://www.bushveldenergy.com)

[info@bushveldenergy.com](mailto:info@bushveldenergy.com)

+27 11 268 6555