Objectives

• Provide an overview of the Bushveld Group and efforts across the Vanadium energy storage value chain by Bushveld Energy;

• Understand energy storage in general

• Deep-dive into the Vanadium Redox Flow Battery (VRFB) technology and its applications;

• Energy storage systems co-located alongside renewable energy plants.
Bushveld Minerals is a leading low-cost, vertically integrated primary vanadium mining and processing platform.

Source: Bushveld Minerals
Bushveld Minerals is a leading, low cost, vertically integrated primary vanadium mining and processing platform seeking beneficiation

- Bushveld Minerals’ ambition is to grow into one of the world’s most significant, lowest cost and vertically integrated vanadium companies

- This allows the Company to leverage its large low cost production base and be a catalyst in the emerging energy storage industry

  - Largest primary vanadium resource base in the world (~550 Mt) with tier 1 $V_2O_5$ grades
  - 3 deposits, well serviced with logistics infrastructure

The Group is targeting a production >8,400 mtVp.a. and a nameplate capacity of 10,000 mtVp.a. within the next 5 years

Focus for Bushveld Energy

- Electrolyte manufacturing
- Scope to co-locate in Vametco process => significantly lowering costs

- Large, low cost, flexible & scalable primary vanadium processing facilities
- Focus on expansion and enhancement of brownfield operations

- VRFB Assembly & manufacturing
- MW scale energy storage project development
- Deployment models include PPAs, leasing models

Targeting initial 200MWh of electrolyte p.a.

Targeting 1000 MWh opportunities by 2020

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1. Based on a Ferrovanadium price year to date average price as at 30 September 2018 of US$72.3/kgV
2. Citigroup Report: $400 billion energy storage market by 2030

Source: Bushveld Minerals analysis, CitiGroup, Roskill, TTP Squared
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One of the most dynamic technology sectors, energy storage is recognised for its ability to fundamentally reshape the power system

- Energy storage is a process by which energy created at one time is preserved for use at another time, with a focus on electrical energy.

- Electrical energy by its very nature cannot be stored in the form of electricity, however, it can be converted into other forms of energy and stored for later use.

- Many different processes exist to convert electrical energy into other forms of energy, including mechanical, thermal, electrical, chemical, etc.

- Even in the power sector there is confusion, as energy storage seems similar to generation, but it is not; plus the sector is just now starting to understand renewable energy.

- The amount of different technologies and companies offering these technologies is overwhelming, changing rapidly and lacking standardisation on terminology, performance evaluation or a history of best practices.

Source: Press
Navigant Research forecasts energy storage to be a $50 billion market within 10 years

Stationary energy storage demand is growing rapidly and will exceed 468GWh by 2027 on a cumulative, installed basis

Most projects point to 20-40GWh of storage deployed by 2025

Annual additions are forecast to reach 80GWh by 2025

Growth may appear excessive, but it is similar to solar PV growth over the past 10 years

Note: Utility segment includes thermal storage technology
Source: Navigant Research
Stationary Energy Storage offers many benefits to power system on top of its ability to support renewable energy

Stationary energy storage usage parallels that of transmission lines, which move electricity from one location to another. Similarly, Energy storage moves electricity from one time to another.

Different types of storage and storage technologies are relevant for different applications, often determined by the amount of time stored energy that is required.

While storage is needed to stabilise and make variable generation from solar and wind dispatchable (or “base load”), the value of storage goes far beyond supporting renewable energy.

### Types of power sector applications of stationary energy storage

- **Bulk energy services**
- **Ancillary services**
- **Transmission infrastructure services**
- **Distribution infrastructure services**
- **Customer energy management services**
- **Off-grid**
  - **Solar home systems**
  - **Mini-grids: System stability services**
  - **Mini grids: Facilitating high share of VRE**

**Boxes in grey:** Energy storage services directly supporting the integration of variable renewable energy

**Source:** International Renewable Energy Agency (IRENA)
One way to envision how energy storage can be used is by the required storage duration and whether power or energy is the priority.

- Power is measured in watts (kW, MW, GW)
- Energy is measured in watt-hours (kWh, MWh, GWh)

Stationary storage applications

- Large scale wind, PV, grid support
- Voltage regulation
- Frequency regulation
- Black start
- Load following
- Off-grid utility scale
- Off-grid/end-user self consumption
- Arbitrage
- T&D deferral
- Inter-seasonal storage
- Seasonal storage

Source: Parsons Engineering
Just how different uses vary by power and energy requirements, so do storage technologies, with batteries being the most flexible.

Energy storage design, configuration and technology selection are all based on the combination of power and energy requirements at a potential site.

Source: Parsons Engineering
Stationary energy storage, such as batteries, consists of multiple components and on the outside can look like containers or even buildings.

Major components of a battery system:
- Container/Housing
- Energy Management Systems
- DC block
- AC conversion
- Thermal Management
- Power electronics
- Transformer
- Thermal management
- Fire Protection System
- System

Examples of battery system installations:

Most of the technical differences are on the DC side.

Source: IRENA; Sumitomo, Tesla, UET, http://www.greenbuildingadvisor.com
The challenge and opportunity lies in monetising and calculating (or stacking) multiple possible value streams.

For multi-value stream sites, value “stacking” is the approach to quantify total value.

Although simple in theory, actual stacking requires significant analysis of questions such as:

- How many of the values can one system perform?
- To what degree can each value be captured (e.g. 50%, 80%)?
- How will multiple implications impact the battery’s cost (e.g. inverter, software) and lifetime (e.g. cycles, stage of charge)?
- How to value future cost increases?

Source: Lazard’s levelized cost of storage
Many factors go into the cost of energy storage

- Media focus tends to be only on the cost of lithium ion cells, targeting $100/kWh
- The well-known 128MWh Tesla system in Australia cost $66m or $516/kWh

### Observations

- Will vary for power (watts) and energy (watt hours)
- Some firms quote for AC, others for DC
- What is “containerised”?
- Transformers, site controllers?
- Is this done by the OEM, EPC, developer, integrators, etc.?
- Highly site specific (and do not forget about time)

### Total cost of an energy storage site

- Upfront (capital) cost
  - DC block
  - AC equipment
  - Housing, grid & interconnections
  - Installation & commissioning
  - Delivery

- On-going annual (O&M) cost
  - AC-AC efficiency
  - Maintenance or warranty cost
  - Degradation rates
  - Battery lifetime
  - Financing costs

### Source: Bushveld Energy
Besides suitability for certain applications, energy storage technologies vary in their technical performance and life-span.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Average Project Power Capacity (MW)</th>
<th>Average Discharge Duration (Hours)</th>
<th>Average Round-Trip Efficiency</th>
<th>Estimated Cycle Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Lead-Acid Battery</td>
<td>.1 – 25 MW</td>
<td>1</td>
<td>50 – 85%</td>
<td>3,000 – 4,500</td>
</tr>
<tr>
<td>Compressed Air</td>
<td>25 – 250 MW</td>
<td>4 – 12</td>
<td>65 - 75%</td>
<td>15,000 – 25,000</td>
</tr>
<tr>
<td>Flow Battery</td>
<td>.5 – 100 MW</td>
<td>3 – 10</td>
<td>65 – 85%</td>
<td>5,000 – 15,000</td>
</tr>
<tr>
<td>Flywheel</td>
<td>.5 – 25 MW</td>
<td>0.1 – 0.5</td>
<td>90%</td>
<td>100,000 +</td>
</tr>
<tr>
<td>Lithium-ion Battery</td>
<td>.1 – 100 MW</td>
<td>0.5 – 5</td>
<td>85 – 95%</td>
<td>500 - 10,000</td>
</tr>
<tr>
<td>NaS Battery</td>
<td>1 – 100 MW</td>
<td>6</td>
<td>75 – 90%</td>
<td>2-000 - 6,000</td>
</tr>
<tr>
<td>Hydrogen / power to gas</td>
<td>1 – 100 MW</td>
<td>N/A</td>
<td>35 – 50%</td>
<td>N/A</td>
</tr>
<tr>
<td>Pumped Hydro Storage</td>
<td>50 – 500 MW</td>
<td>4 – 12</td>
<td>70 - 80%</td>
<td>15,000 – 25,000</td>
</tr>
<tr>
<td>Ultracapacitor</td>
<td>.1 – 25 MW</td>
<td>0.1</td>
<td>70 – 95%</td>
<td>100,000 +</td>
</tr>
</tbody>
</table>

Source: Navigant Research
Multiple technologies are already commercially viable, although lithium and flow batteries are regarded as most viable for the next 10-15 years.

<table>
<thead>
<tr>
<th>Technology</th>
<th>2018-2021</th>
<th>2022-2027</th>
<th>Beyond 2027</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Lead-Acid</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>CAES</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Flow Batteries</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Flywheel</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Li-ion</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>NaS</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Power-to-Gas</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Pumped Hydro</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Ultracapacitors</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Next Generation Advanced Batteries</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Source: Navigant
Costs are expected to come down for all technologies due to scale, competition and lower transaction costs.

Utility-Scale Energy Storage CAPEX Assumptions by Technology for Bulk Storage/Energy Services, Average Installed Costs, World Markets

Source: Navigant Research
Solar plus storage is already beating gas for certain applications, questioning the medium term relevance of gas to power plans in South Africa.

**Solar-plus-storage is already competitive with combined-cycle gas turbines (CCGTs) in Morocco and Jordan**

The LCOE gap between standalone PV and solar-plus-storage will narrow significantly by 2023.

Levelized cost of energy range for solar and solar-plus-storage in our five target countries* vs. our expected range of LCOE CCGT for Morocco and Jordan, 2018-2023

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*Target countries for modelling are Egypt, Morocco, Jordan, UAE-Dubai, South Africa

Source: Wood Mackenzie Power & Renewables
Is a 40% increase in cost able to be offset by the use-case benefits of an increase in usable energy hours from 30% in the day to 70% in the day?

<table>
<thead>
<tr>
<th>Application</th>
<th>Technology</th>
<th>LCOS USD/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wholesale</td>
<td>Lithium</td>
<td>298</td>
</tr>
<tr>
<td>Flow (v)</td>
<td></td>
<td>390</td>
</tr>
<tr>
<td>Flow (Zn)</td>
<td></td>
<td>300</td>
</tr>
<tr>
<td>T&amp;D</td>
<td>Lithium</td>
<td>471</td>
</tr>
<tr>
<td>Flow (v)</td>
<td></td>
<td>467</td>
</tr>
<tr>
<td>Flow (Zn)</td>
<td></td>
<td>464</td>
</tr>
<tr>
<td>Utility Scale (S+S)</td>
<td>Lithium</td>
<td>140</td>
</tr>
<tr>
<td>Flow (v)</td>
<td></td>
<td>222</td>
</tr>
<tr>
<td>Flow (Zn)</td>
<td></td>
<td>167</td>
</tr>
<tr>
<td>C&amp;I (Standalone)</td>
<td>Lithium</td>
<td>1152</td>
</tr>
<tr>
<td>Flow (v)</td>
<td></td>
<td>1225</td>
</tr>
<tr>
<td>Flow (Zn)</td>
<td></td>
<td>1204</td>
</tr>
<tr>
<td>C&amp;I (S+S)</td>
<td>Lithium</td>
<td>366</td>
</tr>
<tr>
<td>Flow (v)</td>
<td></td>
<td>399</td>
</tr>
<tr>
<td>Flow (Zn)</td>
<td></td>
<td>378</td>
</tr>
<tr>
<td>Residential</td>
<td>Lithium</td>
<td>735</td>
</tr>
<tr>
<td>Flow (v)</td>
<td></td>
<td>707</td>
</tr>
<tr>
<td>Flow (Zn)</td>
<td></td>
<td>675</td>
</tr>
</tbody>
</table>

Source: Lazard
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• Energy storage systems co-located alongside renewable energy plants.
The VRFB is the simplest and most developed flow battery in mass commercial operations

- 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 reversible 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 chemical additive acids such as sulphuric acid or hydrochloric acid.

VRFB technology offers significant advantages

- **Long lifespan cycles**: Ability to repeatedly charge / discharge over 35,000 times for a lifespan of over 20 years
- **100% depth of discharge**: Without performance degradation is unique to VRFBs
- **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
- **100% of vanadium is re-usable** upon decommissioning of the system
- **Scalable capacity** to store large quantities of energy (MW-range)
- **Flexibility**: Allows capture of the multi-stacked value of energy storage in grid applications
- **Very fast response time** of less than 70ms
- **No cross-contamination**: Only one battery element, unique among flow batteries

Source: IRENA
Especially in Asia, VRFBs are used in large scale energy storage projects

I. 60 MWh VRFB from Sumitomo in Hokkaido, Japan

II. 800 MWh VRFB by Rongke Power in Dalian, China

- 3-phase project to be finished by 2020
- Cornerstone of a new smart energy grid in Hubei Province.
- Will serve as a critical peaker plant, deliver reliability and reduce emissions

III. 400 MWh VRFB from Pu Neng in Hubei, China

Containerised solutions are ideal for installations in the 500kWh to 50MWh sizes, as per Bushveld’s current project with Eskom

Source: Sumitomo; Rongke Power; Pu Neng; UET; Bushveld Energy
VRFB is argued as being 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

Analysis of typical hazards by ESS Type

<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>
</tr>
<tr>
<td>Toxicity</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<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>
</tr>
<tr>
<td>Stranded Energy</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

“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

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The term ‘co-location’ covers a wide range of project configurations:

• Truly integrated solutions constructed and commissioned simultaneously;
• The retrospective addition of storage to an existing generating station;
• Stand-alone generation and storage projects utilizing shared land or grid infrastructure.

Maximizing generation output and existing revenue streams, particularly if the project is affected by grid constraints;

Access to price arbitrage, especially for projects whose output is restricted to specified times, such as solar and tidal;

Access to additional revenue streams, such as frequency response.

The risks:

• Technically DC/ DC connection or DC/ AC connection;
• The system management and integration.

The effect on commercial outcomes:

• Decentralisation of energy as a utility strategy.

The advent of the IPP:

• The monitoring and measurement of policy and regulation that delivers a level of bankability.
• The development of that policy;
• The development of standards;
• The development of revenue models applicable to energy storage.

The development of the business case.

• The PPA;
• The cost comparatives;
• The regulatory and permitting frameworks;
• The opportunities to get it right.
Q&A

THANK YOU
Due to a combination of maturity, performance and cost, lead acid, lithium ion and flow battery technologies are the most prominent on the market.

In its most recent review of energy storage, the investment bank Lazard focused on only three technologies based upon commercial readiness.

<table>
<thead>
<tr>
<th>Overview of Selected Energy Storage Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compressed Air</strong></td>
</tr>
<tr>
<td>Compressed Air Energy Storage (&quot;CAES&quot;) uses electricity to compress air into confined spaces (e.g., underground mines, salt caverns, etc.) where the pressurized air is stored. When required, this pressurized air is released to drive the compressor of a natural gas turbine.</td>
</tr>
<tr>
<td><strong>Flow Battery</strong></td>
</tr>
<tr>
<td>Flow batteries store energy through chemically changing the electrolyte (vanadium) or plating zinc (zinc bromine). Physically, systems typically contain two electrolyte solutions in separate tanks, circulated through two independent loops, separated by a membrane. Emerging alternatives allow for simpler and less costly designs utilizing a single tank, single loop, and no membrane. The subcategories of flow batteries are defined by the chemical composition of the electrolyte solution, the most prevalent of such solutions are vanadium and zinc-bromide. Other solutions include zinc-chloride, iron-chromium and zinc chromate.</td>
</tr>
<tr>
<td><strong>Size (MW)</strong></td>
</tr>
<tr>
<td>150 MW+</td>
</tr>
<tr>
<td>30 kW - 1 MW</td>
</tr>
<tr>
<td>100 MW+</td>
</tr>
<tr>
<td>5 MW - 100 MW</td>
</tr>
<tr>
<td>1 MW - 100 MW</td>
</tr>
<tr>
<td>1 MW - 100 MW</td>
</tr>
<tr>
<td>1 MW - 100 MW</td>
</tr>
<tr>
<td>5 kW - 100 MW+</td>
</tr>
</tbody>
</table>

Source: Lazard
Lazard uses the levelized cost of energy storage (LCOS) to compare technologies, but the method has limitations.

**Investment bank Lazard analysis shows that VRFBs have the potential to achieve the lowest costs in the industry**

<table>
<thead>
<tr>
<th>USD / kWh, 2018, levelised costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wholesale</td>
</tr>
<tr>
<td>Lithium-Ion</td>
</tr>
<tr>
<td>0.20</td>
</tr>
<tr>
<td>0.26</td>
</tr>
<tr>
<td>0.11</td>
</tr>
</tbody>
</table>

**Limitations to Lazard’s approach**

- All analyses assume not more than one 100% discharge cycle per day.
- A single battery, well-placed within a power system can be used for multiple uses, decreasing its LCOS further.
- Lack of public information on costs and performance creates a wide range of pricing in the analysis of both technologies, which will fall over time.

Notes: VRFB 1.5 cycles LCOS takes Lazard’s VRFB LCOS and adjusts for 1.5 full daily cycles, rather than the 1 cycle assumed. T&D stands for Transmission and Distribution use case. 

**Source:** Lazard’s Levelised Cost of Energy Storage Analysis – Version 4.0 (November 2018); Bushveld Energy analysis
Calculating and evaluating the stacked values and how the VRFB can perform them all is a major component of Bushveld’s current project with Eskom

Context to project

- Peak 120kW/450kWh VRFB located at Eskom’s Research & Technology micro-grid site
- Project development by Bushveld Energy and IDC
- Integration performed by Bushveld Energy, with VRFB from UniEnergy Technologies
- Eskom’s operational objectives for the VRFB:
  - Minimum load shifting;
  - Wind smoothing;
  - Solar smoothing;
  - Improved power quality;
  - Micro-grid black-start;
  - A combination of the above (including cannibalisation);
  - Other applications, as to be determined.
Energy storage projects are providing quantifiable returns which take the form of multiple sources of revenue.

1 Lazard’s Value Snapshot analysis intentionally excluded a Transmission and Distribution use case from its international analysis.

Source: Lazard – Levelized Cost of Energy Storage 4.0