Energy Storage & Vanadium Redox Flow Batteries 101

13 November 2018

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Bushveld Minerals' presenters

Fortune Mojapelo
Chief Executive Officer

- Co-founder and Chief Executive Officer (CEO) of Bushveld Minerals
- Co-founder and director of VM Investment (Pty) Ltd, a principal investments and advisory company focusing on developing mining projects in Africa
- Founding CEO of Bushveld Minerals Limited where he has played a lead role developing and executing the company's vanadium strategy
- Played a leading role in the origination, establishment and project development of several junior mining companies in Africa including Greenhills Resources, Bushveld Resources
- Fortune's corporate career started at McKinsey & Company as a strategy consultant

Mikhail Nikomarov
Chief Executive Officer
Bushveld Energy

- 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)
- Chair of the Energy Storage Committee of Vanitec, the global non-profit association of vanadium producers
- Previously worked for McKinsey & Company in Russia and across Africa, focusing on the power sector (strategy and plant operations) and economic development. Mikhail's corporate career started as a commercial banker in the USA

Objectives for today's session

- **Understand energy storage, focusing on stationary storage, it's importance, use and the different technologies available for those uses;**
- Present a deep dive in vanadium redox flow batteries (VRFBs), covering their unique applications, how they compare to alternatives such as lithium-ion and discuss the challenges and opportunities that the VRFB value chain faces today. This will include trends currently impacting stationary energy storage deployments globally;
- Highlight the size of the market opportunity for stationary energy storage and discuss the implications it has on overall demand for VRFBs and vanadium;
- Briefly touch on the use of vanadium in other types of energy storage;
- Provide an overview of Bushveld Minerals and Bushveld Energy in an integrated effort to create value across the vanadium energy storage value chain.

Energy storage is one of the most dynamic technology sectors, 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.

Forbes: *Why Energy Storage May Be The Most Important Technology In The World Right Now*

REUTERS: *Bill Gates, Jeff Bezos, and other influential billionaires are investing in 2 start-ups that could solve the biggest problem with renewable energy*

CNBC: *Energy storage has the potential to change the way we live*

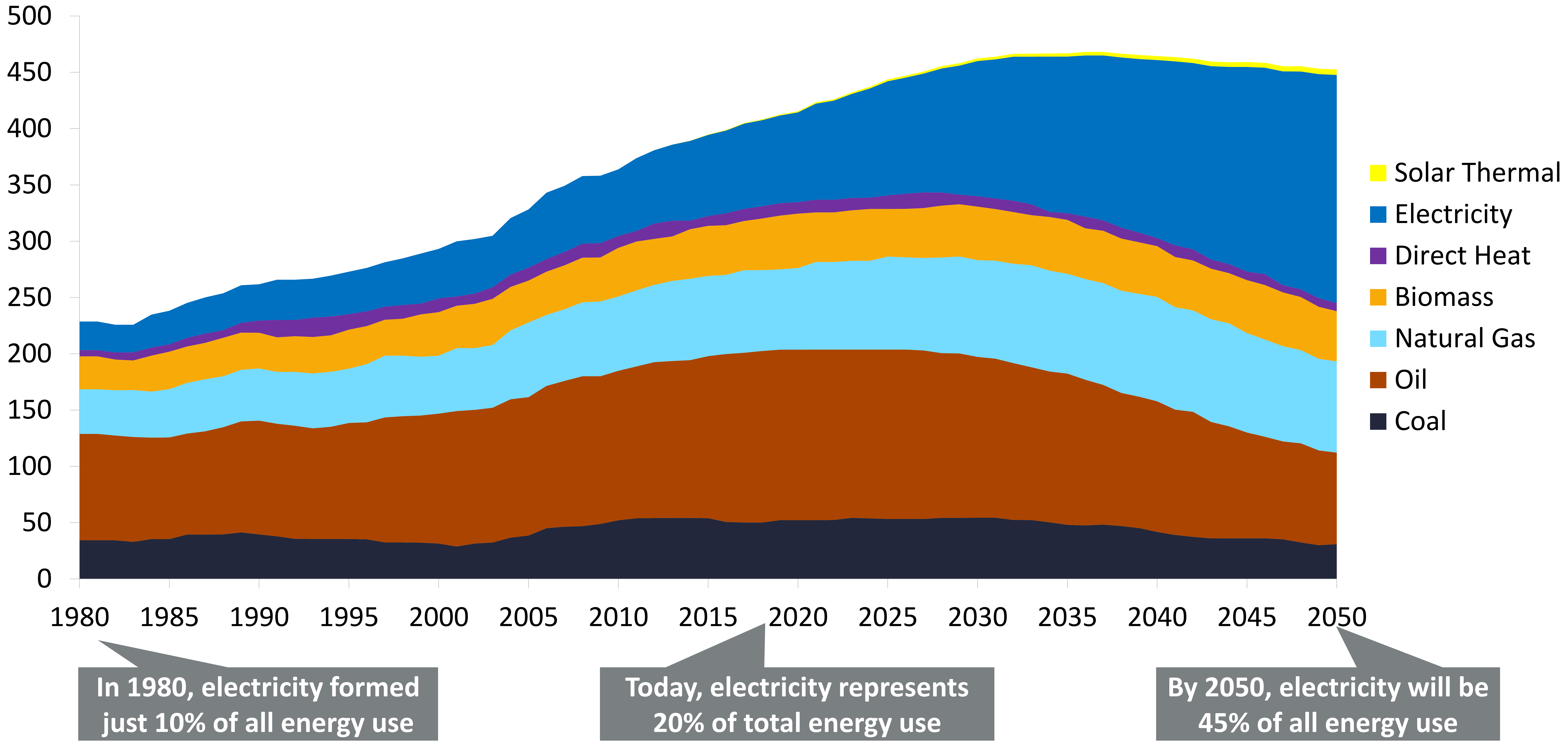
GreenBiz: *Why batteries are the 'holy grail' for clean energy*

Eskom | Powering your world: *At this stage, the focus is on storing energy for the benefit of all our customers. The aim is to ensure the security of power supply.*

Source: Bushveld Energy, Press

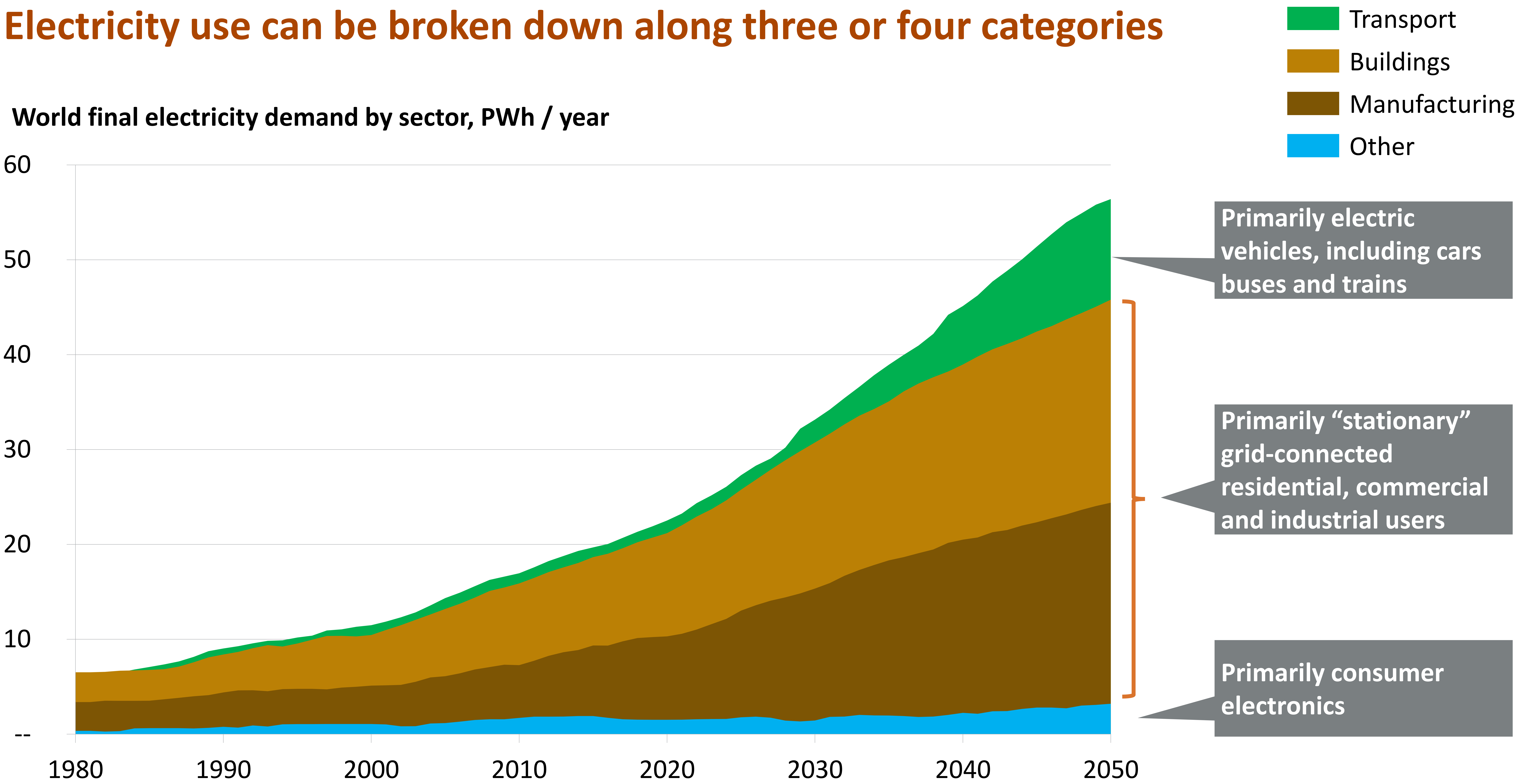
Electrical energy storage is important because the role of electricity in our lives is increasing, leading to a future with "electrification of everything"

World energy demand by carrier, EJ/year



Source: DNV GL Energy Transition Outlook 2018

Electricity use can be broken down along three or four categories

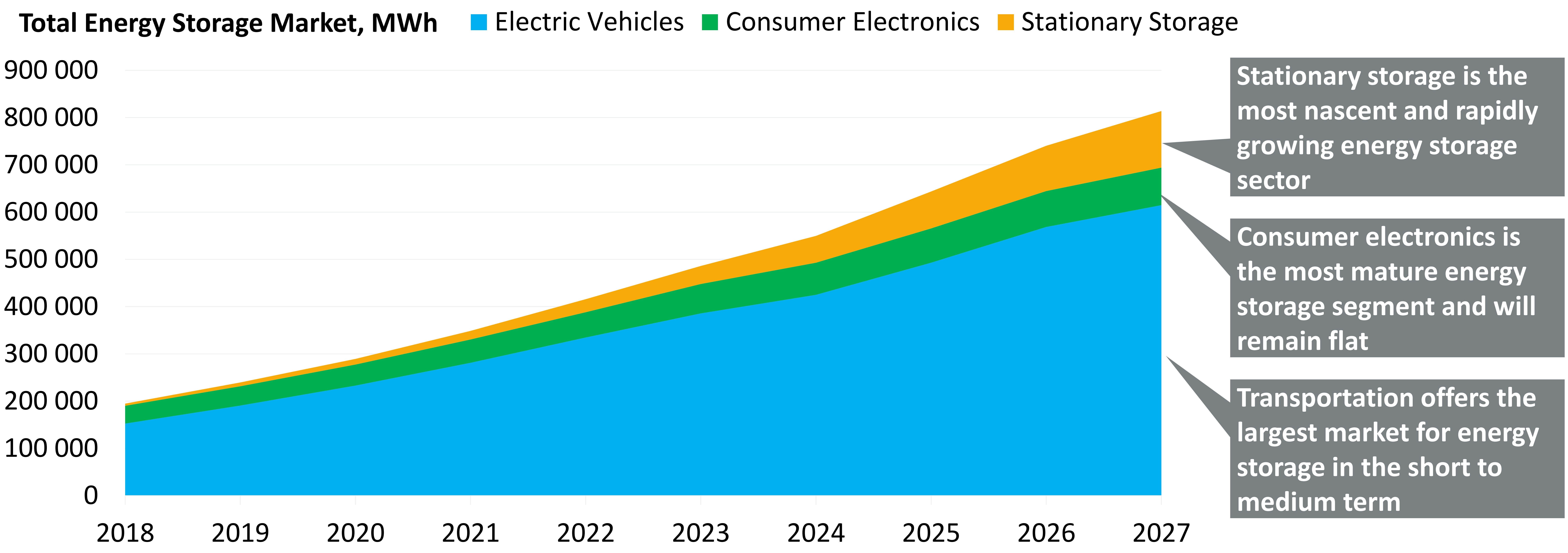


Source: DNV GL Energy Transition Outlook 2018

Stationary storage is the most nascent but also the fastest growing sector in energy storage

- The nature of how electricity is supplied to each type of use determines to what degree storage is required
- Thus, it is helpful to break down demand into three broad types of “energy storage” uses:
  - ➢ Stationary applications (such as power utilities that supply buildings and manufacturing through a power grid) –**focus of this document**
  - ➢ Mobile or transport applications (such as electric vehicles)
  - ➢ Consumer electronics

Total Energy Storage Market, MWh



Source: Navigant

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**

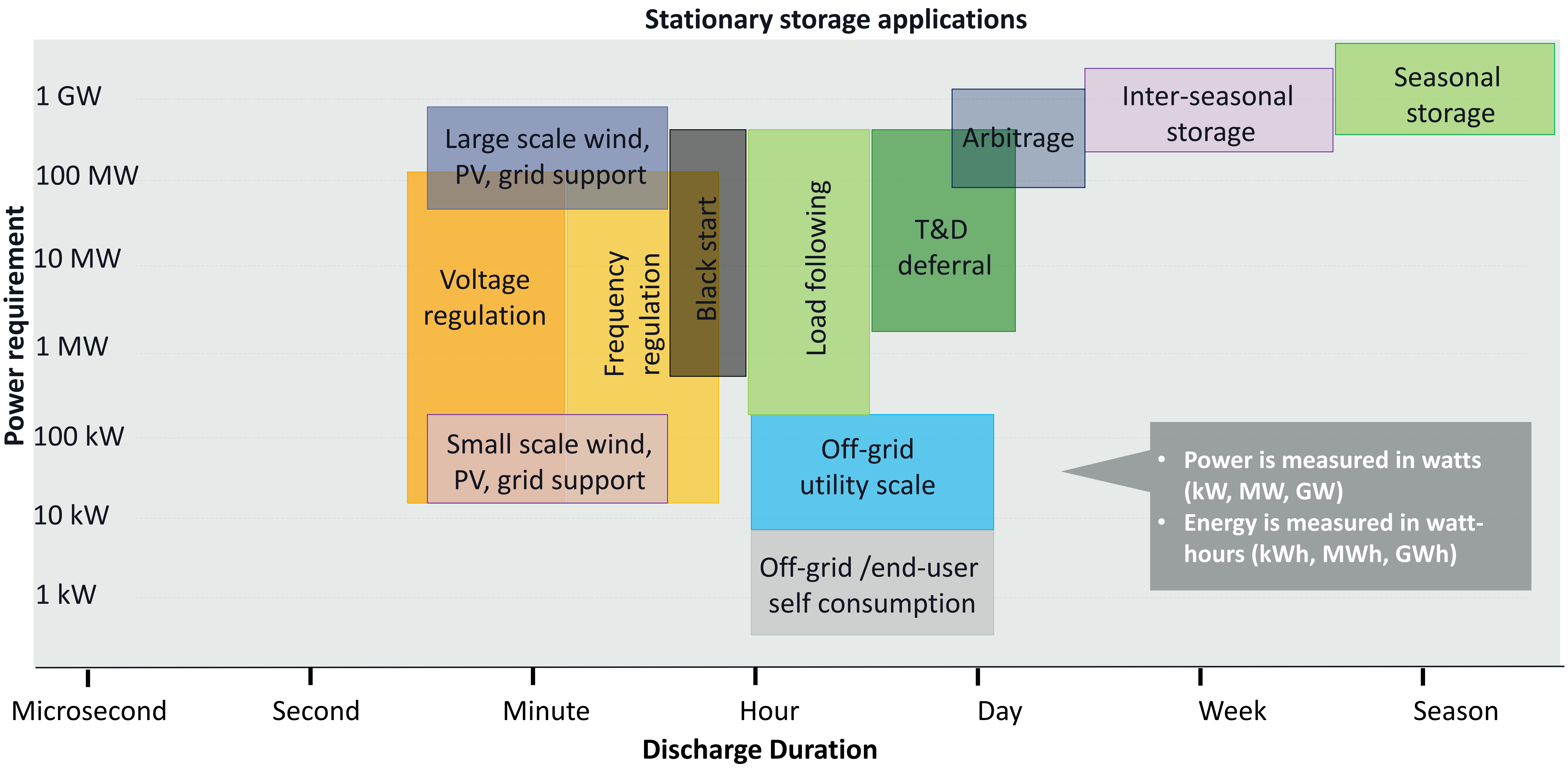
Types of power sector applications of stationary energy storage

Bulk energy services	Ancillary services	Transmission infrastructure services	Distribution infrastructure services	Customer energy management services	Off-grid
Electric energy time-shift (arbitrage)	Frequency regulation	Transmission upgrade deferral	Distribution upgrade deferral	Power quality	Solar home systems
Electric supply capacity	Spinning, non spinning and supplemental reserves	Transmission congestion relief	Voltage support	Power reliability	Mini-grids: System stability services
	Voltage Support			Retail electric energy time-shift	Mini grids: Facilitating high share of VRE
	Black start			Demand charge management	
				Increased self-consumption of Solar PV	

Boxes in grey: Storage services directly supporting the integration of 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



Source: Parsons Engineering

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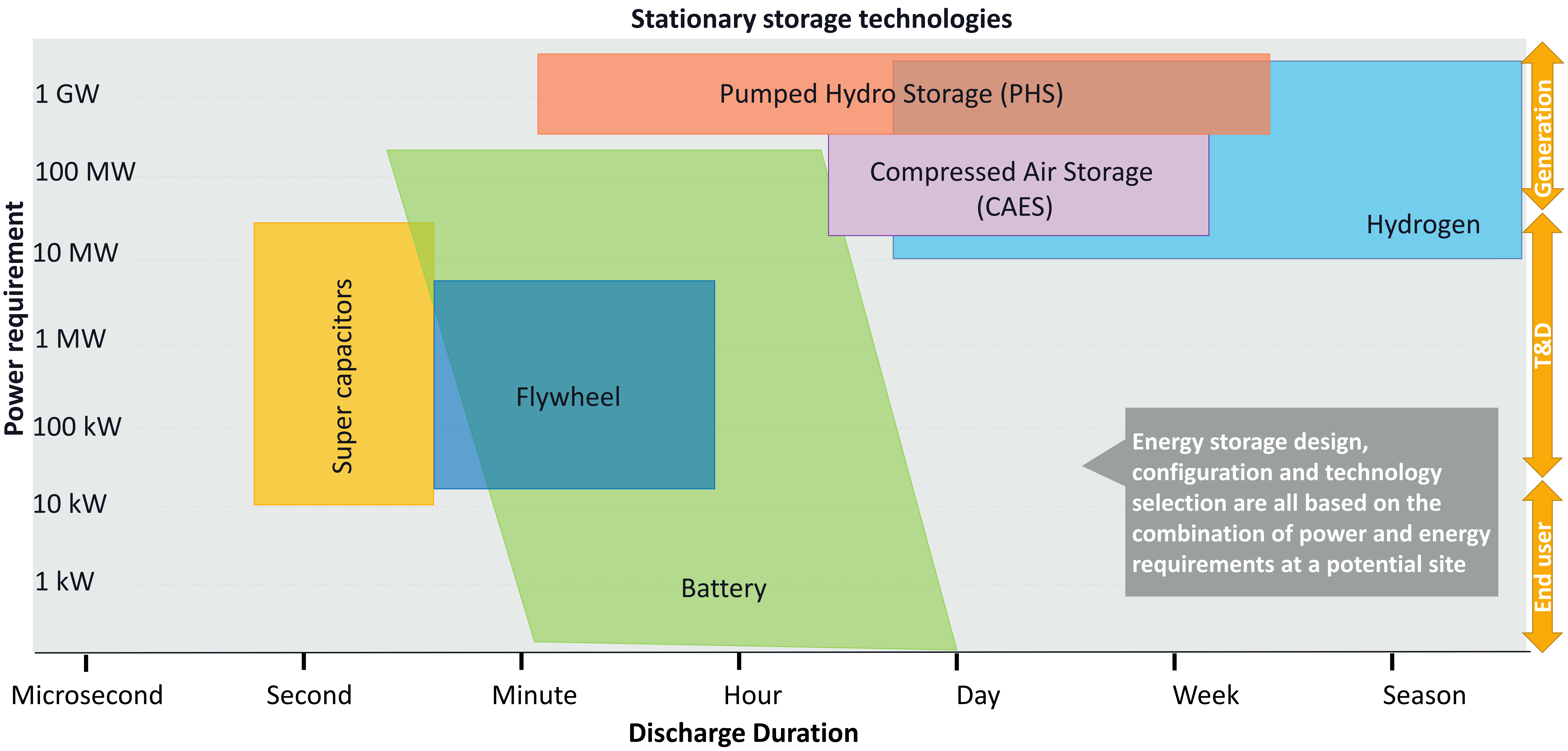


Source: Parsons Engineering

Besides suitability for certain applications, energy storage technologies vary in their technical performance and life-span

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

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

Technological and commercial viability of energy storage technologies			
Technology	**2018-2021**	**2022-2027**	**Beyond 2027**
Advanced Lead-Acid	Medium	Medium	Low
CAES	Low	Medium	Medium
Flow Batteries	Medium	High	High
Flywheel	Low	Medium	Medium
Li-ion	High	High	High
NaS	Medium	Low	Low
Power-to-Gas	Low	Medium	Medium
Pumped Hydro	Medium	Medium	Low
Ultracapacitors	Low	Low	Low
Next Generation Advanced Batteries	Low	Medium	Medium

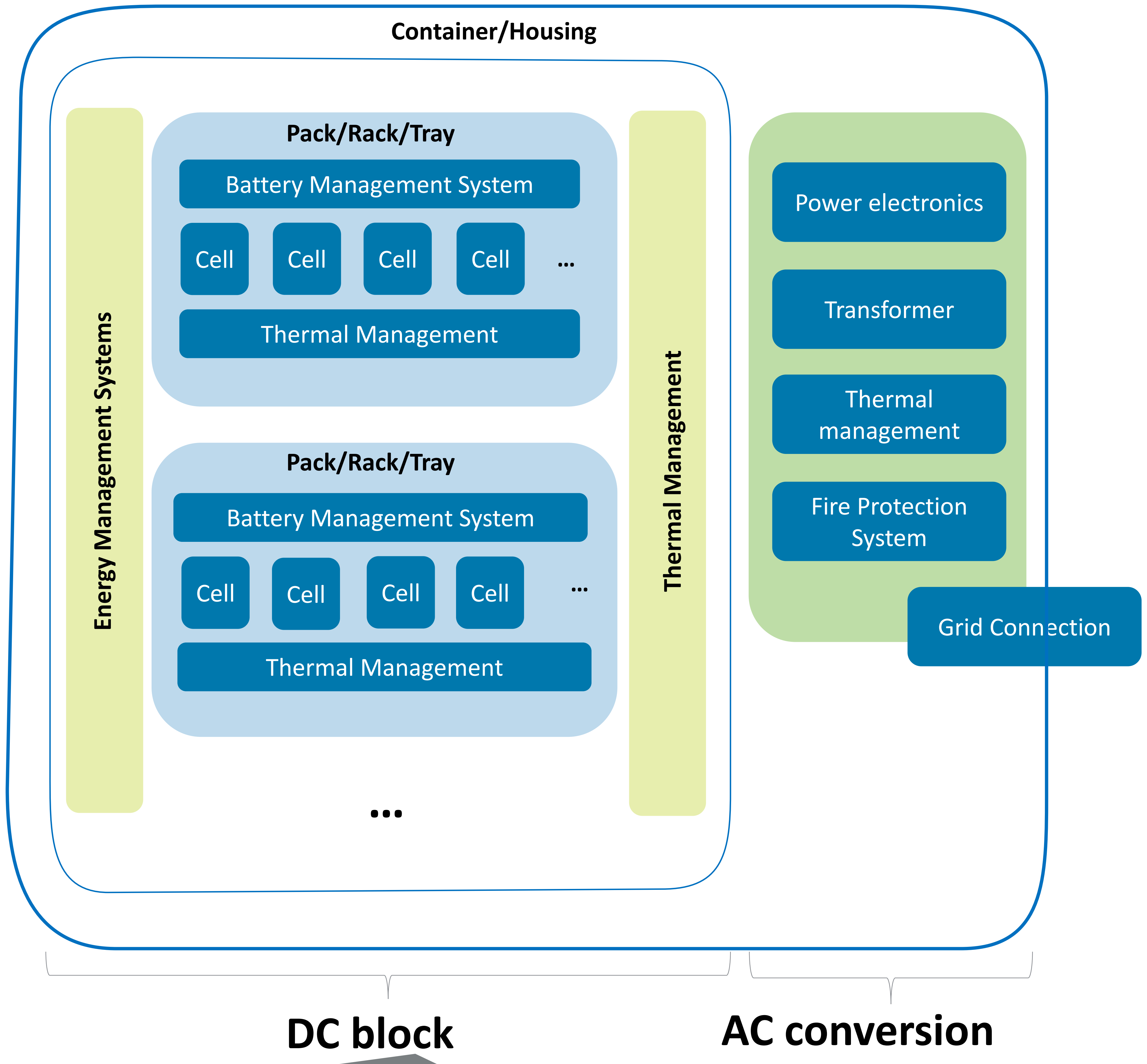
Source: Navigant

Pumped hydro is the most prominent energy storage technology to date, accounting for 99% of energy storage deployed. While already cheap, pumped hydro has many limitations, including:

- **Requiring specific topography that limits possible locations (with many ideal locations already taken)**
- **High upfront capital costs with economics that only make sense at large scale**
- **Significant environmental impact and water usage**
- **No flexibility**

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



Most of the technical differences are on the DC side

Examples of battery system installations

Source: IRENA; Sumitomo, Tesla, UET, http://www.greenbuildingadvisor.com

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**

Total cost of an energy storage site = Upfront (capital) cost + On-going annual (O&M) cost

- **Focusing on upfront costs only, ignores many other cost drivers;**
- **Life-time cost of ownership or levelized costs (LCOES) are a better, but imperfect comparison metric**

Cost	Factor	Observations
Upfront (capital) cost	DC block	• Will vary for power (watts) and energy (watt hours)
	AC equipment	• Some firms quote for AC, others for DC
	Housing, grid & interconnections	• What is "containerised"? • Transformers, site controllers?
	Installation & commissioning	• Is this done by the OEM, EPC, developer, integrators, etc.?
	Delivery	• Highly site specific (and do not forget about time)
On-going annual (O&M) cost	AC-AC efficiency	• All batteries lose energy and all have parasitical AC systems
	Maintenance or warranty cost	• These costs are predictive • How strong is the warranty?
	Degradation rates & battery lifetime	• Includes, temperature, DoD, "rest periods" • Can be measured in years or full cycles or both
	Availability	• Percentage of time a battery is operational (e.g. not under repair)
	Financing costs	• Loan repayment or internal rate of return (incl. taxes and incentives)

Source: Bushveld Energy

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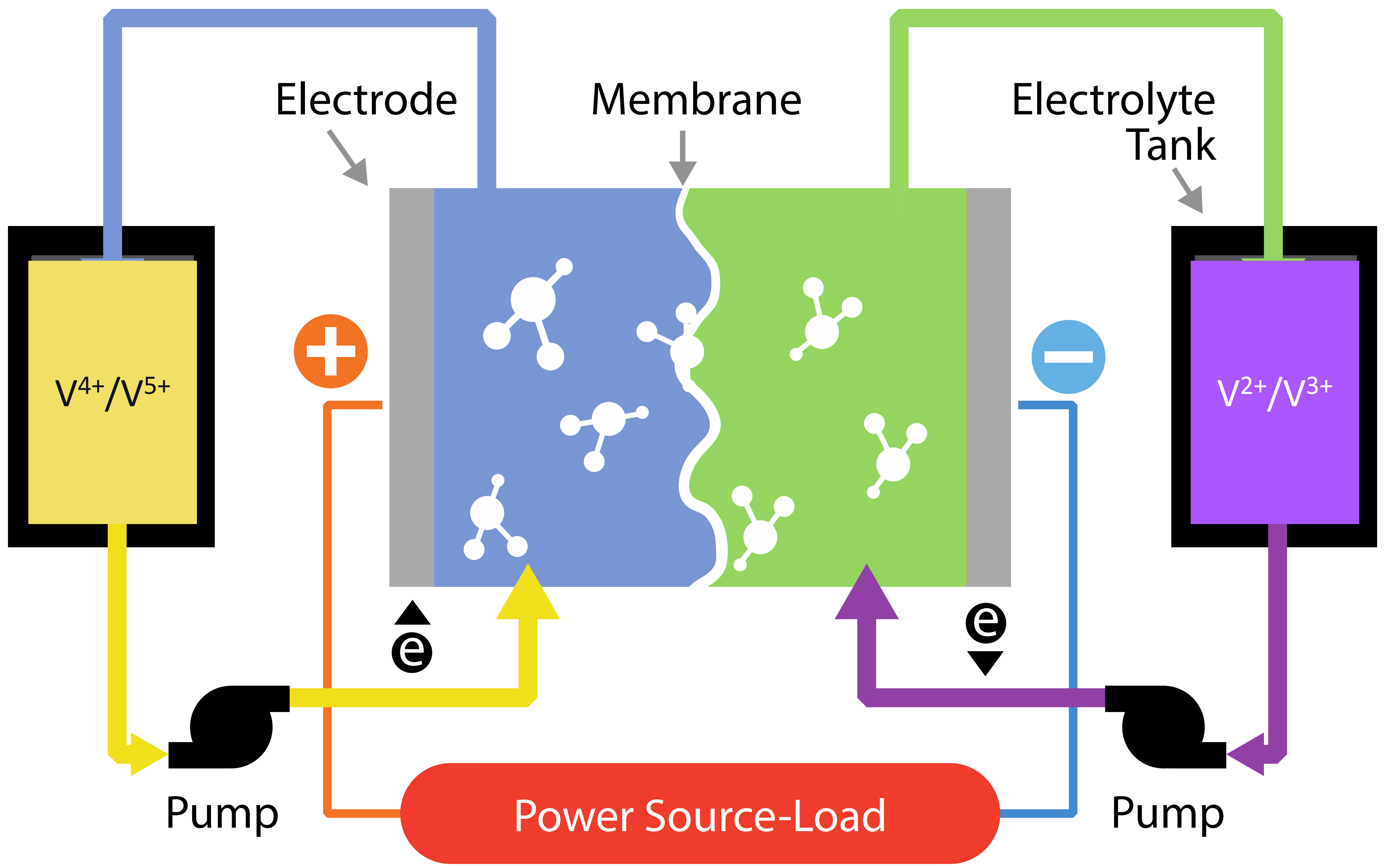
The VRFB is the simplest and most developed flow battery in mass commercial operations

- 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 reversable 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



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 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
- **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

Based upon these technical advantages, the most common question about VRFBs is how they compare to lithium-ion

Four key categories to consider	VRFBs	Lithium-ion
1. Technical performance	• Excellent for energy applications (4+hrs) • Lower roundtrip efficiency but longer life and no degradation	• Excellent for power applications • Degradation accelerates with frequent use, temperature and deep discharges
2. Safety	• No risk of thermal runaway • Electrolyte spillage is main risk	• Thermal runaway creates risk of fire and smoke that must be managed
3. Cost	• Have yet to experience scale economies • High contribution of vanadium is both a risk and an opportunity	• Significant cost decreases in recent years due to R&D and capacity growth • Cost reductions expected to slow
4. Market acceptance	• More nascent technology • Challenge from fragmented supply market dominated by start-up companies	• Growing acceptance from deployment in frequency control markets • Credibility of large, consolidated cell manufacturers helps

In summary, there is no clear superiority, with use cases and site requirements often determining the optimal solution

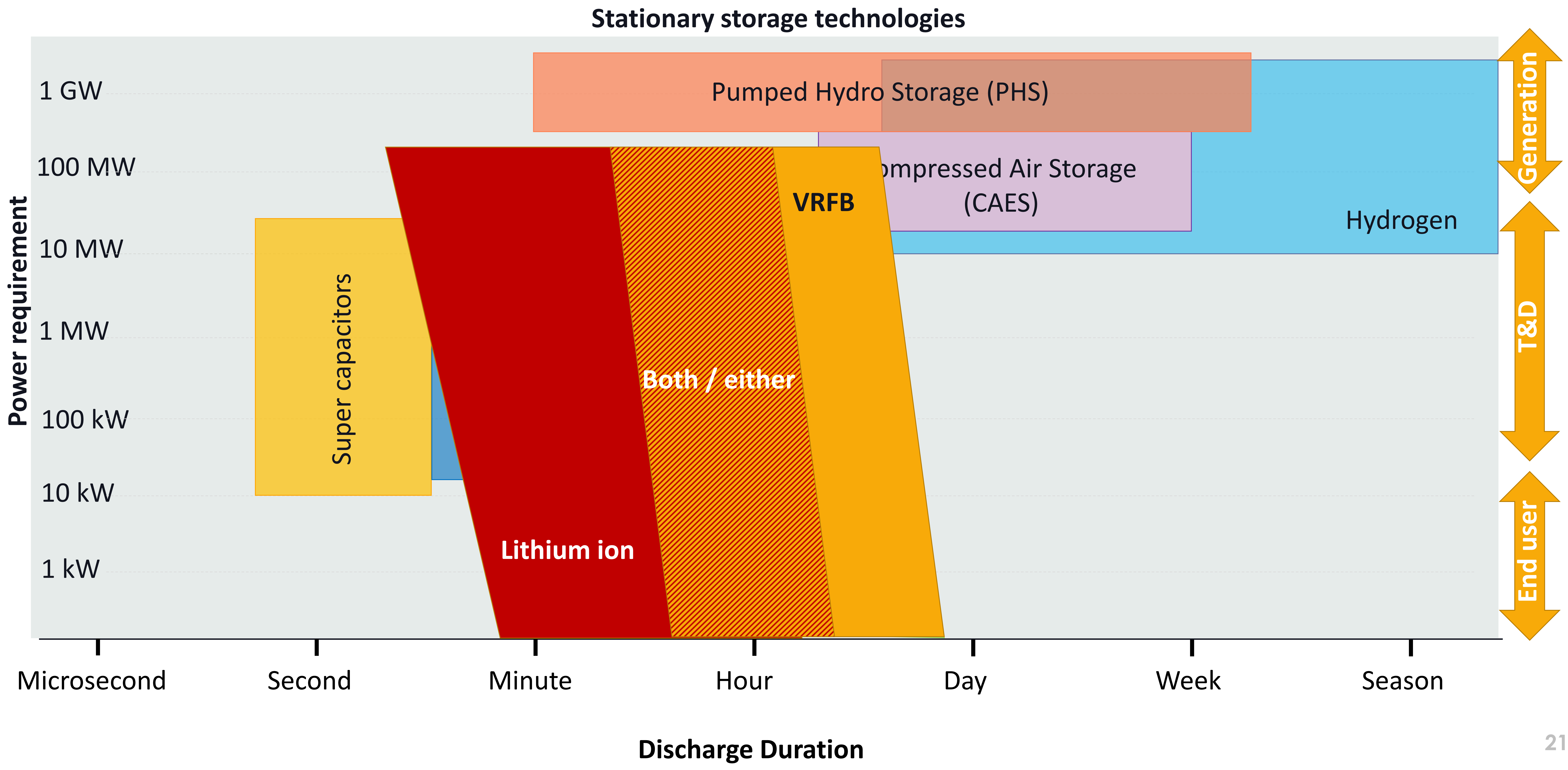
Source: Bushveld Energy

A. There are clear performance benefits to both technologies

Metric	VRFB	Lithium-ion
Sub-chemistries	H_2SO_4-based, HCl-based	LFP, LMO, NCA, NMC, LTO
Energy Density	20-40 Wh / kg	80-200 Wh/kg
Discharge Time	3-10 hours	0.5-5 hours
DC Efficiency	75-90%	92%-99%
Cycle Life	20,000-30,000 cycles	600-12,000 cycles
Calendar Life	20-25 years	3-10 years
Depth of Discharge	100%	80-95%
Ambient temperature	-20 - 50^{o} C	0-30^{o} C
Self-discharge (24h)	2.5%	5%
Safety Notes	Corrosive electrolyte	Susceptible to thermal runaway
Applications	Suited for energy applications	Suited for power and energy applications

Source: Bushveld Energy, Navigant

1. VRFBs are ideal for daily storage requiring at least 3 hours of storage



Source: IDC; Parsons Engineering

2. VRFBs are intrinsically safer than solid state batteries as they have no "thermal runaway" risk

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	

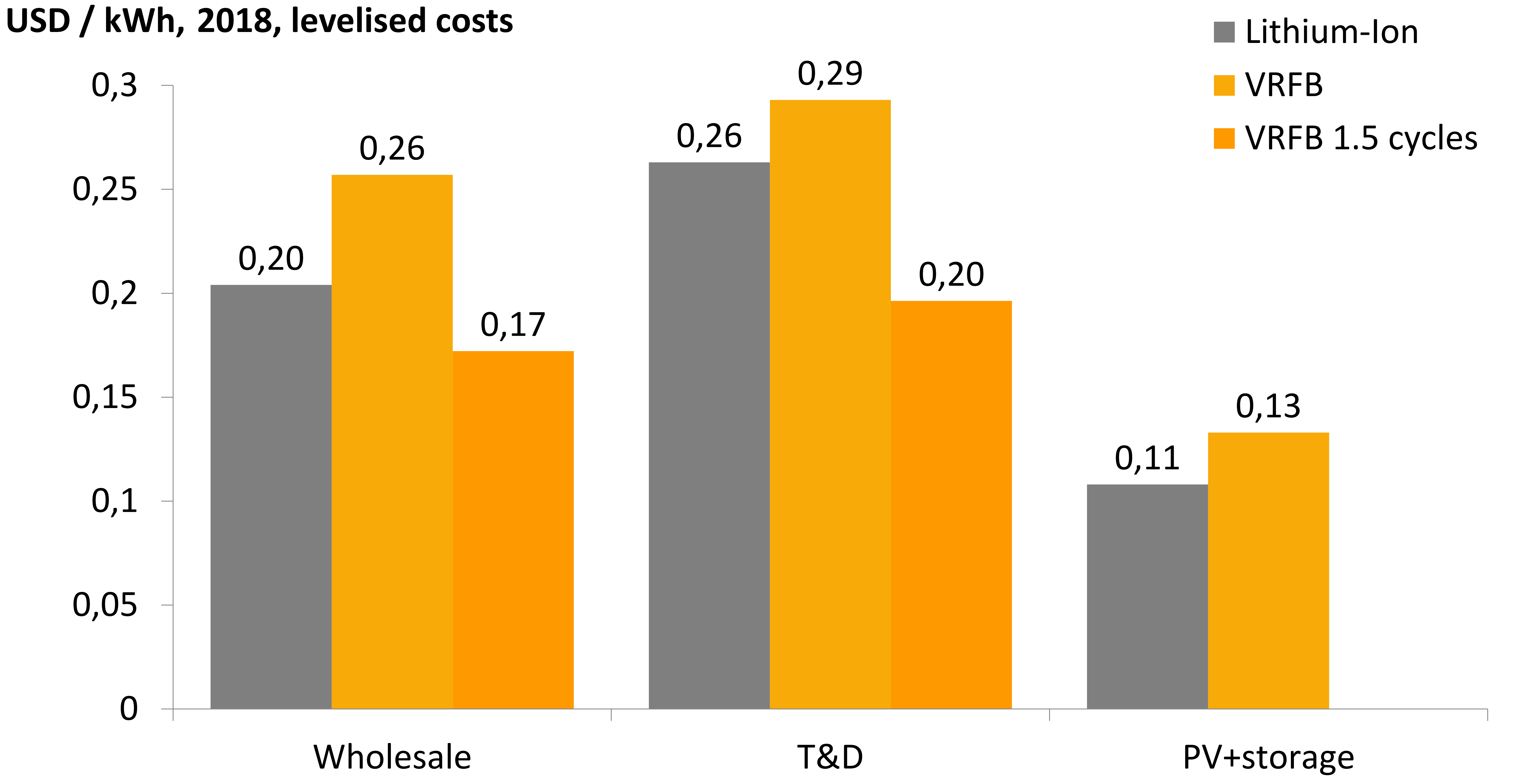
"VRFB along with lead acid is the only battery chemistry to receive a letter of no objection from the New York Fire Department."

- ESJ (Energy Storage Journal), 14.11.16

Source: "Energy Storage System Safety: Vanadium Redox Flow Vs. Lithium-Ion," June 2017, Energy Response Solutions, Inc., energyresponsesolutions.com; www.energystoragejournal.com

3. 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



Limitations to Lazard's approach

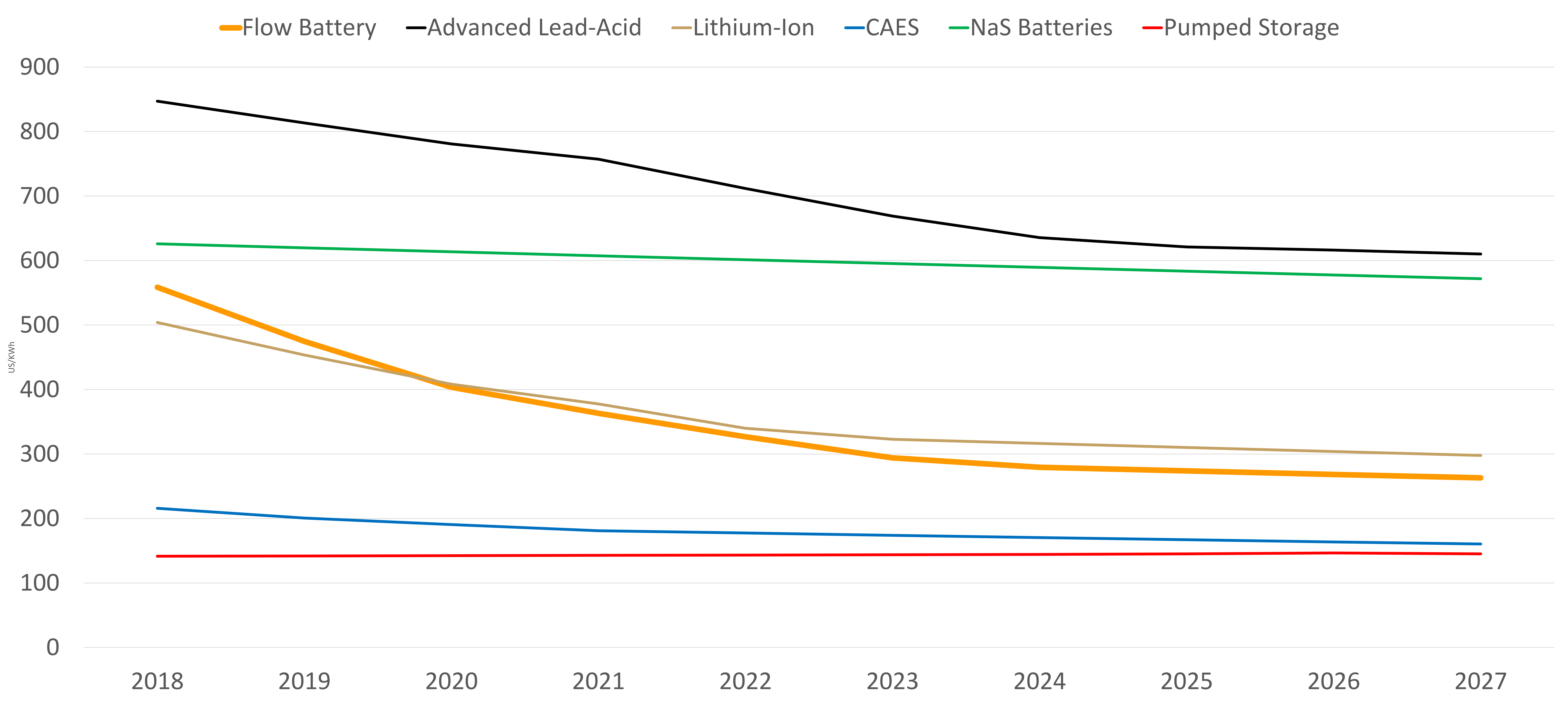
- **All analyses assume not more than one 100% discharge cycle per day. For a VRFB, achieving two cycles per day would cut the LCOE by 50%;**
- **A single battery, well-placed within a power system can be used for multiple uses, decreasing its LCOES further;**
- **Lack of public information on costs 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

LAZARD

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

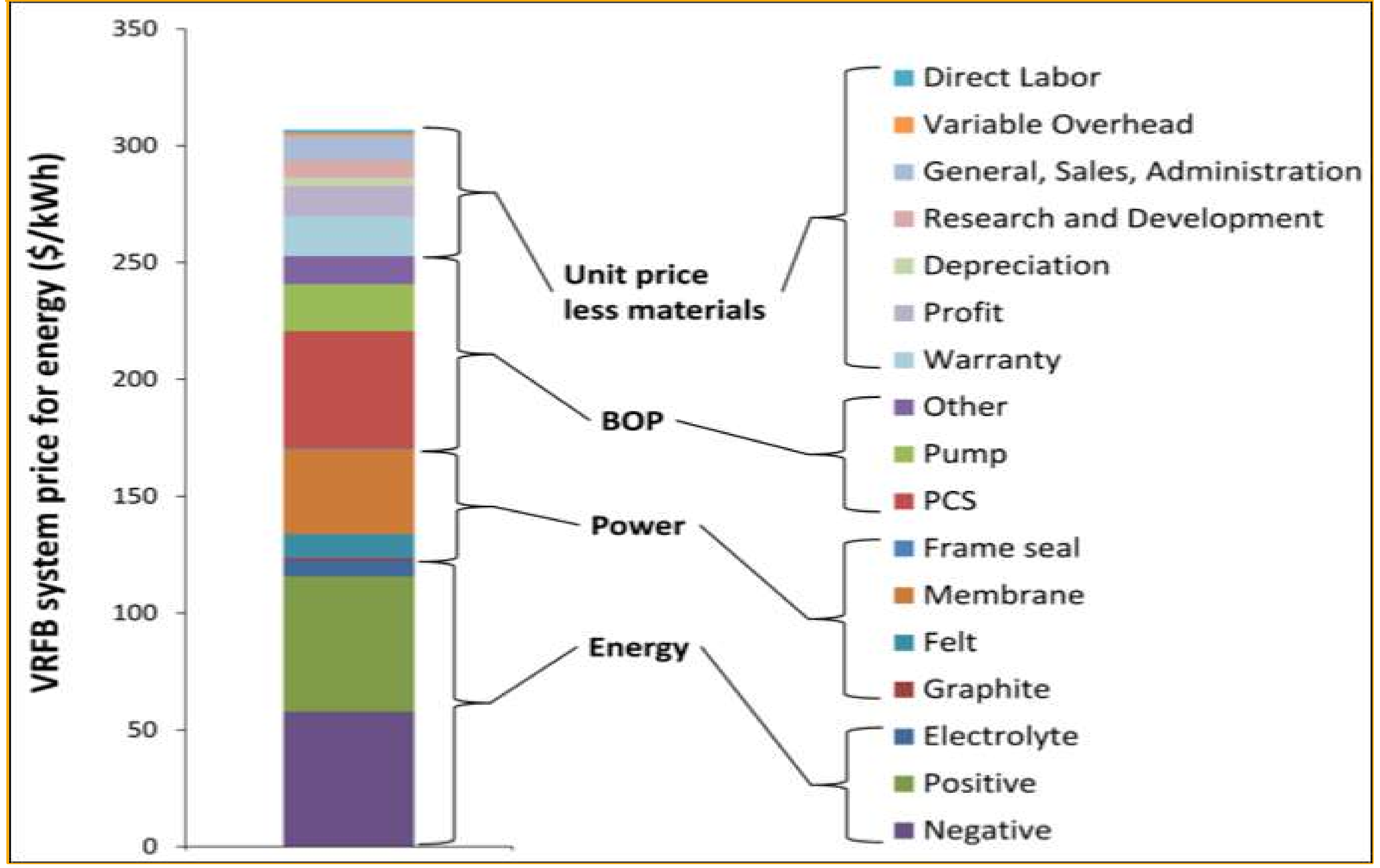
Utility-Scale Energy Storage CAPEX Assumptions by Technology for Bulk Storage/Energy Services, Average Installed Costs, World Markets



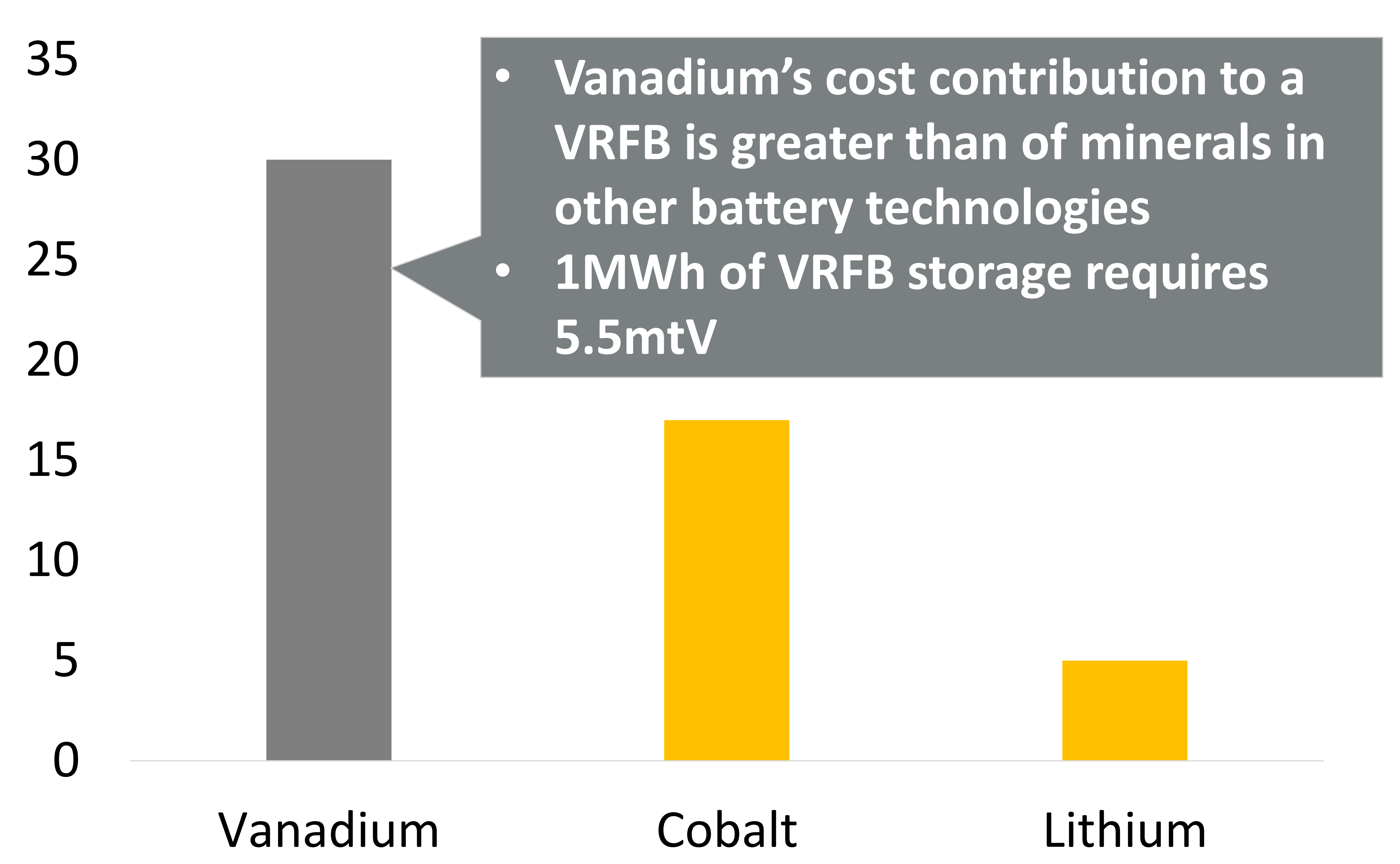
Source: Navigant Research

3. Vanadium is a more significant contributor to the cost of Vanadium Redox Flow Batteries than key minerals in comparative battery technologies

Vanadium redox flow battery's cost breakdown[1]



Mineral cost contribution[2] to respective battery, %



- **High dependence on one mineral presents a challenge for the technology, as it puts a higher "theoretical cost floor" than other batteries**
- **This creates an opportunity for vanadium suppliers to develop and deploy strategies to counter vanadium prices and potentially remove vanadium from the capital cost**

1 Based on scaled up production volumes of 20,000 stacks per annum

2 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

Source: Bushveld Minerals analysis, Joint Center for Energy Storage Research (JCESR), Roskill

3. Bushveld Energy's electrolyte rental model addresses the upfront cost of vanadium

Financial Institution

Leasing
Bank
Guarantee
SBLC

- Pays interest on the credit facility
- Settles the outstanding loan at contract termination

Advances a credit facility to Intermediary

Delivers required vanadium units to the Intermediary

Intermediary
Special Purpose Lease Co.

- Converts vanadium into electrolyte
- Supplies vanadium under rental contract
- Recovers vanadium at contract expiration

VRFB customer

(Off-Taker)

- Pays nominal upfront deposit for electrolyte
- Pays annual rental fee for the rent (covering interest payments and a price risk premium)

Miner
Vametco

BUSHVELD VAMETCO ALLOYS

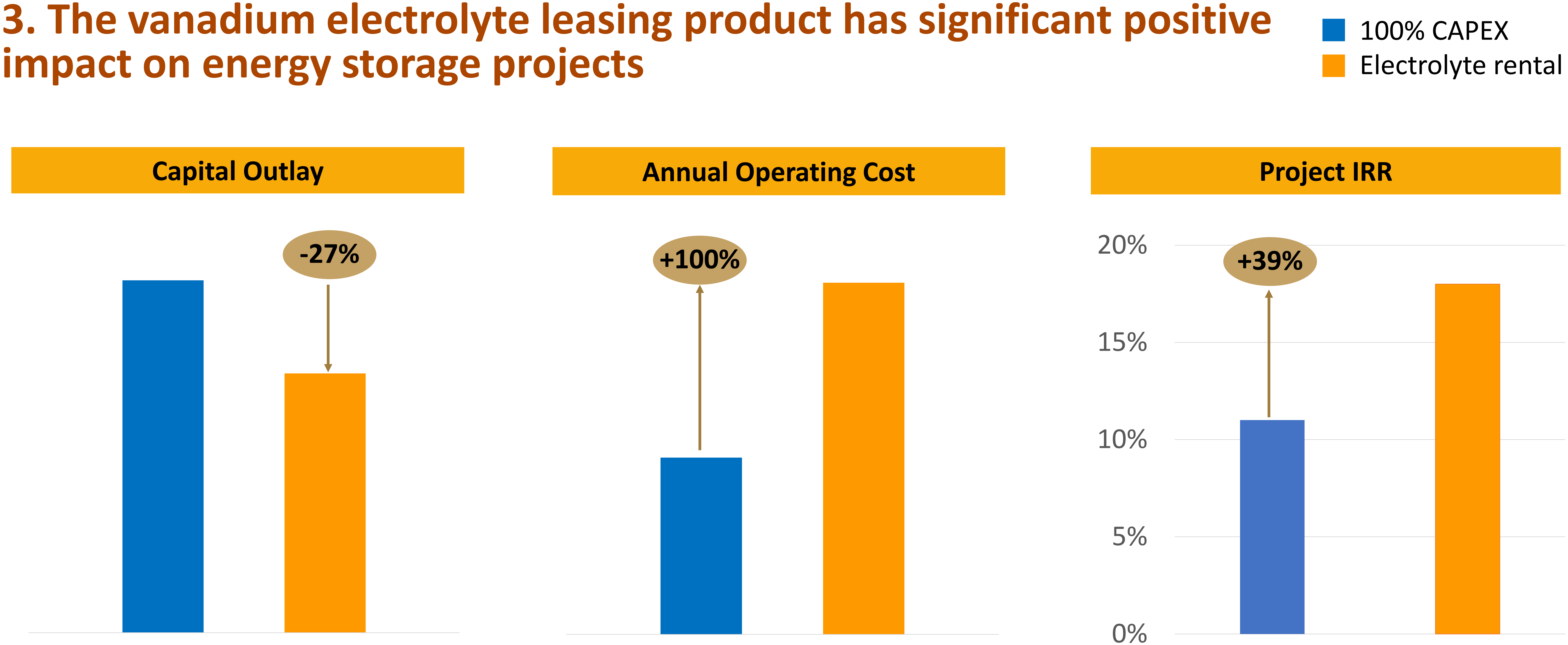
Pays cash for the supplied vanadium units at market rates

Benefits of the product to VRFB customers or manufacturers include:

- **Significantly lower and predictable CAPEX for the electrolyte components of the battery;**
- **A manageable annual fee that is added to the battery's maintenance costs;**
- **Overall lower total cost of ownership / levelized cost for a VRFB than if an outright purchase.**

Source: Bushveld Energy

3. The vanadium electrolyte leasing product has significant positive impact on energy storage projects



- 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

Source: Bushveld Energy Project in SA

4. Can the industry successfully address the VRFB market acceptance challenge?

"Market acceptance is a condition in which a good or service satisfies the needs of a sufficiently large number of customers to continue or increase its production or availability."

As a second mover in stationary energy storage, VRFB faces two types of acceptance challenges:

- **VRFB industry specific challenges**
- **Comparison to market incumbents**

Industry specific challenges

- Lack of a long-standing reputation and financial strength of most VRFB vendors. This creates challenges in
  - ➢ Bankability of VRFB technology (e.g. will it last for 20 years?)
  - ➢ Bankability if VRFB companies (e.g. will the company be around in 20 years?)
  - ➢ Difficult and costlier financing
- Absence of large scale manufacturing capacity to quickly respond to major orders and take advantage of scale economies

Comparison to incumbents

- General "sticker shock" in comparing batteries to pumped hydro and inability to use all capabilities provided by battery storage, especially unique advantages of VRFBs (e.g. long duration applications, locations where Li-ion batteries are difficult to permit because of fire safety issues, etc.)
- Increasing pressure from entrenchment of lithium ESS, as seen in:
  - ➢ Several Li-ion battery vendors have been active with the technology for decades (e.g. in frequency control market or consumer electronics)
  - ➢ Greater public awareness due to electric vehicle narrative

Source: Bushveld; Navigant

4. There are a lot of VRFB companies – but how many of them are recognisable?

Dozens of OEMs are now in the VRFB space

Lithium-ion cell production is concentrated

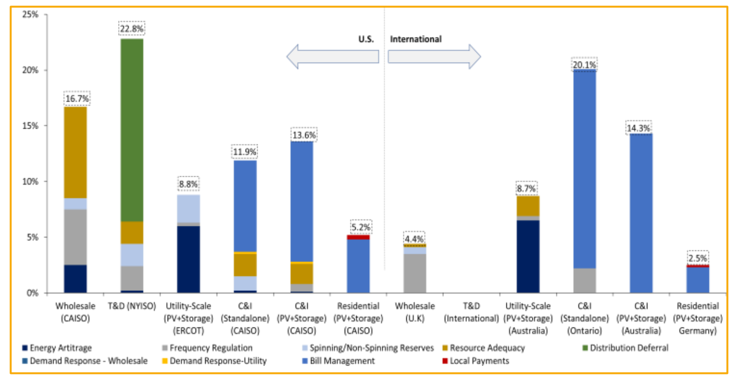
"The main reason for [lithium-ion batteries'] success is the reputation and financial strength of battery manufacturers"

- Navigant Research

Source: BMI; Fraunhofer ICT; Vanitec

4. There is a lot of optimism for Vanadium Redox Flow Batteries, nevertheless

A



Evolution of energy storage use cases suits VRFBs better, with emphasis on longer durations and multi-purpose systems

B

Chinese political support is behind Vanadium Redox Flow Batteries

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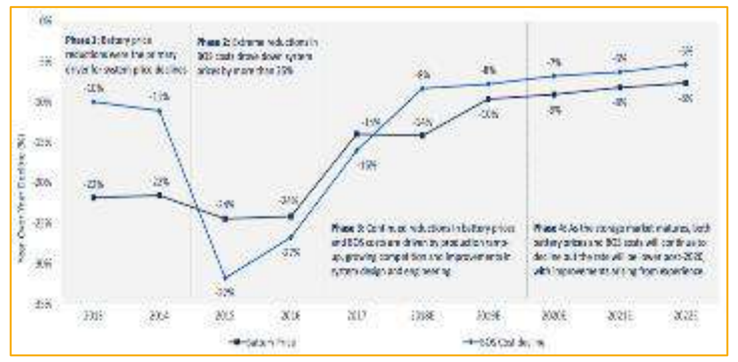
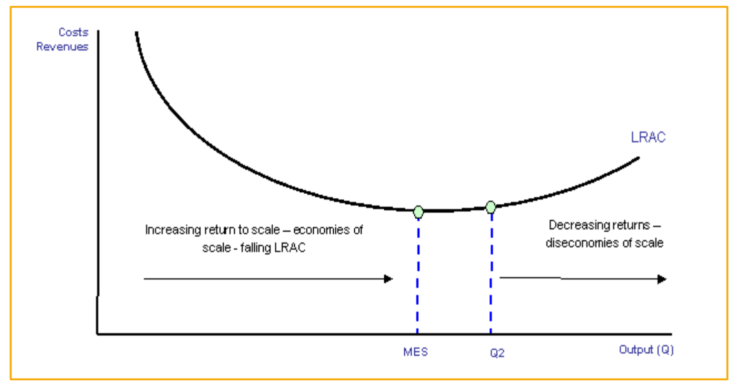


Lithium cost reductions are slowing

D



VRFBs do not need the scale of lithium to achieve similar economic benefits

E

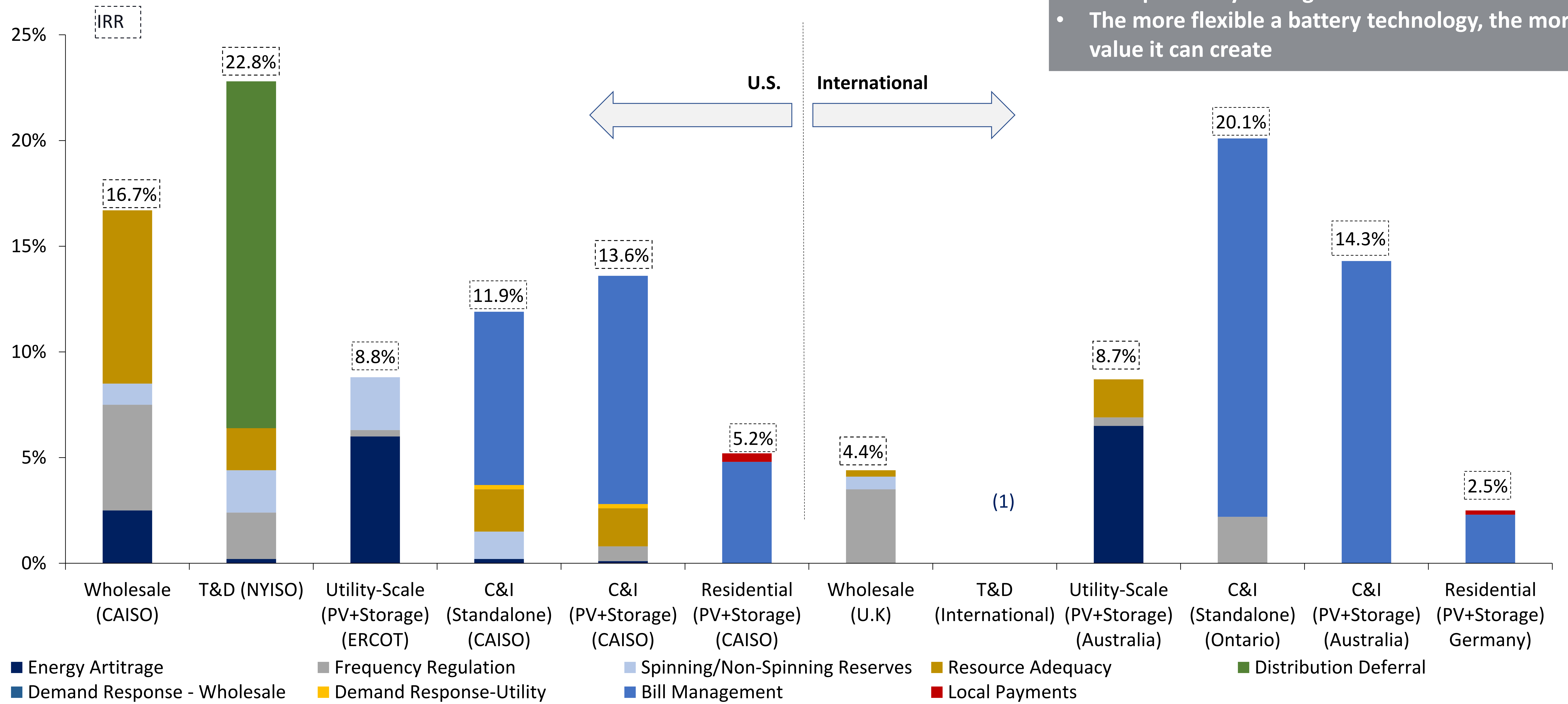
Consolidation in vanadium energy storage is a likely next step in its market evolution

Source: Bushveld Energy

4A. Growing opportunities in the power system to use one battery for multiple benefits gives technologies that favour high utilisation rates an advantage

Energy Storage project economics analysed by Lazard in the Value Snapshots

- **Projects that derive value from a battery through multiple uses yield higher rates of return**
- **The more flexible a battery technology, the more value it can create**



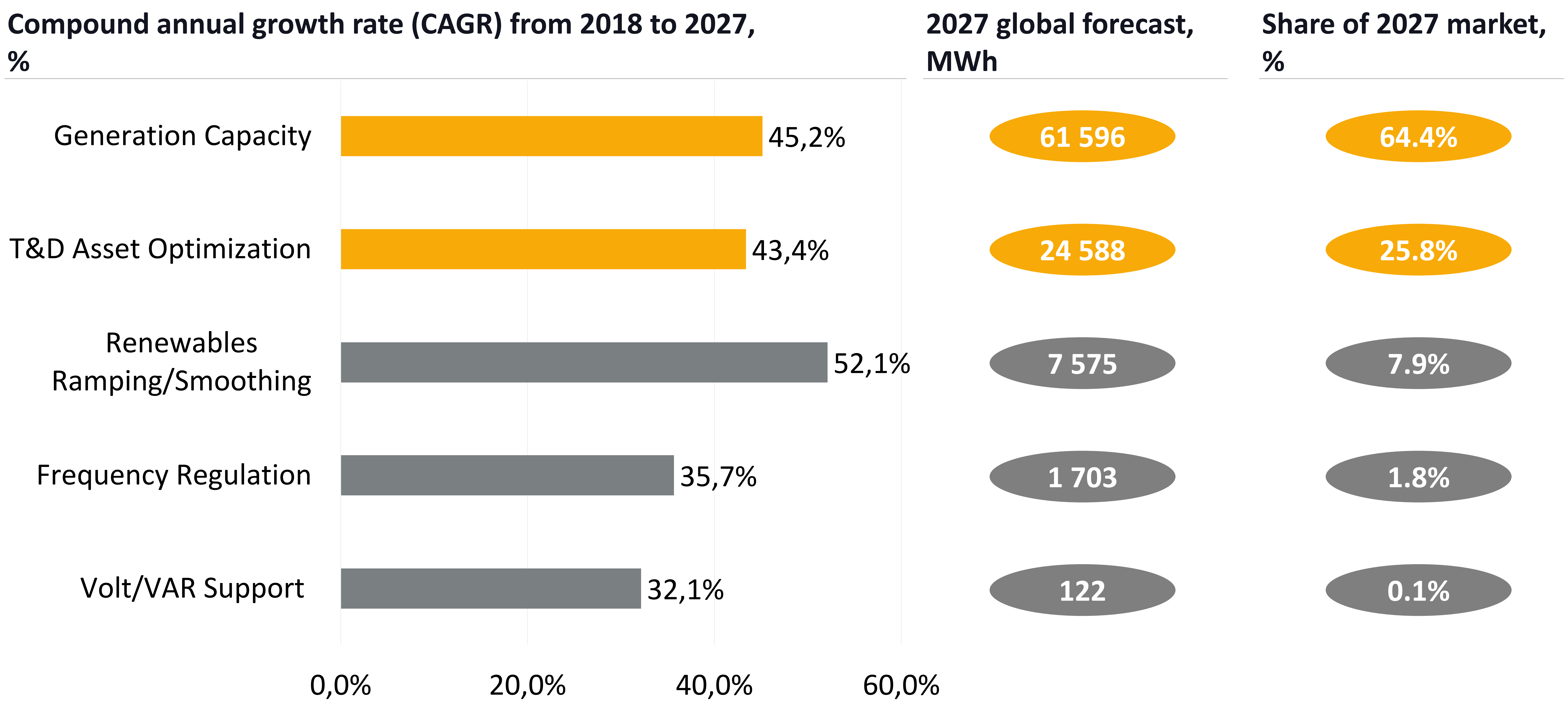
1 Lazard's Value Snapshot analysis intentionally excluded a Transmission and Distribution use case from its international analysis.

Source: Lazard – Levelized Cost of Energy Storage 4.0

4A. As global energy storage usage moves from short to long duration, the business case for VRFBs strengthens

Long duration
Short duration

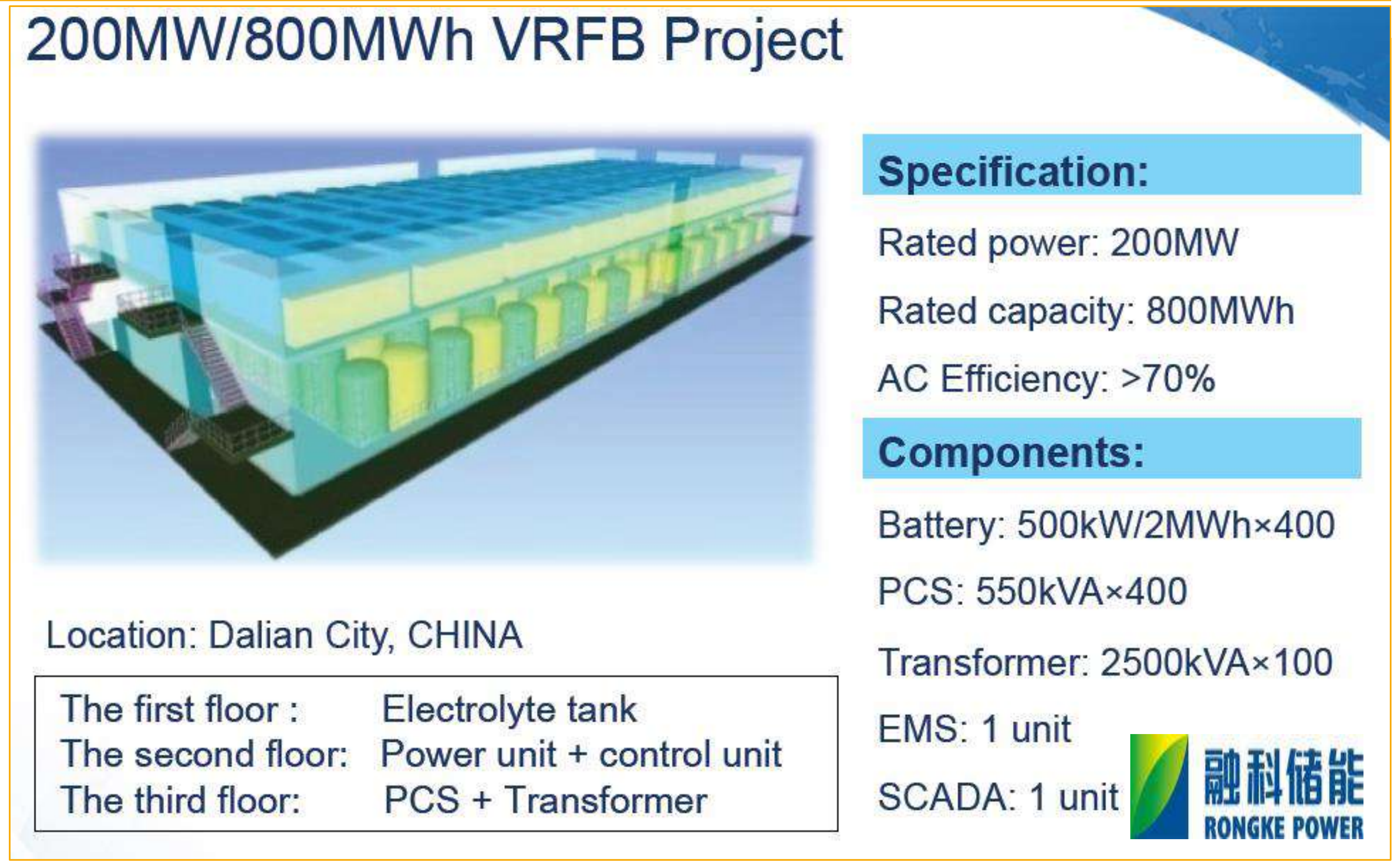
According to Navigant, the two largest market segments in utility energy storage for the next 10 years will require long duration energy storage



Source: Navigant

4B. China's political support is behind Vanadium Redox Flow Batteries, leading to greater VRFB deployment in Asia, when compared to other regions

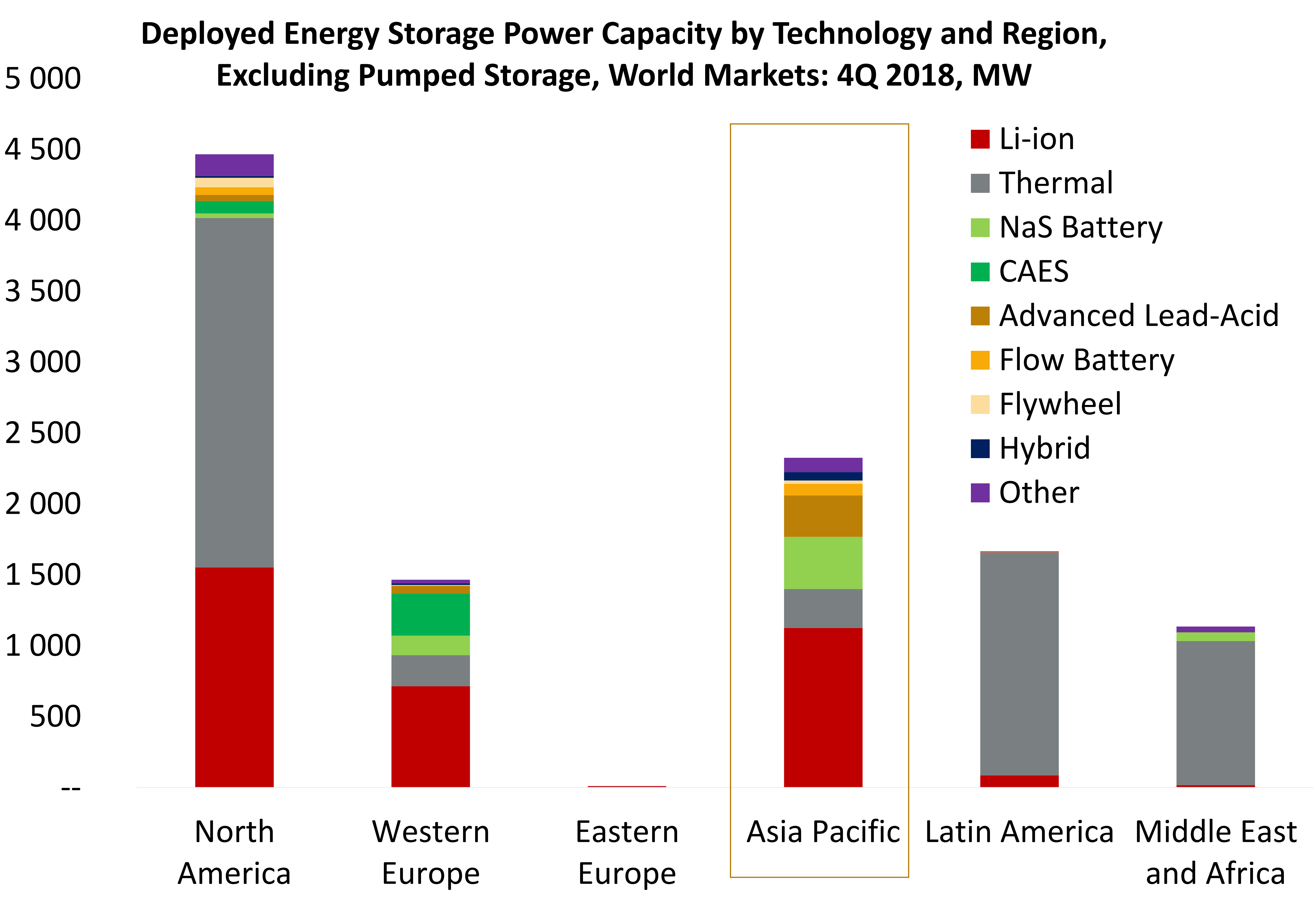
800 MWh by Rongke Power in Dalian



400 MWh from Pu Neng in Hubei

- 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

PU NENG
THE FUTURE OF ENERGY STORAGE



These large VRFBs are part of China's new National Development Plan's "focus includes 100MW-grade, vanadium redox flow battery energy storage stations

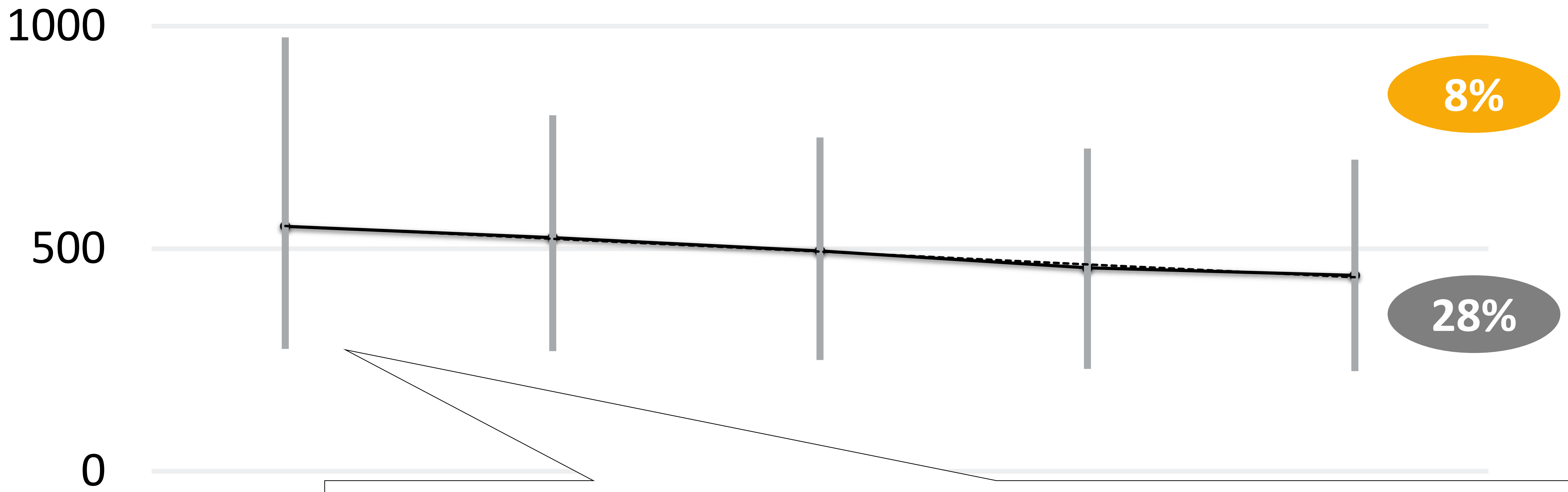
Source: Navigant, VRB Energy, Rongke Power

4C. Lithium battery cost reductions are slowing, with VRFB costs expected to decrease faster going forward

Capital Cost ($/kWH)

x% 5 year CAGR   x% 5 year decrease

Lithium- ion

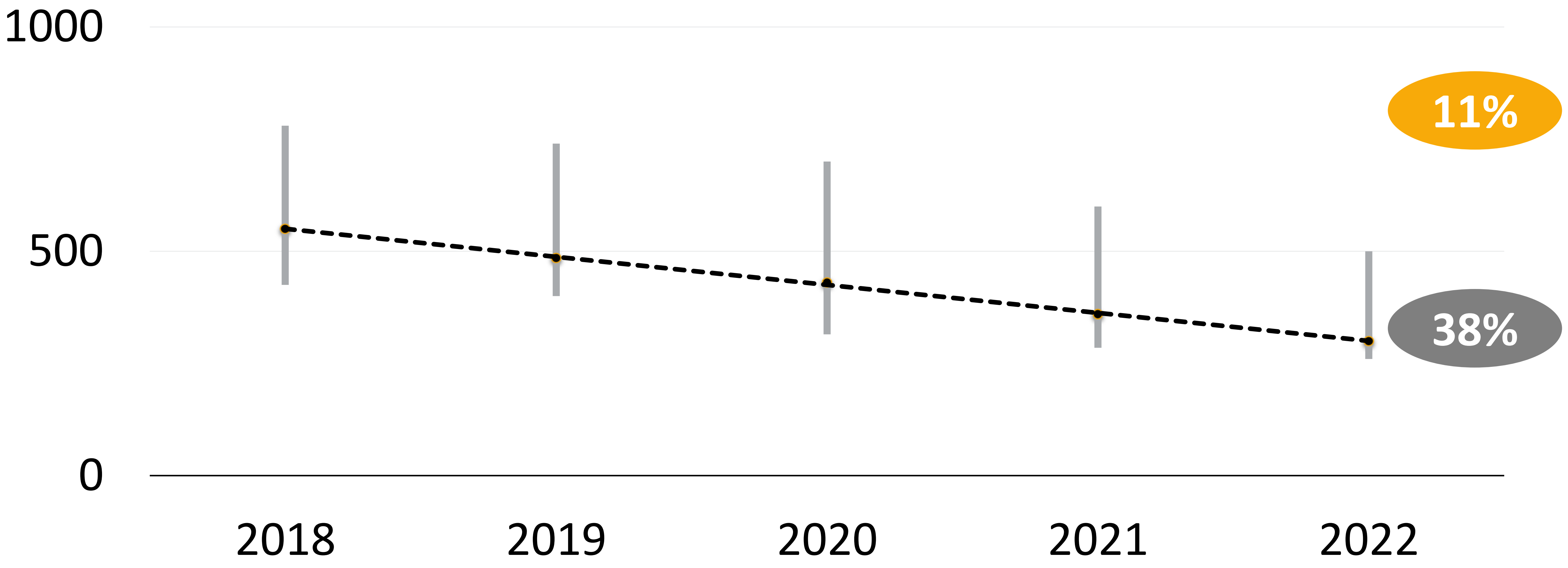


Lithium ion are cost decreases are slowig for multiple reasons:

- "Near-term capacity tightness"
- "Slower cost declines in BOS, EPC and PCS costs"
- "higher raw material" costs, especially cobalt

"Tesla Powerwall 2 battery prices jump, as production focuses on Model 3 EV "
– reneweconomy.com.au, October 2018

Flow Battery- Vanadium



Opportunities for VRFB cost decreases beyond vanadium itself include:

- "Increased manufacturing scale"
- "Increased energy densities"
- "Focus on providing plug and play (e.g., turnkey) units to keep EPC costs down"

Source: Lazard – Levelized Cost of Energy Storage 4.0; *reneweconomy.com.au*

4D. According to a 2017 study by Imperial College, Vanadium Redox Flow Batteries do not need the scale of lithium-ion to achieve similar economic benefits

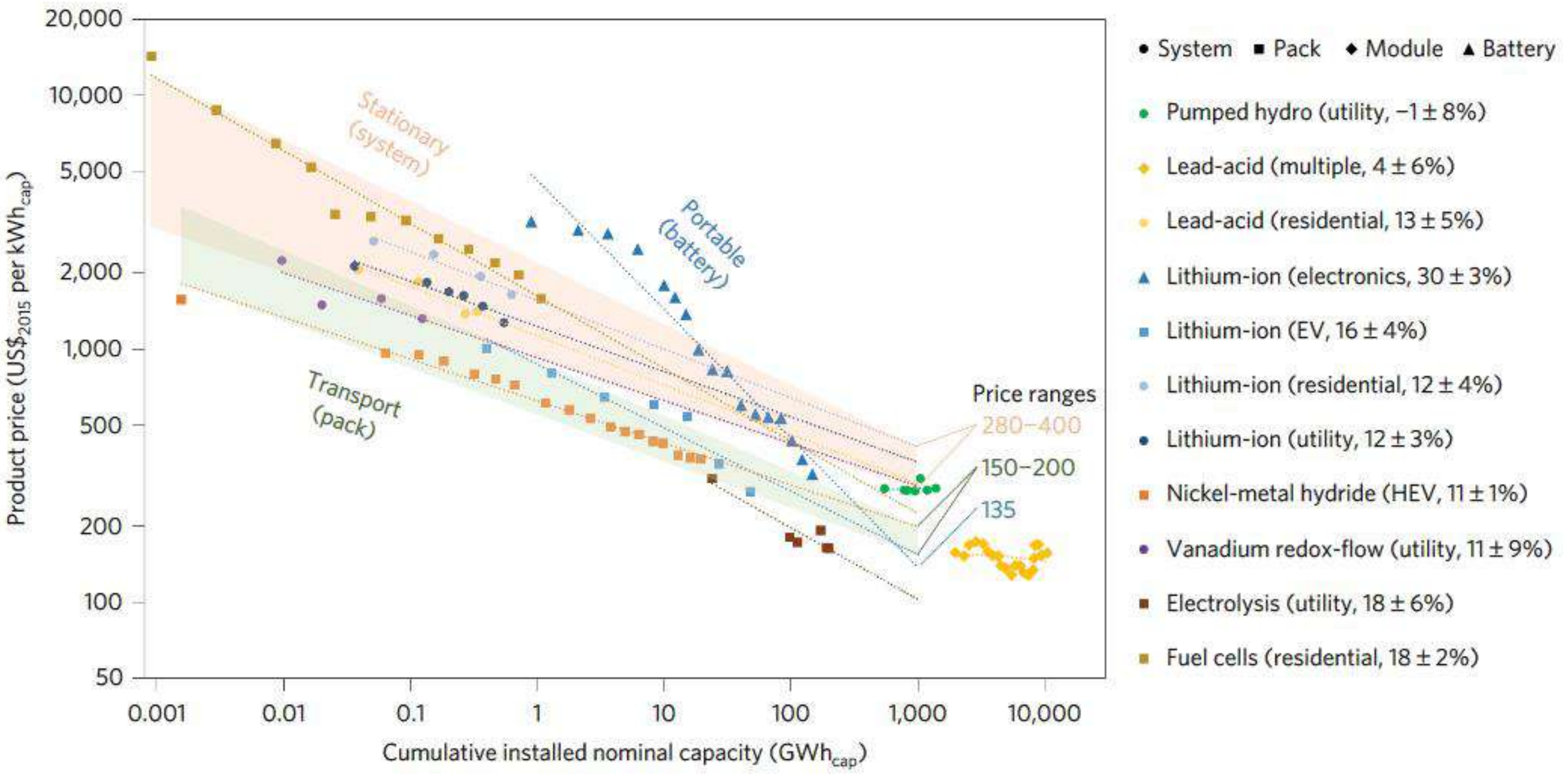


Figure 2 | Future cost of EES technologies at 1 TWh cumulative capacity. Experience curves (dotted lines) are projected forwards to analyse product prices at future amounts of cumulative capacity. In the legend, symbol shape indicates technology scope and colour denotes technology (including application and experience rate with uncertainty). Shaded regions are visual guides indicating the cost reduction trajectory for each application category (at a particular technology scope). These narrow to the price ranges given on the right of the figure: systems used for stationary applications, US$280–400 kWh^{-1}; packs used for transport applications, US$150–200 kWh^{-1}; batteries used for portable applications, US$135 kWh^{-1}. The experience curves outside of these ranges refer to technologies where product prices are reported for a different technology scope (stationary fuel cells and electrolysis: pack-level; lead-acid: module-level). A fuel cell–electrolysis combination that could be used for stationary electrical energy storage would cost US$325 kWh^{-1} at pack-level (electrolysis: US$100 kWh^{-1}; fuel cell: US$225 kWh^{-1}). kWh_{cap}, nominal energy storage capacity.

Key insights from the study include:

- **Economies of scale for VRFB technology is achieved at 7GWh of installed utility-scale capacity;**
- **This scale point is 1/5th required for lithium-ion, which needed 33GWh.**

Imperial College London

Source: "The future cost of electrical energy storage based on experience rates," O. Schmidt, A. Hawkes, A. Gambhir and I. Staffell

4E. Energy storage is experiencing a trend in vertical consolidation, which is likely to happen to Vanadium Redox Flow Batteries, as well

Energy storage has seen significant major M&A activity in the industry over the past 2 years, including the following:

- Project developer AES Energy Storage combining with Siemens to form Fluence
- Storage software provider and project developer Greensmith's acquisition by global power plant developer Wartsila
- Distributed storage developer and integrator Green Charge Networks' acquisition by multinational utility ENGIE
- Storage software provider and project developer 1Energy Systems' acquisition by global power plant developer Doosan
- Battery manufacturer Saft's acquisition by multinational oil & gas developer Total
- Storage software provider and project developer Younicos' acquisition by global power generation provider Aggreko

"These developments have brought both greater levels of financial resources and maturity to the still developing energy storage industry."

\- Navigant Research, 2018

Group with mid-stream vanadium chemical production, stack manufacturing and downstream VRFB design and production in China and USA

Junior vanadium miner with 2017 acquisition of a well-established Austrian VRFB manufacturer and manufacturer of switchgear and control systems

2017 acquisition of well-stablished Chinese VRFB manufacturer by well-capitalised global mining exploration company

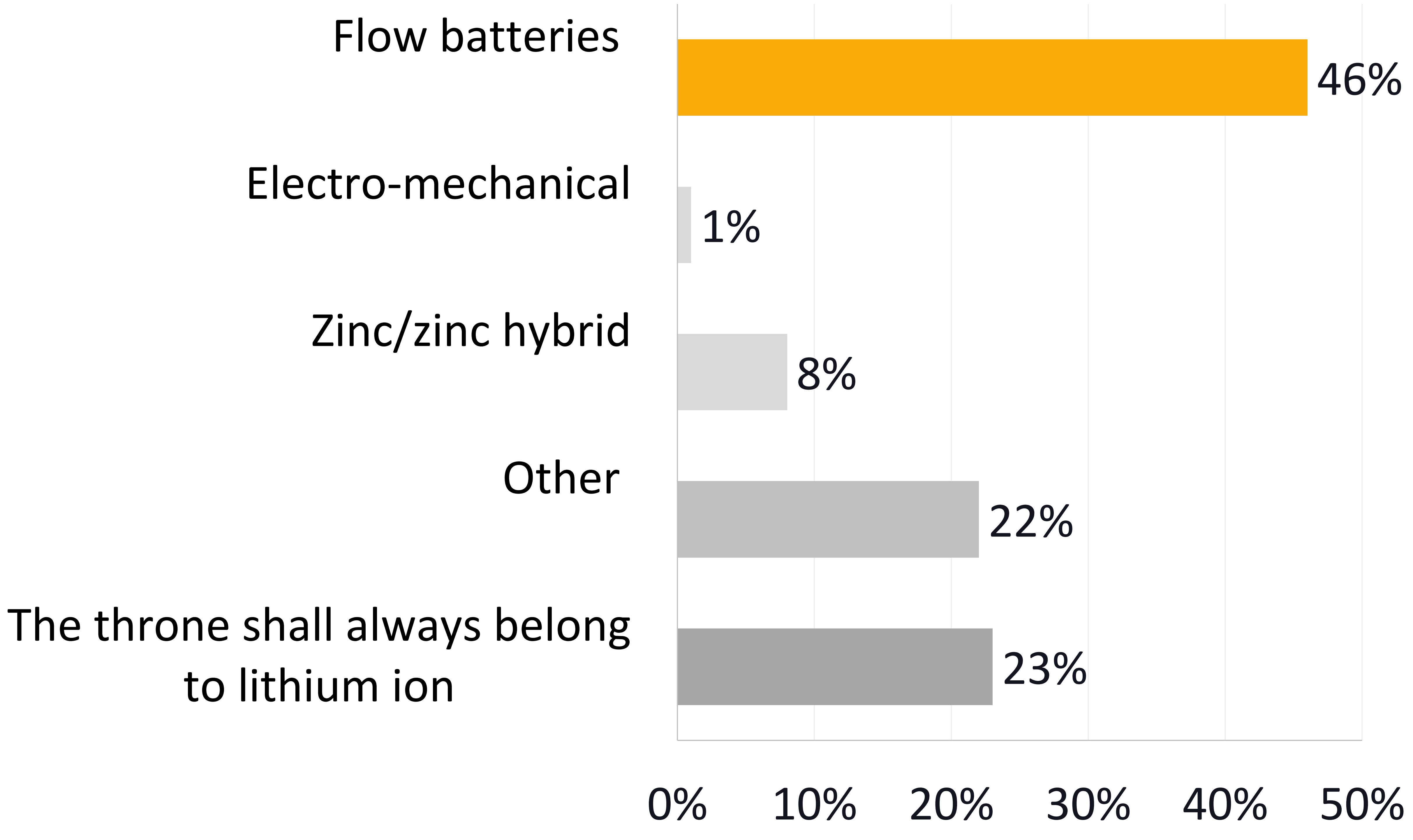
- **Such transactions are a prelude to greater future activity toward consolidation in vanadium energy storage**
- **Bushveld's integrated strategy anticipated the necessity of this trend earlier this decade**

Source: Navigant; Bushveld Energy

4. Strong industry sentiment towards VRFBs is present even in lithium-dominated North America

- In North America, industry sentiment towards VRFBs is also strong
- In Greentech Media's 2017 Energy Storage Summit poll of 500 professionals on the next 5 years for energy storage, flow battery technology achieved the most support

What technology has the best chance of supplanting lithium-ion as the dominant utility-scale advance technology?



Observations:

- The largest share of experts expect flow batteries will become dominant
- Less than 1 in 4 respondents believe that lithium-ion technology will remain dominant in utility scale storage

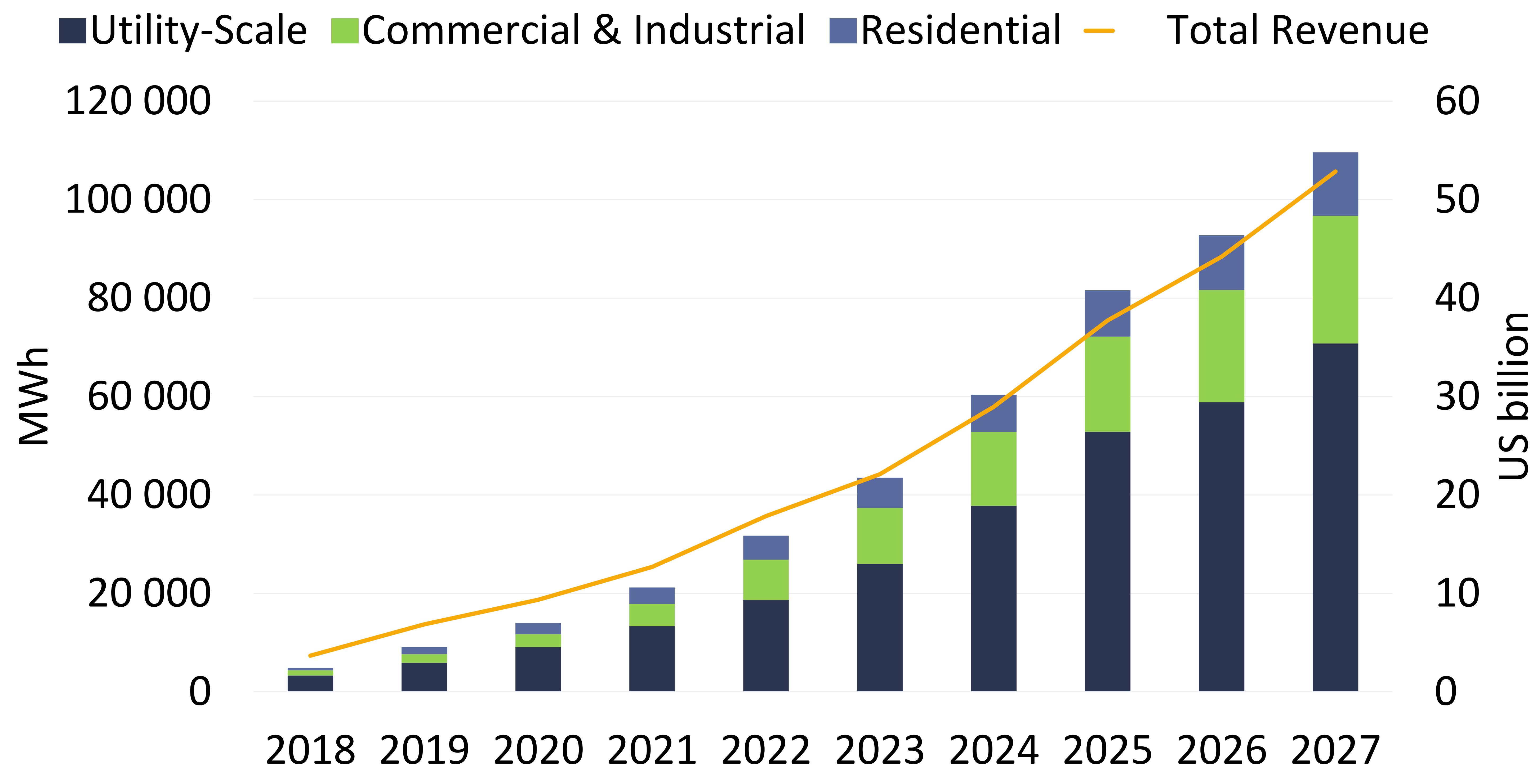
Source: Bloomberg New Energy Finance, Greentechmedia.com, TTP Squared

Objectives for today's session

- Understand energy storage, focusing on stationary storage, it's importance, use and the different technologies available for those uses;
- Present a deep dive in vanadium redox flow batteries (VRFBs), covering their unique applications, how they compare to alternatives such as lithium-ion and discuss the challenges and opportunities that the VRFB value chain faces today. This will include trends currently impacting stationary energy storage deployments globally;
- **Highlight the size of the market opportunity for stationary energy storage and discuss the implications it has on overall demand for VRFBs and vanadium;**
- Briefly touch on the use of vanadium in other types of energy storage;
- Provide an overview of Bushveld Minerals and Bushveld Energy in an integrated effort to create value across the vanadium energy storage value chain.

Navigant Research forecasts energy storage to be a $50 billion market within 10 years, with flow batteries poised to capture nearly 20%

Annual Installed Stationary Energy Storage Capacity and Deployment Revenue by Market Segment



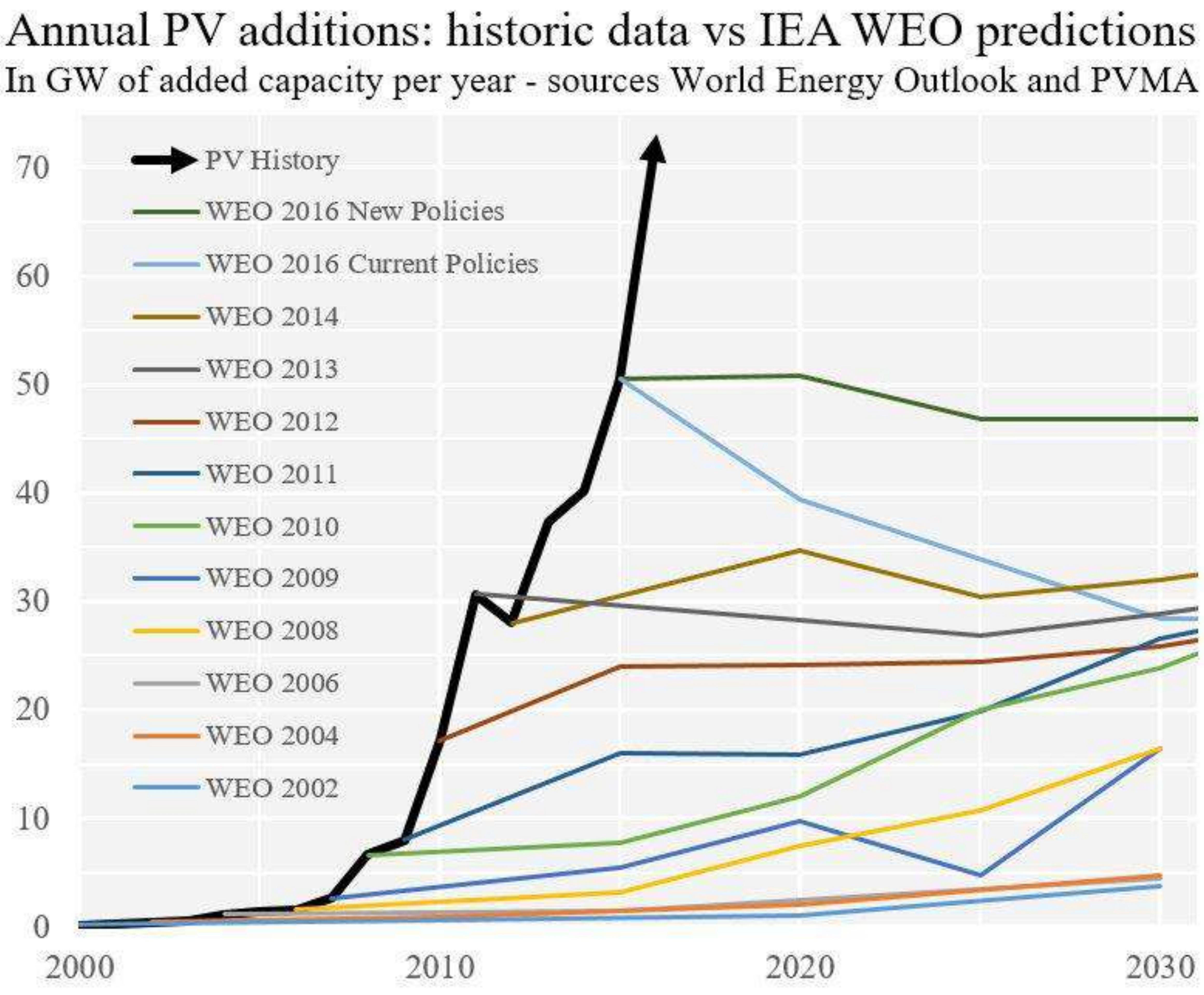
- **Stationary energy storage demand is growing rapidly at a rate of 58% p.a. and will exceed 100GWh by 2027**
- **Multiple technologies will be successful due to unique technical and cost advantages;**
- **Flow batteries expected to capture 18% of the market, according to Navigant;**
- **This equates to 20GWh of demand and nearly $10 billion in revenue by 2027**

- 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

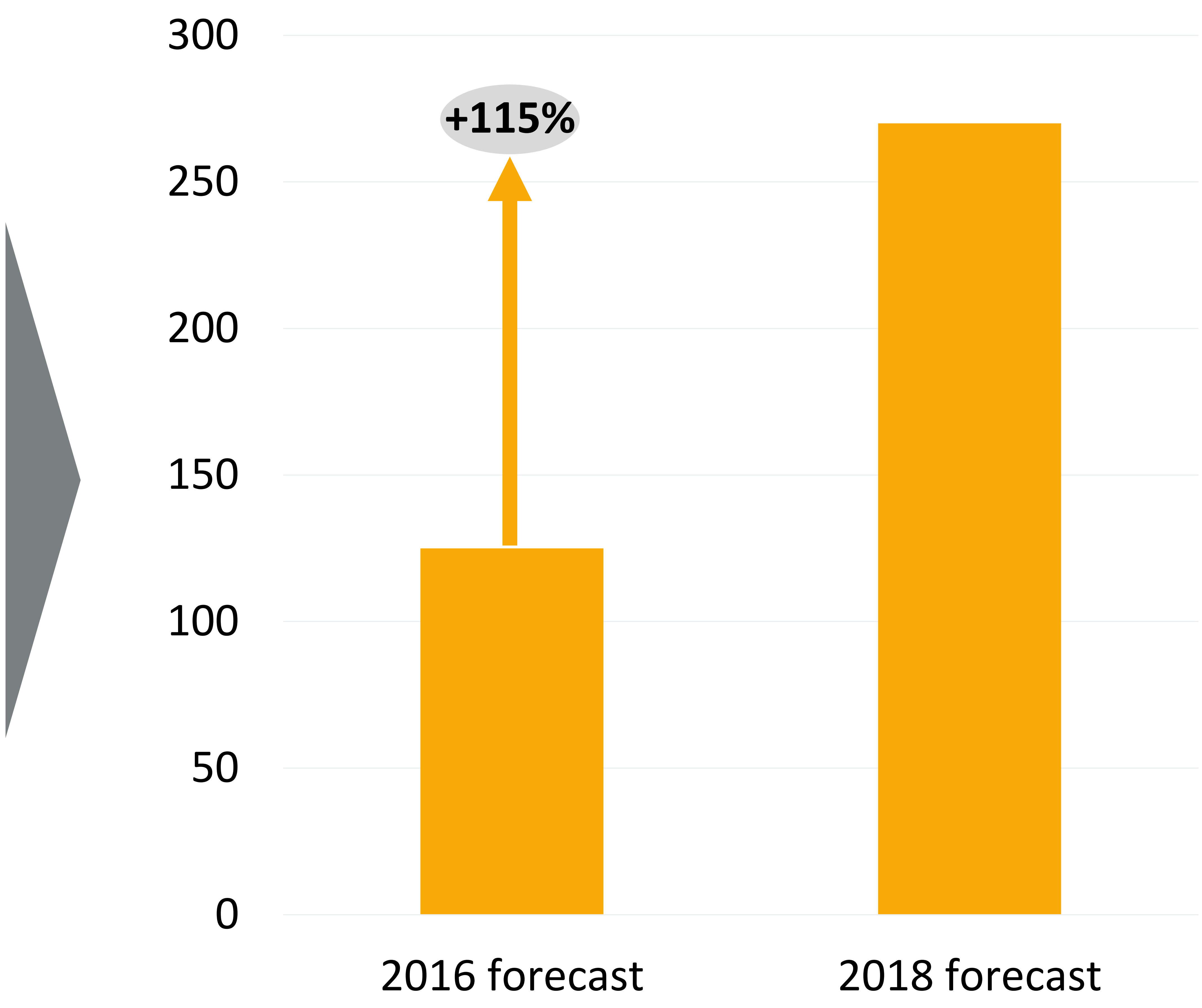
Note: Utility segment includes thermal storage technology
Source: Navigant Research

Energy forecasts for new technologies may significantly undervalue actual growth potential

Solar PV growth continues to exceed forecasts



The same phenomenon is occurring with energy storage, where Bloomberg New Energy Finance has more than doubled its 2030 energy storage forecast in two years



Source: World Economic Outlook; PVMA; www.visualcapitalist.com; BNEF Energy Outlook 2016; BNEF Energy Outlook 2018;

The upside for VRFBs could be even greater than we discussed earlier this year

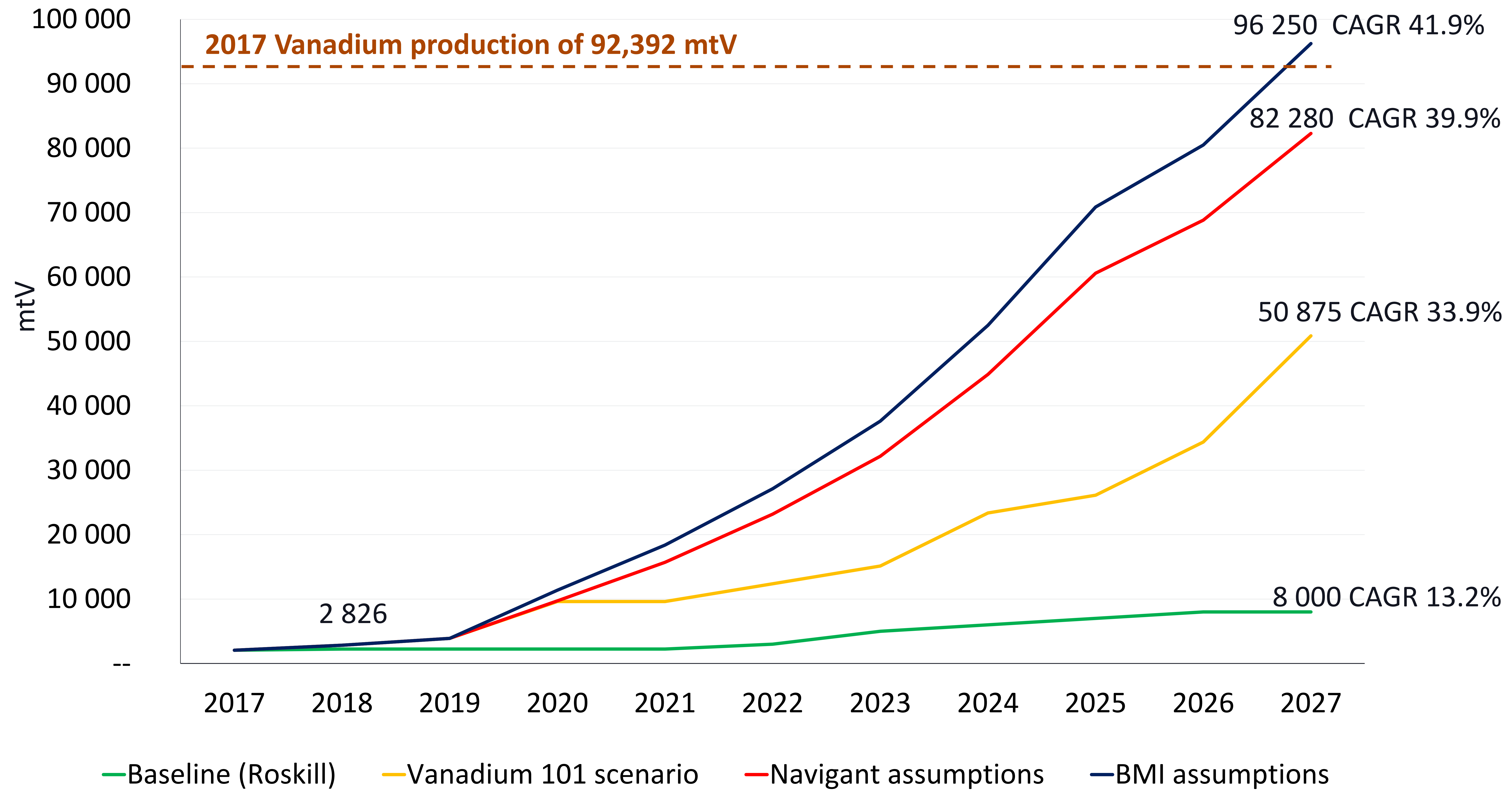
Scenario	Assumption	VRFB demand in 2027, MWh	Vanadium use in VRFBs in 2027, mtV
Vanadium 101 - scenario	• VRFB forecast scenario from Bushveld Minerals May "Vanadium 101" presentation • Scenario used 25% market share and Bloomberg New Energy ESS forecast • 5.5 kg of vanadium per kWh	9 250	50 875
Baseline – Navigant forecast	• Flow battery forecast from Navigant, assuming 18% market share • VRFBs are the successful flow battery technology • 4.4 kg of vanadium per kWh	18 700	82 280
Upside – BMI forecast	• VRFB forecast from Benchmark Minerals (BMI) • Assumes 25% market share of Navigant's overall energy storage forecast • 3.5 kg of vanadium per kWh	27 500	96 250

- **Major driver for increased VRFB demand is a larger energy storage market forecast from Navigant than the BNEF forecast used in Vanadium 101 presentation assumptions**
- **BNEF has since more than doubled its forecast for energy storage**
- **VRFB manufacturers are researching ways to use more of the electrolyte to reduce costs and improve energy density. Bushveld's scenarios assume these improvements are achieved to support market penetration**

Source: Navigant Research; BNEF; BMI; Bushveld Minerals "Vanadium 101";

This upside for vanadium use in energy storage may exceed our own expectations

VRFB Vanadium Demand Forecast Scenarios



- **While the market share of VRFBs compared to other energy storage technologies is a key assumption, the ultimate size and growth rate of the stationary energy storage market has even greater impact;**
- **Recent trends to revise energy storage forecasts upward imply that vanadium demand from VRFBs may be greater than expected even under "aggressive forecasts"**
- **Within 10 years demand for vanadium by energy storage could equate to 50-100% of today's global market**

Source: Bloomberg New Energy Finance (BNEF), Bushveld Minerals analysis, Roskill, TTP Squared, Navigant, BMI, Bushveld Energy analysis

Objectives for today's session

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- Present a deep dive in vanadium redox flow batteries (VRFBs), covering their unique applications, how they compare to alternatives such as lithium-ion and discuss the challenges and opportunities that the VRFB value chain faces today. This will include trends currently impacting stationary energy storage deployments globally;
- Highlight the size of the market opportunity for stationary energy storage and discuss the implications it has on overall demand for VRFBs and vanadium;
- **Briefly touch on the use of vanadium in other types of energy storage;**
- Provide an overview of Bushveld Minerals and Bushveld Energy in an integrated effort to create value across the vanadium energy storage value chain.

Vanadium use in mobile applications, such as electric vehicles is limited but offers future opportunities with some manufacturers

Geely, Volvo, Swatch, Belenos Clean Power Holding Ltd, smart

Role of vanadium

- Used in the cathode material of the battery
- Exact formula unknown but Lithium Vanadium Oxide likely
- Anode remains lithium-based
- Replaces the need for cobalt in cathode

Expected benefits

- 30% more powerful than conventional counterparts for the same battery weight
- Faster recharging capabilities
- Currently under development

Subaru

Role of vanadium

- Lithium Vanadium Phosphate $Li_3V_2(PO_4)_3$ formula
- Used in the cathode material of the battery
- Anode remains lithium-based
- Replaces the need for cobalt

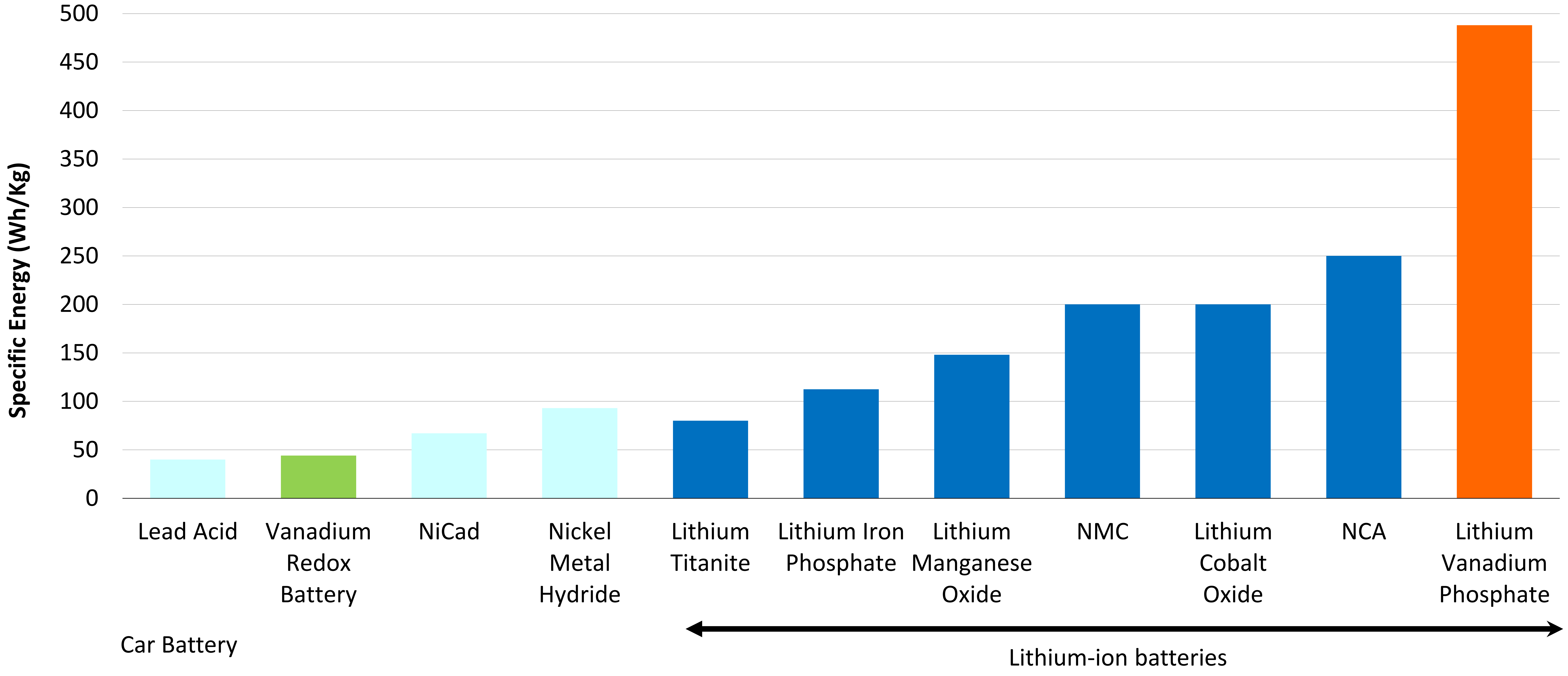
Expected benefits

- Able to store two to three times more lithium-ions than conventional lithium-ion batteries to provide a higher energy density
- Used in a prototype EV (Subaru G4e) but not developed since

Source: www.roadandtrack.com; Swiss Chamber of Commerce

EV manufacturers focus on increasing energy density of EV batteries, thus moving to different lithium-ion formulations, some of which include vanadium

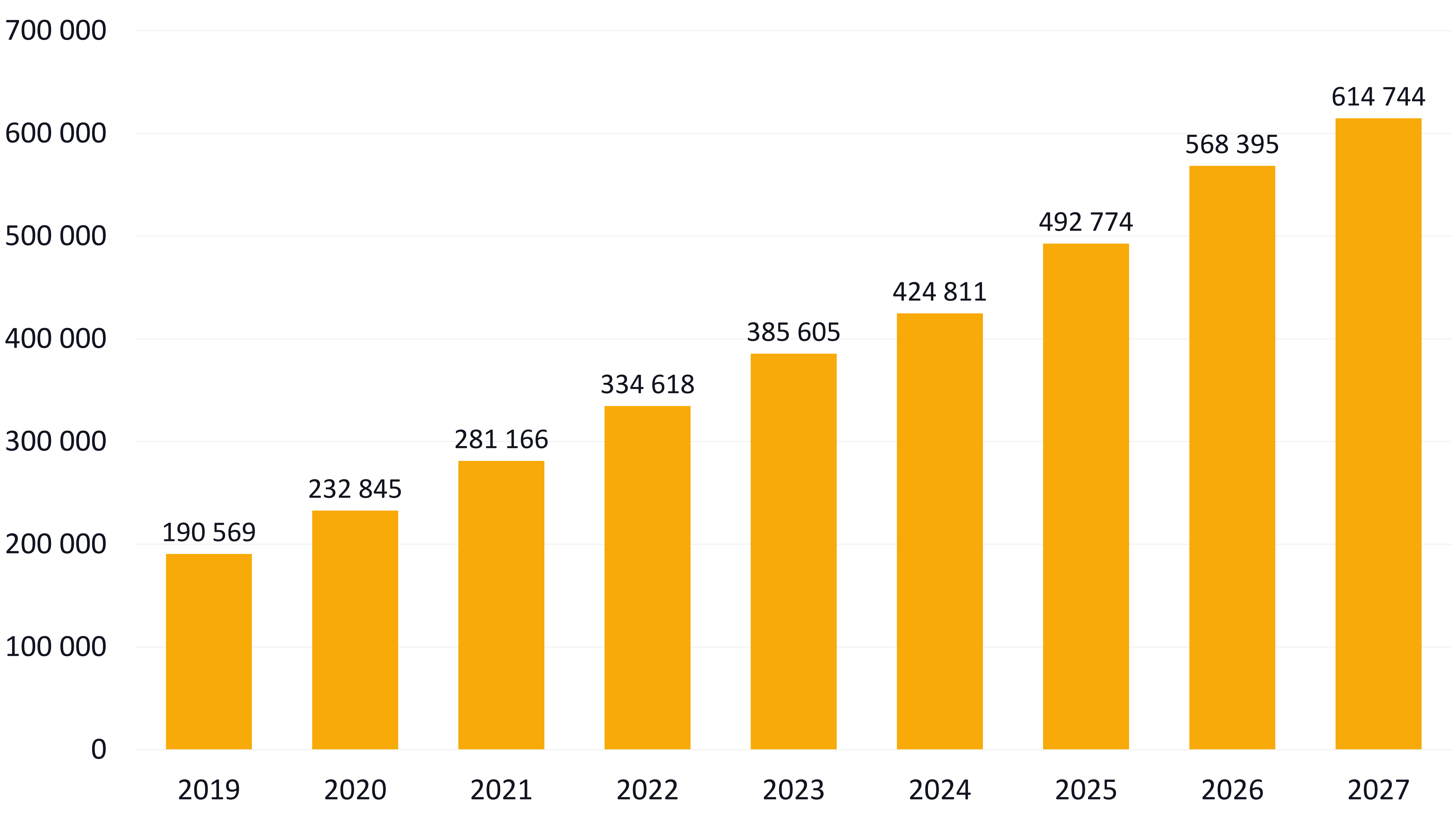
Comparison of Specific Energy or Capacity (Wh/Kg) of various batteries



Source: batteryuniversity.com

If successful, vanadium uses in electric vehicles could start in the mid to late 2020's, when the Electric Vehicle (EV) market would be even larger

Total EV Advanced Battery Energy Capacity and Revenue, MWh per annum



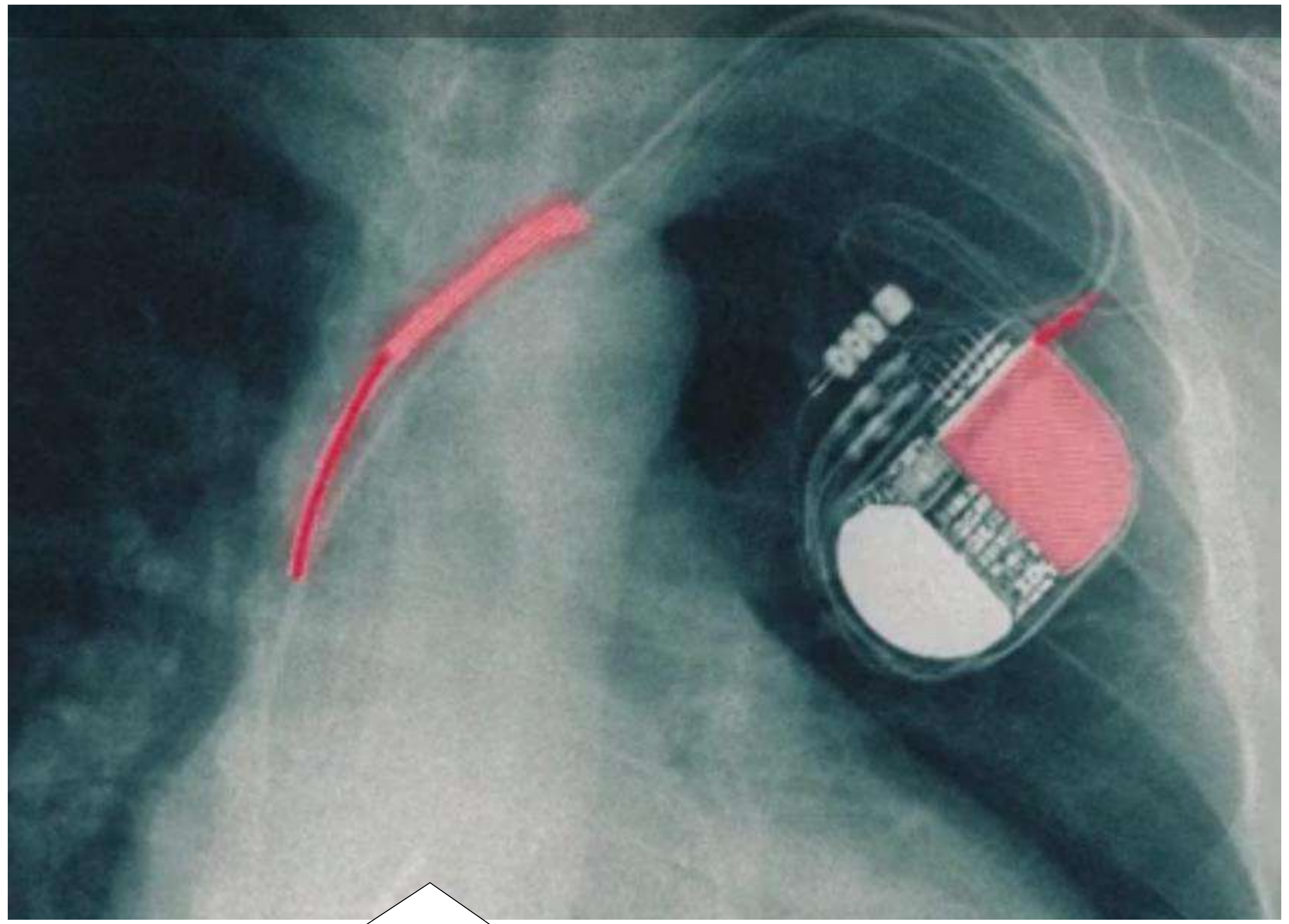
- EV manufacturers tend to align with a specific battery formulation;
- Even if one or two major car brands switch to a type of lithium-vanadium battery, it could account for 5-10% of the market share of EV market;
- The weight and value contribution of vanadium to EV batteries is smaller, implying that the net impact on vanadium demand would be less than that of stationary storage.

Source: Navigant Research

Vanadium uses in consumer electronics are limited but life-saving

A) Lithium Vanadium Silver Oxide battery – SVO

- The battery is used extensively in implantable cardiac defibrillators (ICDs) and Cardiac Rhythm Management (CRM) systems, with around 300,000 SVO-powered systems installed annually
- The benefits of the SVO over traditional implant batteries, such as those installed in pace-makers, include
  - Low self-discharge of less than 2% per year.
  - A discharge curve where voltage decreases with depth of discharge.
  - Rigorous to the type of environmental and abuse characteristics required for implantable applications



"The vanadium was important to provide long life and high voltage"
- Dr. Esther Sans Takeuchi, developer of SVO battery

B) Vanadium Pentoxide Lithium battery

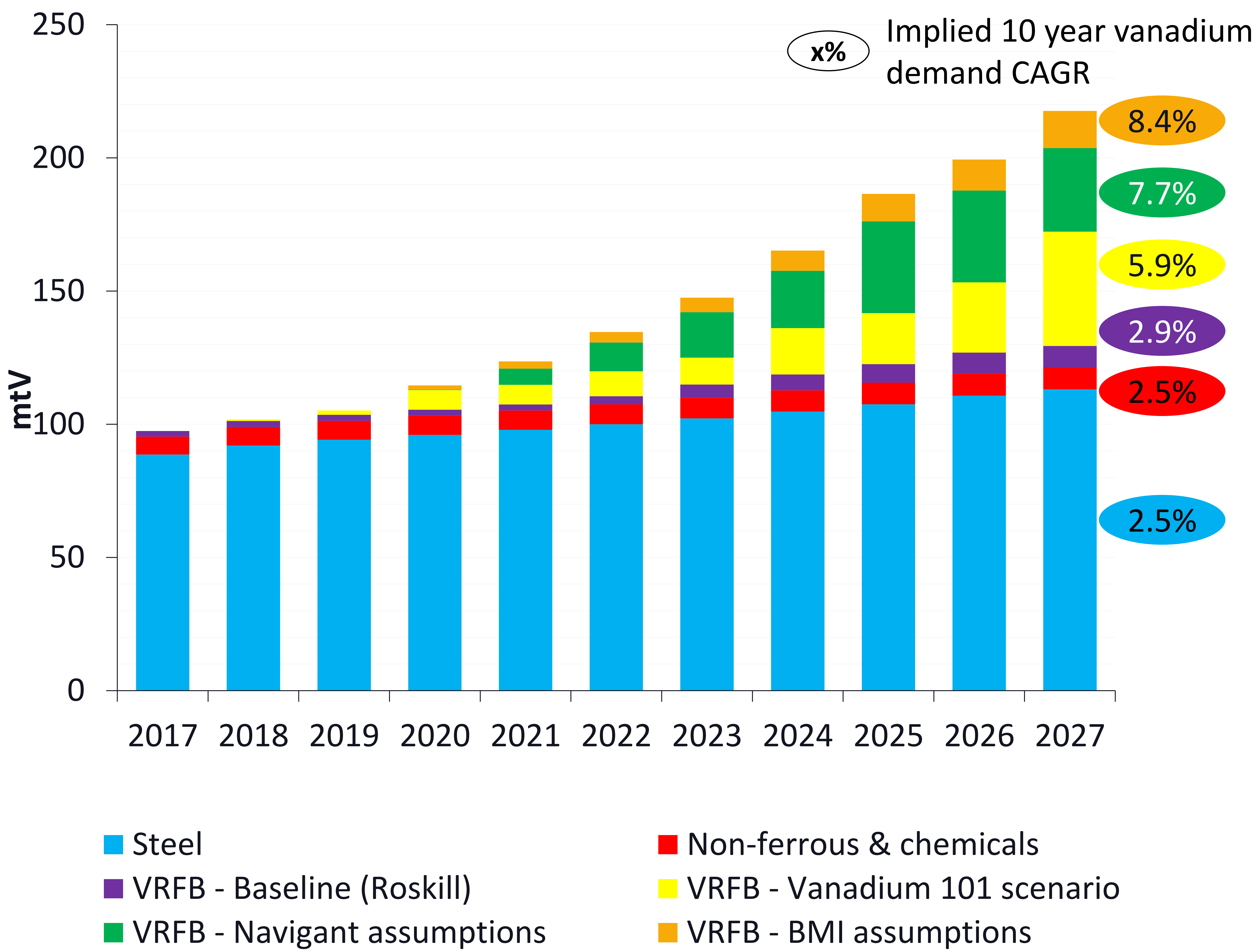
- A coin or button-shaped battery, currently in production by Panasonic

Source: www.epo.org/news-issues/press/releases/archive/2018/20180424h.html

Although there is a significant growing demand and upside from energy storage, vanadium demand remains anchored to steel

- Vanadium demand has for decades been underwritten by the steel market, which accounts for over 90% of vanadium consumption
- Steel market set to continue supporting robust vanadium demand, growing by 2.2% CAGR from 2017 to 2027 through. With expected increase of vanadium intensity of steel, vanadium demand CAGR from steel is expect to be 2.5% through 2027
- Significant demand upside from growing applications of vanadium in energy storage industry via VRFBs
    - Stationary energy storage is forecast to grow at CAGR of 58% over the next 10 years, becoming a $50 billion industry by 2027
    - While forecasts for VRFBs vary, they could add between 8,000 and 96,000 tons of vanadium demand by 2027
    - This energy storage "upside" may increase vanadium demand CAGR from 2.5% up to 8.4% for the next 10 years.

Vanadium demand forecast by application and scenario



Source: Bloomberg New Energy Finance, Bushveld Minerals analysis, Roskill

Summary

- Energy storage is a rapidly growing sector, expected to achieve a CAGR of 36% between 2018 and 2027. Stationary energy storage demand is forecasted to be the fastest growing types of storage, at a rate of 58% p.a. and will exceed 100GWh by 2027
- Although many technologies can technically perform the storage function, for utility scale applications the two front runner commercial technologies are flow and lithium-ion batteries. Vanadium redox flow batteries (VRFBs) offer clear advantages technically and financially that sets it apart in large scale stationary applications
- Vanadium use in consumer and mobile energy storage offers future opportunities for vanadium despite limited share in current markets
- Vanadium demand remains underwritten by the steel market and existing demand from steel and chemicals implies a demand CAGR for vanadium of 2.5% from 2017 to 2027; The high dependence of VRFBs on vanadium may increase the demand CAGR up to 8.4%

Energy storage

Long duration utility scale batteries

Electrolyte accounted for **~2%** of 2017 global vanadium consumption, but could grow up to **44% by 2027** as VRFB's gain momentum

Steel

Construction steel - rebar

Alloys for aerospace industry

The steel industry currently accounts for **~90%** of total vanadium consumption and will continue to support robust vanadium demand from greater regulatory enforcement of steel standards

Objectives for today's session

- Understand energy storage, especially stationary storage, what makes it important, what it is used for and the different technologies available for those uses;
- Present a deep dive in vanadium redox flow batteries (VRFBs), covering their unique applications, how they compare to alternatives such as lithium-ion and discuss the challenges and opportunities that the VRFB value chain faces today. This will include trends currently impacting stationary energy storage deployments globally;
- Highlight the size of the market opportunity for stationary energy storage and discuss the implications it has on overall demand for VRFBs and vanadium;
- Briefly touch on the use of vanadium in other types of energy storage;
- **Provide an overview of Bushveld Minerals and Bushveld Energy in an integrated effort to create value across the vanadium energy storage value chain.**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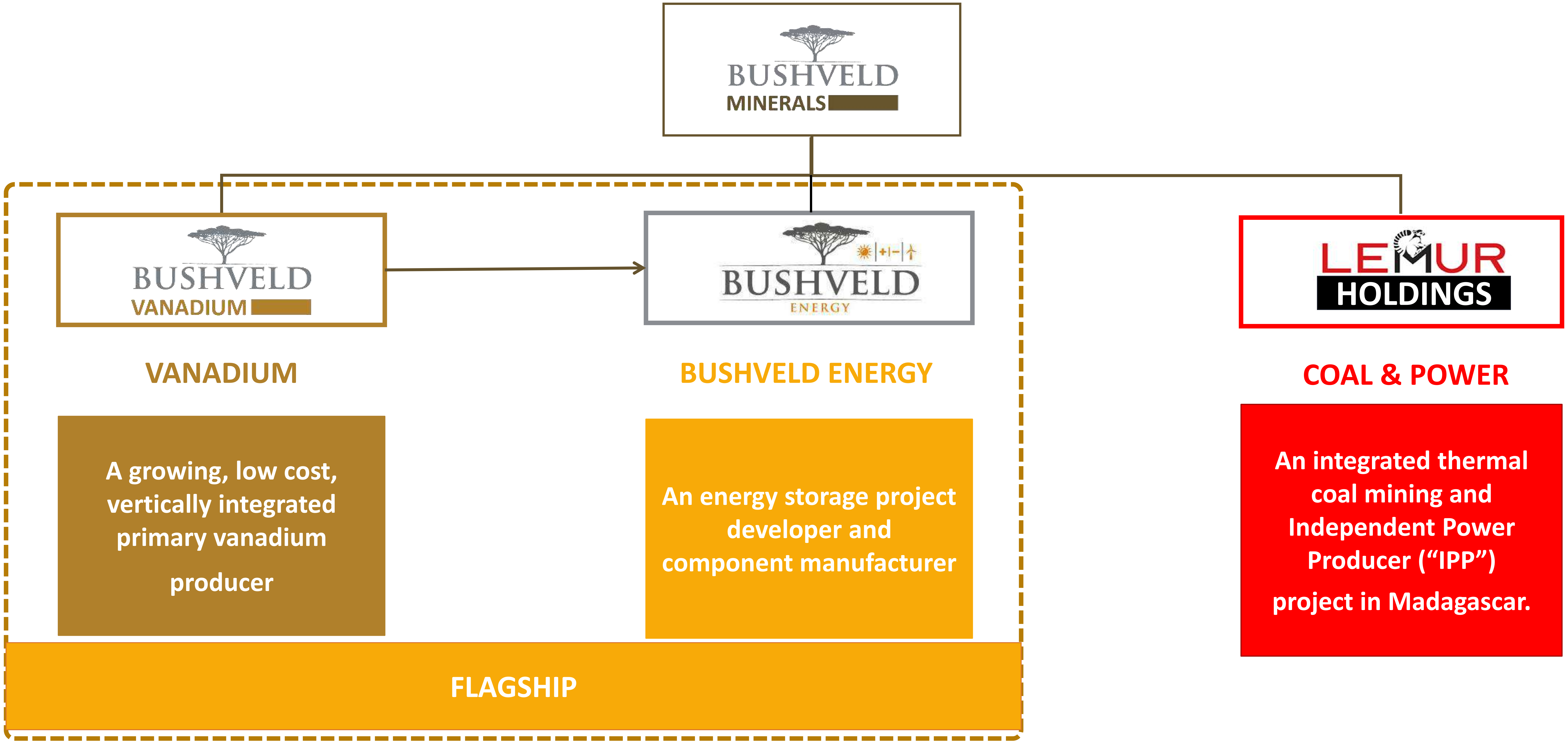
MINERALS

An integrated vanadium platform with investments in coal & power[1]



1. The Company holds a 10.04% shareholding in AIM-listed AfriTin Mining Limited

Source: Bushveld Minerals

Market metrics

Strong share price performance, with increasing interest from institutional investors

BMN Share Price (12 November 2018)	44.50p
Basic Ordinary Shares	1,119,057,953
52-Week Hi-Lo	44.50 - 7.98p
Market Capitalisation	£497,980,789

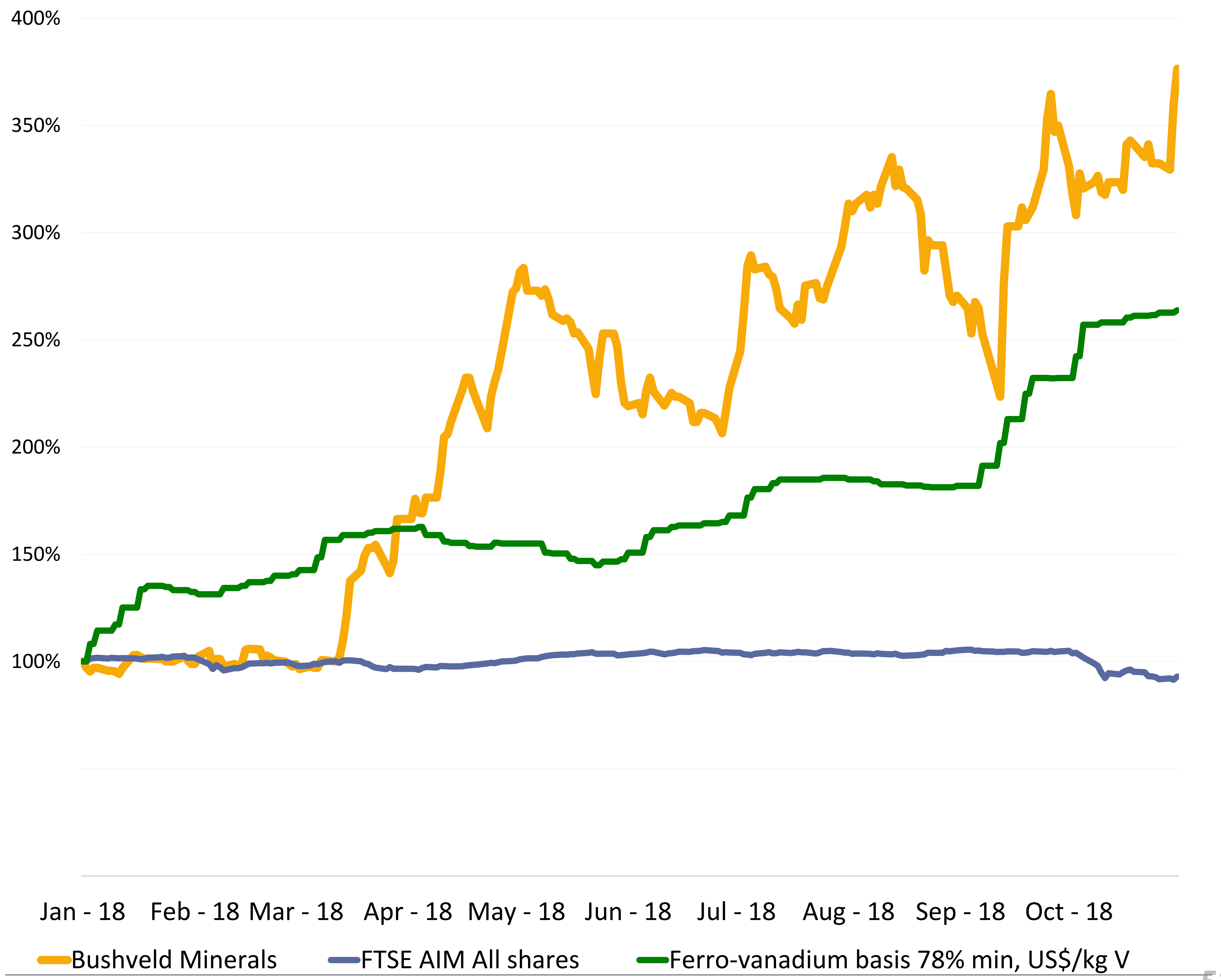
Source: Bloomberg, 12 November 2018

	Bushveld Minerals Top Shareholders	**# shares**	**% ownership**
1	Hargreaves Lansdown Asset Mgt	172,486,661	15.54
2	Halifax Share Dealing	104,013,918	9.37
3	Interactive Investor	103,215,151	9.30
4	Acacia Resources Limited	85,598,644	7.71
5	Yellow Dragon Holding Limited	67,832,778	6.11

	Bushveld Minerals Top Institutional Shareholders	**# shares**	**% ownership**
1	Invesco Perpetual Asset Mgt	21,104,559	1.90
2	Pictet & Cie	11,345,451	1.02
3	Canaccord Genuity Wealth Mgt	11,158,500	1.01
4	Amati Global Investors	10,033,981	0.90

Source: Link Asset Services, as at 31 October 2018

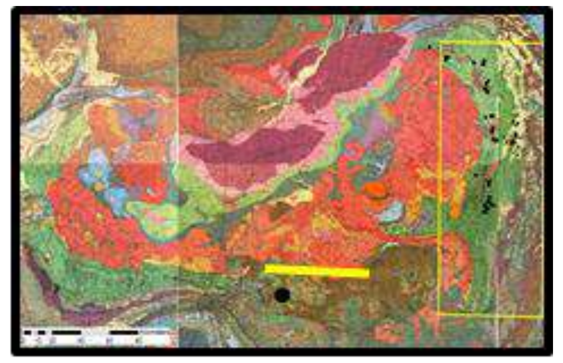
YTD Share Price Performance (indexed) AIM:**BMN**



Source: Bloomberg, 31 October 2018

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

- 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



- Large high grade ore for primary vanadium mining
- Significant resource base in the best areas of the Bushveld complex

- Large, low cost vanadium processing
- Focus on expansion and enhancement of brownfield operation

Targeting 10,000 mtV in the medium term

Focus for Bushveld Energy

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

Targeting initial 200MWh of electrolyte p.a.

- VRFB Assembly & manufacturing

- MW scale energy storage project development
- Deployment models include PPAs, leasing models

Targeting 1000 MWh opportunities by 2020

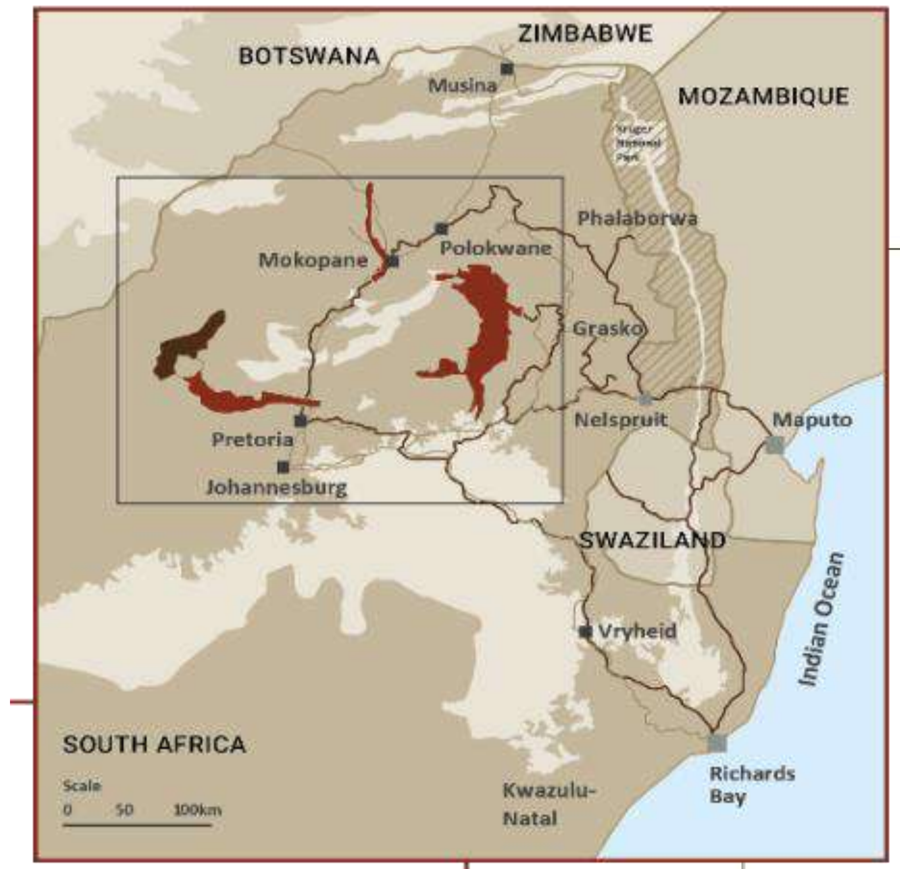
~U$S7 Billion market[1]

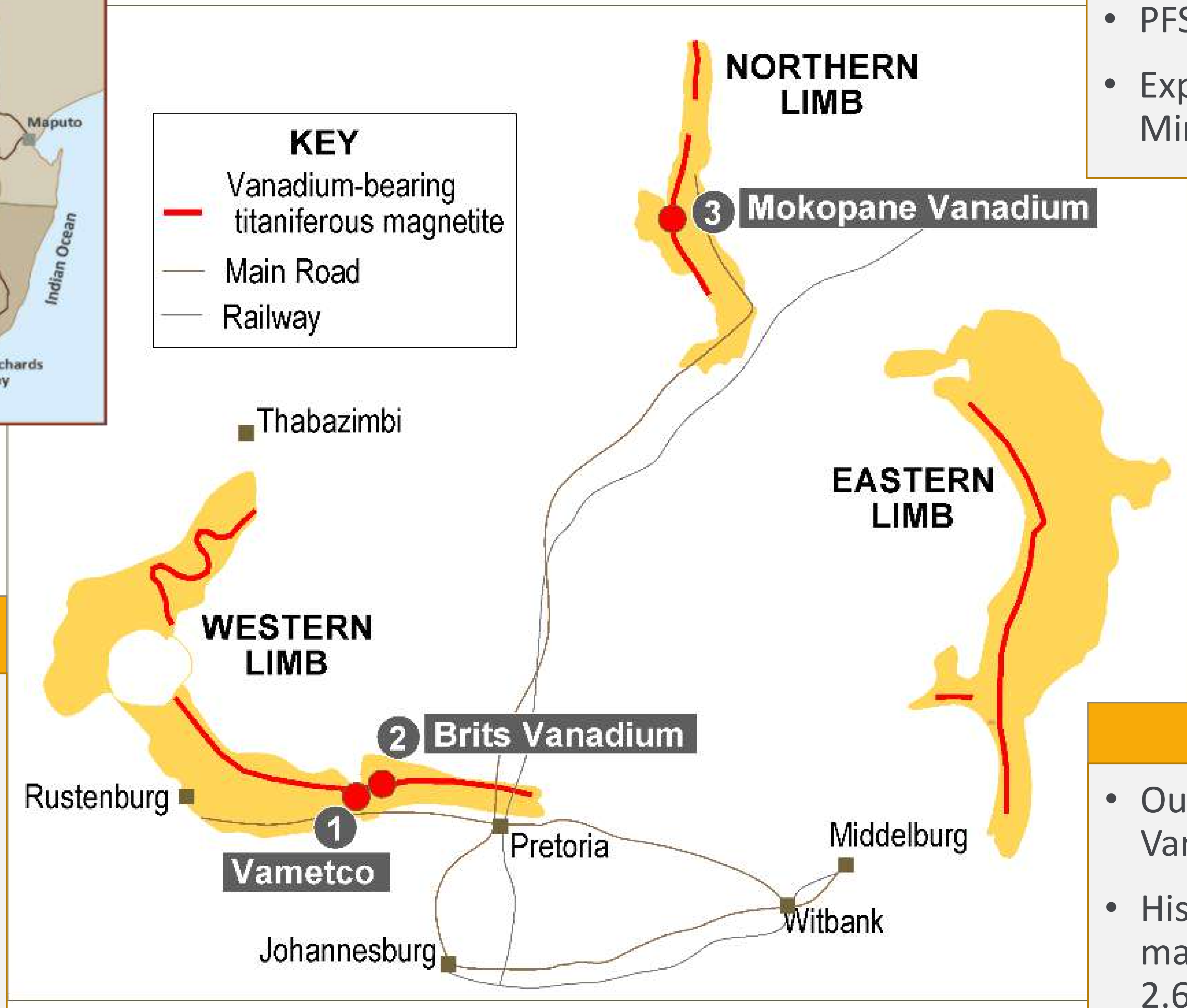
Potential >US$70 Billion[2] addressable market for VRFBs by 2030

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

Quality primary vanadium asset portfolio, with significant potential to expand production and extend life of mine





3. Mokopane Vanadium

- 298 Mt JORC, outcropping reserve and resource
- Vanadium in-magnetite grades of 1.75% V2O5
- PFS completed January 2016
- Expect to be granted a New Order Mining Right

1. Vametco

- 26 Mt reserve average in-magnetite grade of 1.96% V_2O_5 (JORC)
- 142.4 Mt Resource with average in-magnetite grades of 1.96% V_2O_5
- Operating with a RoM of ~1.3 mtpa

2. Brits Vanadium

- Outcropping, strike extension of the Vametco mine
- Historical drilling showed in-magnetite grades of as much as 2.6% V2O5
- Commenced an exploration programme in Q1CY18 which has shown positive drilling results

- **440 Mt high grade open cast primary vanadium resource base**
- **Including ~55Mt combined reserves**
- **High grade of 1.5-2.0% V_2O_5 among the highest in the world**
- **Low cost primary vanadium processing capacity supplying ~3% of global vanadium market**
- **Scalable processing platform with scope for additional brownfield capacity expansions**

Source: Bushveld Minerals

Bushveld Minerals is focused on horizontal and vertical growth

Horizontal Growth

Organic growth

- Leverage high quality vanadium resources
- Existing global vanadium market share of c. 3%, expected to grow to over 5% in the near-term

Targeted brownfield opportunities

- Continued focus on enhancing value through targeting brownfield opportunities
- Diversify product portfolio

Targeting a production platform of >10,000 mtV in the medium term

Vertical Growth

- Portfolio diversification through the supply of electrolyte for vanadium redox flows batteries (VRFBs) for energy storage
- Bushveld Energy established to promote use of vanadium in energy storage by:
  - Exclusively focusing on VRFB technology
  - Marketing and developing utility scale projects using VRFB based energy solutions across Africa
  - Partnering with UniEnergy Technologies (UET), a US-based leading VRFB manufacturer
  - Commissioning a VRFB with a peak power of 120kW and peak energy of 450 kWh into Eskom's RT&D facility in Q4CY18
  - Working with the IDC to build a vanadium electrolyte production plant in East London, South Africa, with a minimum capital expenditure requirement
  - Developing novel business models, such as electrolyte rental, to accelerate VRFB deployments and create new revenue streams

Source: Bushveld Minerals

Bushveld Energy is an energy storage project developer and component manufacturer, focusing on the African market

BUSHVELD
ENERGY

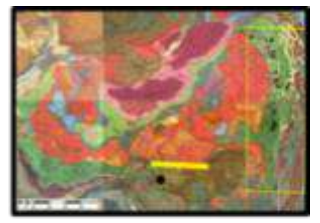
- Bushveld Energy recognises that electricity in Africa intersects paramount **potential for social transformation** with an immense **commercial opportunity**
- The Company is focused on developing and promoting the **role of vanadium** in the growing **global energy storage** market through application in VRFBs
- Its near term strategy is to install several VRFB systems as part of its longer term vision to **become a significant electricity storage provider in Africa** by 2020, meeting the demand for utility scale energy storage in Africa by leveraging South Africa-mined and beneficiated vanadium
- Aligned with the company strategy is the recent announcement from **The World Bank Group** to commit **US$1 billon** of its own funds and mobilise a further **$4 billion to finance 17.5GWh of energy storage by 2025** in low and middle-income countries
- Bushveld Energy, together with the Industrial Development Corporation of South Africa, is currently establishing the **manufacturing of vanadium electrolyte** in South Africa

Source: Bushveld Energy

Vertical integration brings several advantages to Bushveld as a group

Bushveld Mineral's integrated business model

- Bushveld Minerals' ambition is to grow into one of the world's most significant, lowest cost and vertically integrated vanadium companies
- This allows the Bushveld to leverage its large low cost production base and be a catalyst in the emerging energy storage industry



- Large high grade ore for primary vanadium mining
- Significant resource base in the best areas of the Bushveld complex

- Large, low cost vanadium processing
- Focus on expansion and enhancement of brownfield operation

XX Bushveld Energy's activities

Bushveld Energy's focus

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

I IV

- VRFB assembly & manufacturing

V

- MW scale energy storage project development
- Deployment models include PPAs, leasing models

II III

Advantages from vertical integration

1. Enabler to support the growth of energy storage that increases demand for vanadium

2. Diversification of products and customers beyond the steel sector that bring new sources of value creation

3. Exposure to a new, high growth sector that provides access to a market that is multiple times larger than vanadium alone

4. Reduced volatility of revenues and profitability, as energy storage features lower market volatility than commodity markets

5. Higher valuation multiples, as energy and diversified listed companies carry higher earning multiples than miners (in part due to relatively lower capital requirements)

Source: Bushveld Minerals

The forward vertical integration strategy has defined five clear opportunities for revenue in Bushveld Energy's Business Plan

Applications

I. Manufacture electrolyte

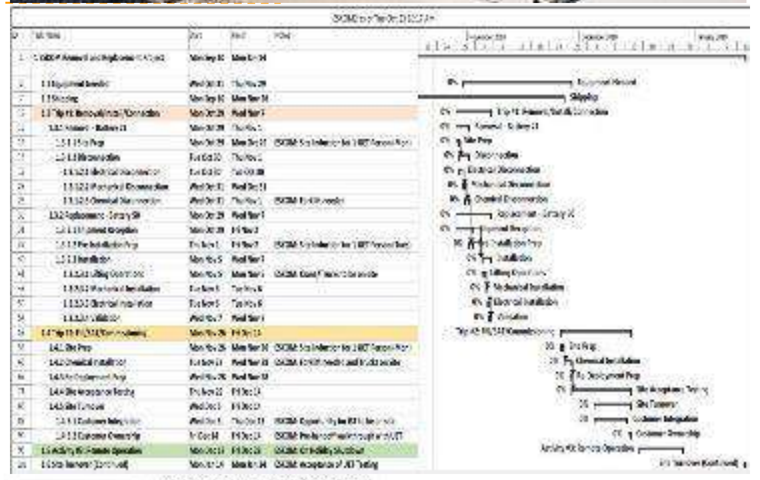
- Building and operating an chemicals plant to convert vanadium feedstock into a liquid electrolyte
- Selling electrolyte to VRFB companies or direct users / buyers of energy storage systems

II. Sell and install VRFB systems

- Re-selling VRFBs as a local, value-adding partner in African markets to VRFB manufactures
- Developing a local logistics chain

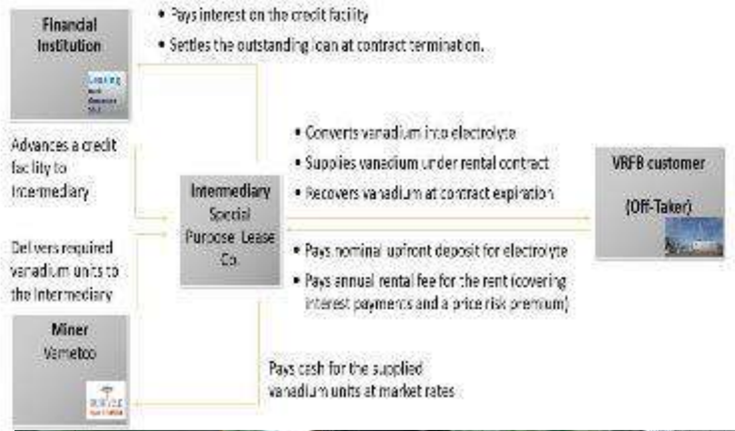
III. Develop and invest in projects

- Identifies sites and defines the economic business case for VRFB installations
- Designs the technical and commercial structure of projects that use VRFBs
- Makes direct investments into such projects



IV. Rent vanadium electrolyte

- Offers a new product that retains ownership of electrolyte and rents out vanadium to the VRFB end user
- Provides a product essential to cover vanadium price peaks and produces a pricing strategy to compete with lithium ion cost reductions



V. VRFB assembly

- Invests in the construction of an assembly plant for a VRFB product (that will be operated by another party)
- This longer term opportunity could involve direct investment into a VRFB company that would own the facility

Source: Bushveld Energy

Bushveld Minerals' investment proposition

1 of 3 operational primary vanadium producers, and 1 of 2 vanadium focused pure-play companies in the world

1

Positive price outlook as a result of sustained **structural deficit** on the back of growing demand amidst constrained and concentrated supply

2

Large, open cast deposits 439.6Mt combined resource (including ~**55 Mt** combined reserves)

~2% in-magnetite V_2O_5 amongst the highest in the world

1st quartile cost curve position

3

Brownfield infrastructure

The company's deposits exist in close proximity to brownfield infrastructure creating scope for **low capex and quick scale-up** of production capacity

4

Vertical integration anchored in **high quality, low cost production base** allows us to be a key player in the multibillion-dollar energy storage industry through application of **vanadium redox flow batteries**

5

Management team combines more than 100 years' experience

6

Concentrated global supply with **South Africa as the largest host of high-grade primary vanadium resources**

7

Shareholder Return

Committed to delivering attractive returns to shareholders

Source: Bushveld Minerals

Appendix: Acronyms and abbreviations

AC	Alternating Current
AES	Associated Energy Services
BOP	Balance of Plant
BOS	Balance of Systems
CAES	Compressed Air Energy Storage
CAPEX	Capital Expenditure
CRM	Cardiac Rhythm Management
DC	Direct Current
DER	Distributed Energy Resource
DoD	Depth of Discharge
EPC	Engineering, Procurement and Construction
ESS	Energy Storage System Safety
EV	Electric Vehicle
ICD	Implantable Cardioverter Defibrillator
IRR	Internal Rate Return
JORC	Joint Ore Reserves Committee
KWh	Kilowatt Hour
LCOE	Levelised Cost of Energy Storage
MW	Megawatt
MWh	Megawatt Hour
NASA	North American Space Agency
NCA	Nickel cobalt Aluminium – lithium battery
NMC	Nickel Manganese cobalt – Lithium battery
O&M	Operations and Maintenance
OEM	Original equipment manufacturer
PCS	Power Conversion system
PHS	Pump Hydro Storage
PV	Photovoltaic
PWh	Petawatt hour
R&D	Research and Development
SPV	Special Purpose Vehicle
SVO	Lithium Vanadium Silver Oxide Battery
T&D	Transmission and Distribution
VRFB	Vanadium Redox Flow Battery

Appendix: Overview of selected energy storage technologies

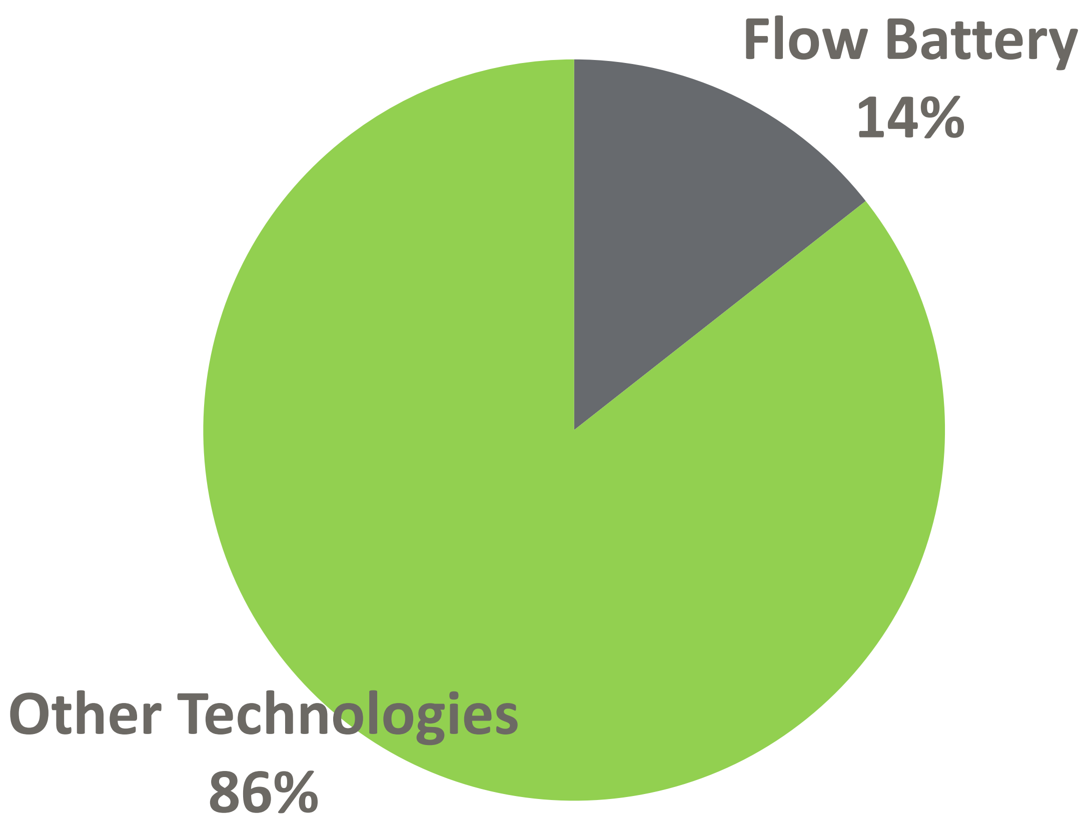
		Description
Mechanical/Gravity/Thermal	Compressed Air	• Compressed Air Energy Storage ("CAES") uses electricity to compress air into confined spaces (e.g., underground mines, salt caverns, etc.) where the pressurised air is stored. When required, this pressurised air is released to drive the compressor of a natural gas turbine
	Flywheel	• Flywheels are mechanical devices that spin at high speeds, storing electricity as rotational energy, which is released by decelerating the flywheel's rotor, releasing quick bursts of energy (i e., high power and short duration) or releasing energy slowly (i.e., low power and long duration),depending on short-duration or long-duration flywheel technology, respectively
	Pumped Hydro	• Pumped hydro storage uses two vertically separated water reservoirs, using low cost electricity to pump water from the lower to the higher reservoir and running as a conventional hydro power plant during high electricity cost periods
	Thermal	• Thermal energy storage uses conventional cryogenic technology,oompress1ng and storing air into a liquid form (charging) then releasing it at a later time (discharge).Best suited for large-scale applications; the technology is still emerging, but has a number of units in early development and operation
Chemical	Flow Battery	• Flow batteries store energy through chemically changing the electrolyte (vanadium) or plating zinc (zinc bromide). Physically, systems typically contain two electrolyte solutions in two 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, ferrochrome and zinc chromate
	Lead Acid	• Lead acid batteries date from the 19th century and are the most common batteries; they are low-cost and adaptable to numerous uses (e.g., electric vehicles, off-grid power systems, uninterruptible power supplies, etc.) • "Advanced" lead-acid battery technology adds ultra-capacitors, increasing efficiency, lifetimes and improve partial state of-charge operability
	Lithium-Ion	• Lithium-ion batteries have historically been used in electronics and advanced transportation industries; they are increasingly replacing lead-acid batteries in many applications, and have relatively high energy density, low self discharge and high charging efficiency • Lithium-ion systems designed for energy applications are designed to have a higher efficiency and longer life at slower discharges, while systems designed for power applications are designed to support faster charging and discharging rates, requiring extra capital equipment
	Sodium	• "High temperature"/ "liquid-electrolyte-flow", sodium batteries have high power and energy density and are designed for large commercial and utility scale projects; "low temperature" batteries are designed for residential and small commercial applications
	Zinc	• Zinc batteries cover a wide range of possible technology variations, including metal-air derivatives; they are non-toxic, non-combustible and potentially low-cost due to the abundance of the primary metal; however, this technology remains unproven in widespread commercial deployment

LAZARD

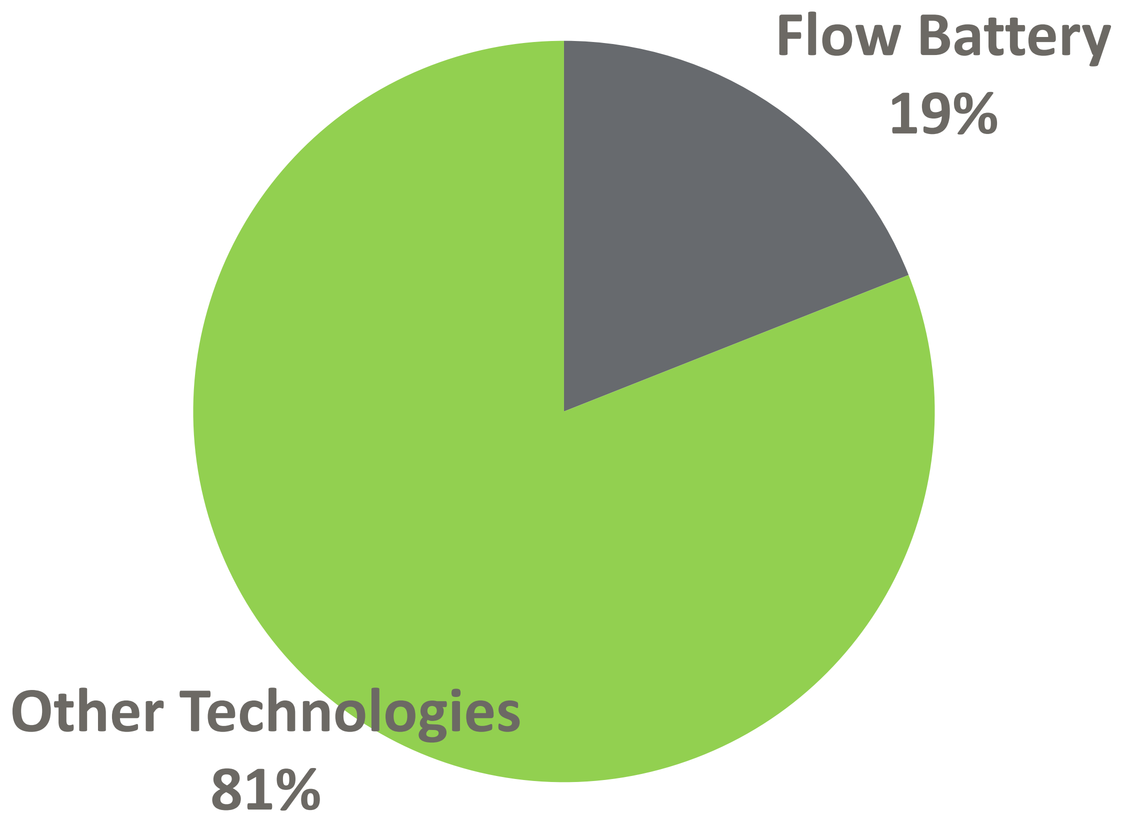
Source: Lazard

Appendix: Navigant Research forecasts flow batteries to capture 18% of all stationary storage, with varying penetration across different applications

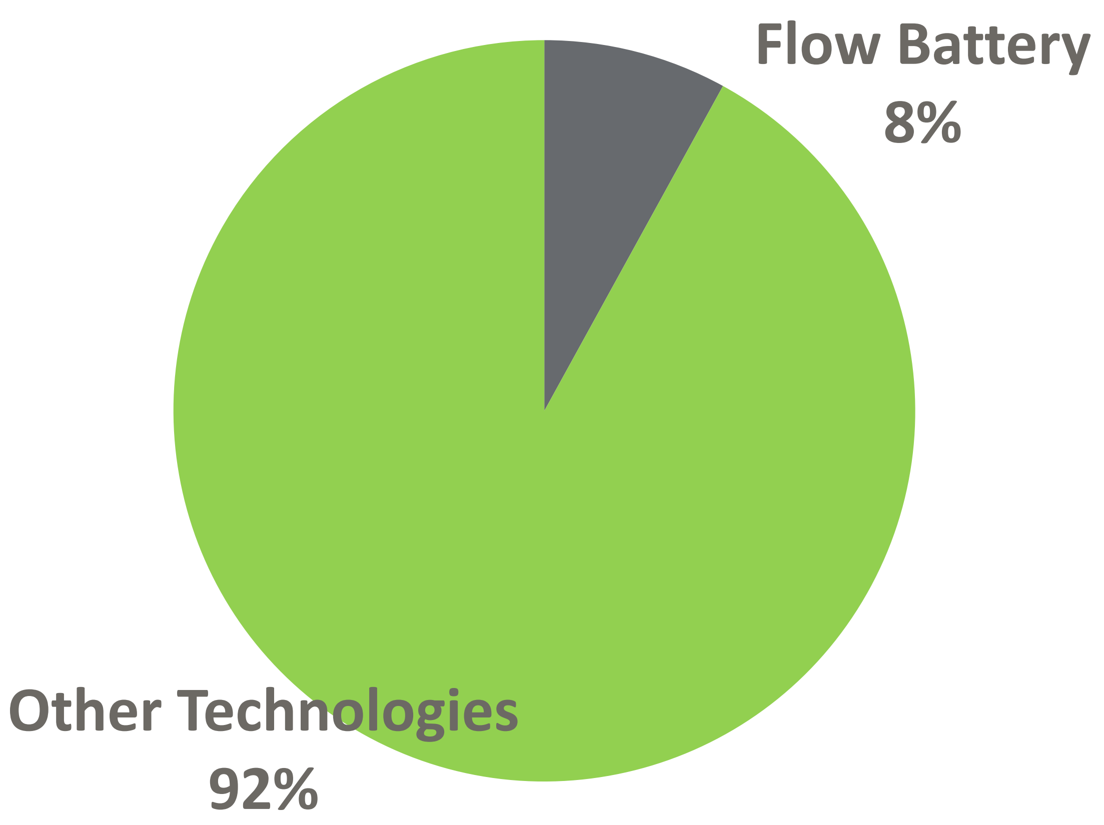
Generation Capacity



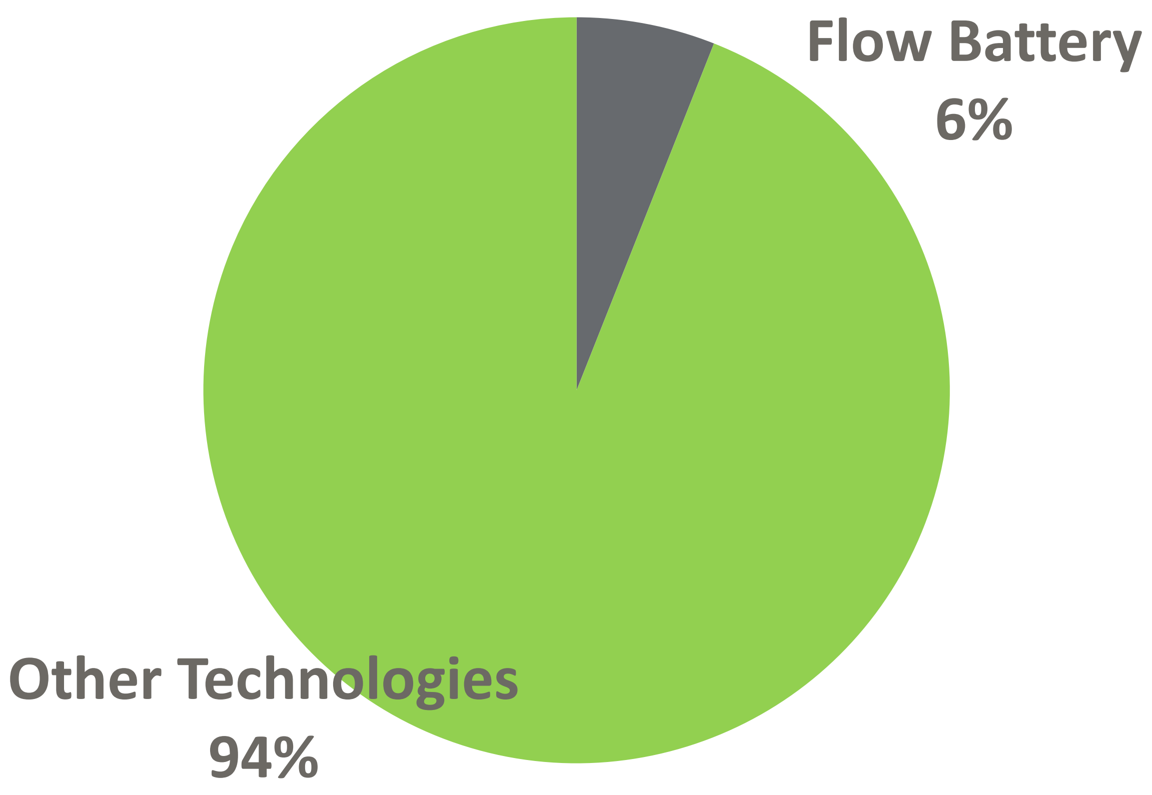
T&D Asset Optimisation



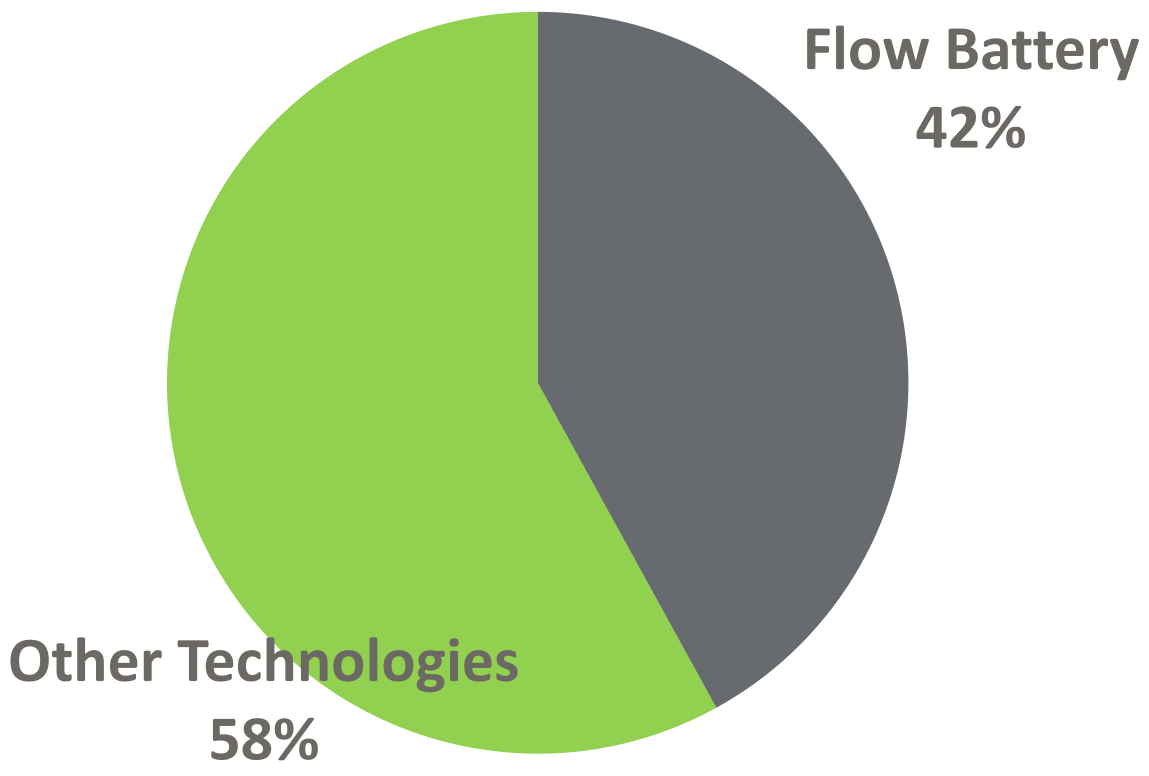
Frequency Regulation



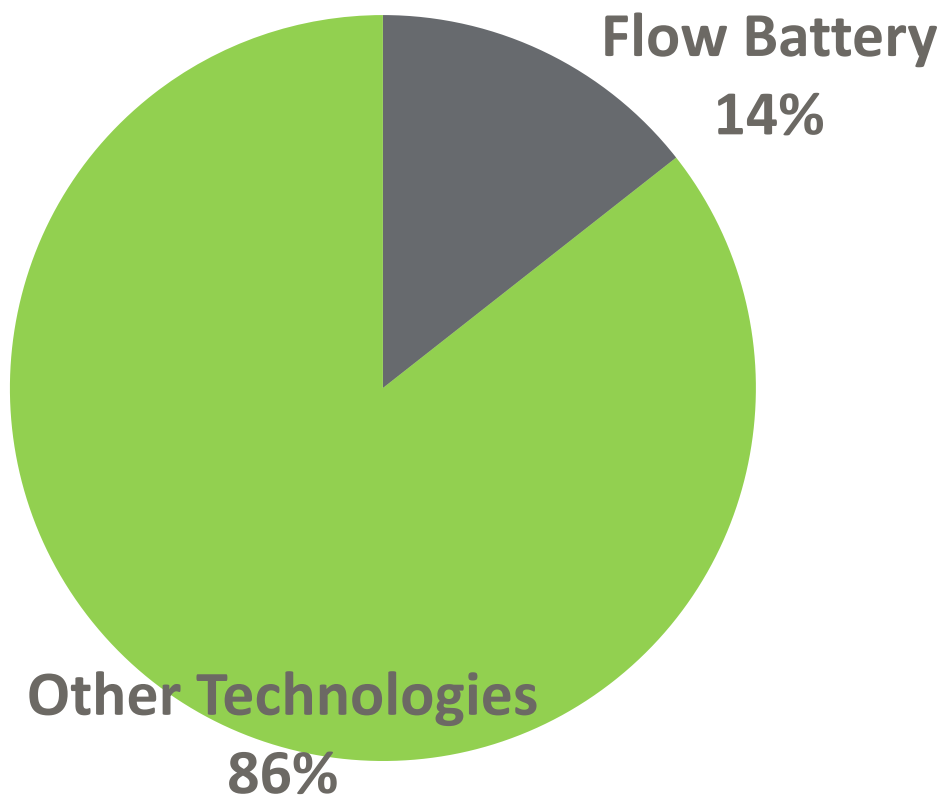
Volt /Var Support



Renewables Ramping & Smoothing



C&I Behind-the-Meter



- Flow batteries are expected to be most successful serving applications that require medium to long discharge durations and need to be sited in specific locations.
- Location-specific applications such as renewables ramping & smoothing cannot typically be served by electromechanical long-duration storage such as pumped hydro, providing an advantage for flow batteries

Source: Navigant Research

Appendix: Growing opportunities in the power system to use one battery for multiple benefits gives technologies that favour high utilisation rates an advantage

A storage system must prioritize a limited number of high-value applications that can feasibly work with one another. Leading ESS market players have indicated that they seek just 2-3 applications for a given system. Applications can have various attributes that impact compatibility:

- Utilization: How frequently ESS must be dispatched to support the application
- Commitment: Necessity for the ESS to be available at specific times
- Location: Some applications can only be performed at certain locations on the grid (e.g., BTM)
- Duration: Duration required for storage to provide full value (<1 hr to >4 hr)

Application	Priority	Value	Utilization	Commit-ment	Duration	Other Considerations
Wholesale/Grid Services						**Limited eligibility of DER to participate; can complicate retail billing; may require aggregation**
Energy Arbitrage (Wholesale)	Low	Typically low	High	Low	Med–Long	Low margins for wholesale energy
Generation Resource Adequacy	High	Can be high	Low	High	Med–Long	Capacity/DR requires high commitment
Frequency Regulation	Med	Can be high	High	Low	Short	Low commitment with moderate-to-high value
Volt/VAR Support	n/a	Low	High	Low	Short	Challenging for aggregation
Black Start	n/a	Low	Low	High	Long	Must be co-located with generation
Retail Services						**Primary drivers for C&I customers**
Demand Charge Management	High	Can be high	Low–Med	High	Med–Long	Primary application driving C&I market; Value depends on retail rates
Energy Arbitrage (Retail)	Med	Based on TOU rates	High	Low	Short–Long	Value depends on retail TOU rates
Backup Power	Med	Can be high	Low	Low–High	Short–Long	No formal approach for monetizing value; May hold in reserve or not
Power Quality	Low	Mostly low	Low–High	Low–High	Short	Some niche customers may value this

Case Study: Energy Storage for C&I Customers of Southern California Edison (SCE):

- C&I ESS projects stack both retail and grid services through a contract with utility SCE
  - Retail: Demand Charge Management, Energy Arbitrage, and Backup Power
  - Grid Services: Generation Resource Adequacy

SOUTHERN CALIFORNIA EDISON

Advanced Microgrid Solutions

stem

Source: Navigant Research

BUSHVELD
MINERALS

Bushveld Minerals corporate Video: https://www.brrmedia.co.uk/broadcasts/5a5626af9ed50c2f9b04679c/bushveld-minerals-an-emerging-integrated-vanadium-producer
Vanadium 101 Webinar: https://edge.media-server.com/m6/p/i2wo6bk9
Vanadium 101 slides: http://www.bushveldminerals.com/wp-content/uploads/2018/05/Bushveld-Minerals-Vanadium-101_Final.pdf