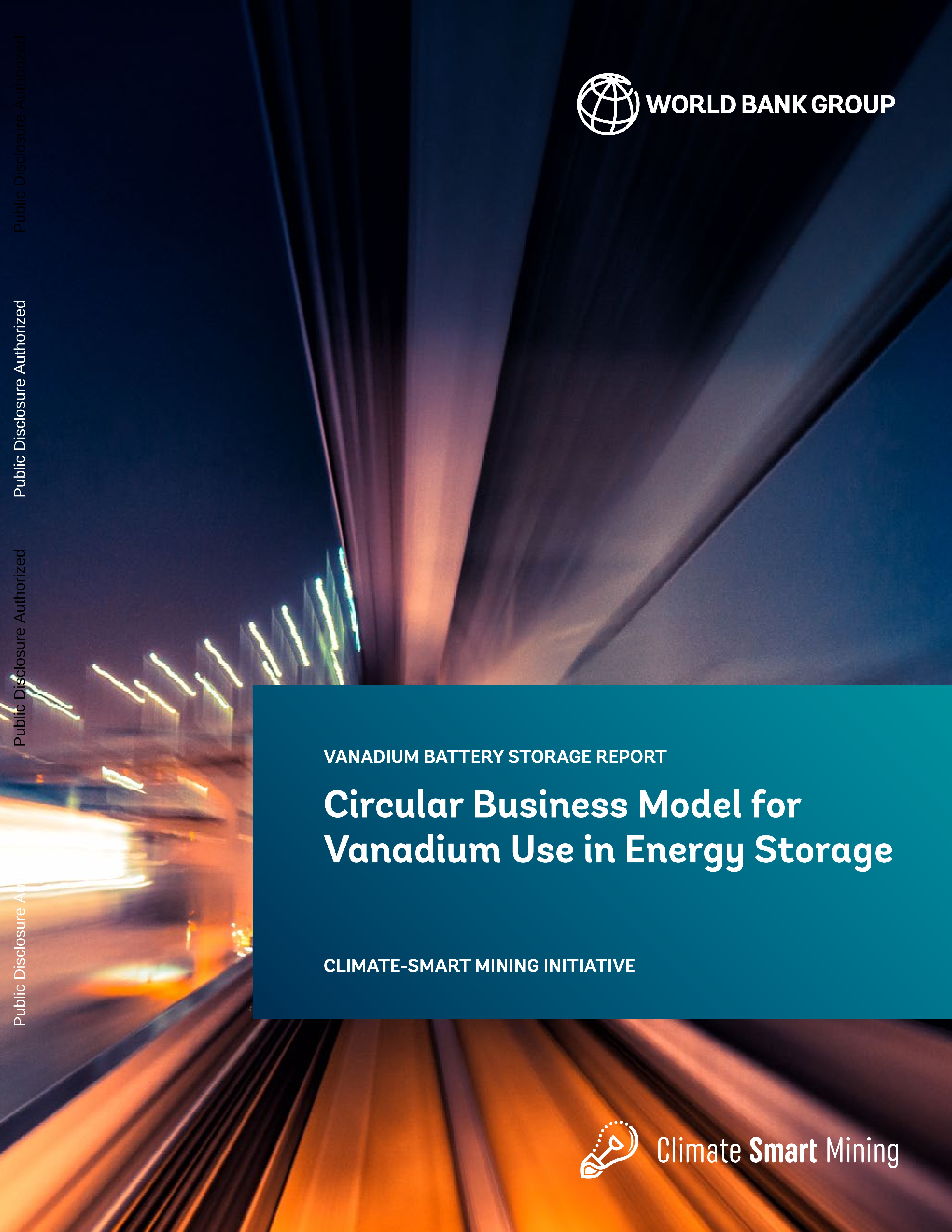

WORLD BANK GROUP

VANADIUM BATTERY STORAGE REPORT

Circular Business Model for Vanadium Use in Energy Storage

CLIMATE-SMART MINING INITIATIVE

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This document was written for the World Bank Group's Climate-Smart Mining Initiative by PwC.

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List of Abbreviations

ABET	Adult Basic Education and Training
AMD	Acid Mine Drainage
B-BBEE	Broad-Based Black Economic Empowerment
BCR	benefit-cost ratio
BESS	Battery Energy Storage System
BoP	Balance of Plant
BTM	Behind-the-Meter
CAGR	Compound Annual Growth Rate
CBA	cost-benefit analysis
CoUE	cost of unserved energy
CoLS	cost of load shedding
CIS	Commonwealth of Independent States
CIT	corporate income tax
CSIR	Council for Scientific and Industrial Research
CSM	Climate Smart Mining
CVBM	Circular Vanadium Business Model
DMRE	Department of Mineral Resources and Energy
DPE	Department of Public Enterprises
DWS	Department of Water and Sanitation
EIAR	Environmental Impact Assessment Report
EIU	Economist Intelligence Unit
EMPr	Environmental Management Programme
EPR	Extended Producer Responsibility
E&S	environmental and social
EV	electric vehicle
ETP	effluent treatment plant
FDI	foreign direct investment
FI	financial institutions
GDP	gross domestic product
GHG	greenhouse gas
GOS	gross operating surplus
GRI	Global Reporting Initiative
HIA	Heritage Impact Assessment
ICMM	International Council on Mining and Metals
IDC	Industrial Development Corporation
IEA	International Energy Agency
IRP	Integrated Resource Plan
IEP	Integrated Energy Plan
IWWMP	Integrated Water and Waste Management Plan
IRR	Internal Rate of Return
IWUL	Integrated Water Use Licence
JV	joint ventures
LCOE	Levelized Cost of Electricity
LCOS	Levelized Cost of Energy Storage
LiB	lithium-ion battery
MEIA	macroeconomic impact assessment (MEIA)
MHIRA	Major Hazard Installation Risk Assessment
ML	Megaliter
MPRDA	Mineral and Petroleum Resources Development Act
NDC	nationally determined contributions
NDP	National Development Plan
NEMA	National Environmental Management Act
NEMBA	National Environmental Management Biodiversity Act
NEMWA	National Environmental Management Waste Act
NEPV	Net Economic Present Value
NHRA	National Heritage Resources Act
NT	National Treasury
NWA	National Water Act
NRCS	National Regulator for Compulsory Specifications
NYP	National Youth Policy
OTC	over-the-counter
PEPUDA	Promotion of Equality and Prevention of Unfair Discrimination Act
PC	personal computer
PGM	platinum group metal
PPE	personal protective equipment
PV	photovoltaic
RE	renewable energy
REIPP	Renewable Energy Independent Power Producer
SABS	South African Bureau of Standards
SAM	Social Accounting Matrix
SARB	South African Reserve Bank
SDG	Sustainable Development Goals
SEZ	special economic zones
SLP	Social Labour Plan
SMME	small, medium and micro enterprises
SOE	State-owned enterprise
SoC	State of Charge
SPV	special purpose vehicle
SSV	sandstone shale-hosted vanadium deposits
UPS	uninterrupted power supply
USGS	United States Geological Survey
VE	vanadium electrolyte
V_2O_5	Vanadium electrolyte
VRFB	vanadium redox flow batteries
VTM	vanadium titanium magnetite
WTP	water treatment plant
WUL	Water Use Licence

1 Executive summary

Lowering the footprint of the global energy transition will induce finding more sustainable ways of extracting and using critical minerals for clean energy and battery energy storage manufacturing: vanadium is one of them. This report delves into the development of circular business models for vanadium, with a particular focus on the leasing model for Vanadium Redox Flow Batteries (VRFB). The report assumes that VRFB will play an increasing role in the power systems decarbonization, because of the niche role of this technology in the bouquet of grid-scale energy storage solutions (VRFB is a long duration, modular and site agnostic energy storage), This report is hence focusing on circular economy principles and will not address VRFB technology development potential nor its energy-specific applications. However, this analysis does highlight the economic attractiveness and climate sustainability of VRFBs as an energy storage solution. It also emphasizes the potential of innovative business models to address the high upfront capital cost barrier that currently hinders wider adoption of VRFB solutions [1]. While showcasing the leasing model as a promising avenue for VRFB deployment, it is crucial to emphasize that this is one among several viable options.

Circular Economy Opportunities in Vanadium and VRFB Value Chain

Vanadium's unique chemical (redox versatility, stability, and recyclability) and VRFB's technical characteristics (modular design, safety features, and potential for second-life applications) make them well-suited for circular business models. The economic viability of these models, however, hinges on increased VRFB deployment as a battery storage solution in the future. This, in turn, depends on growing vanadium demand and the development of a global trading market for VRFB.

Key Objectives and Scope of the Study

Aligned with and funded through the World Bank's Climate-Smart Mining (CSM) Initiative, which promotes sustainable mining practices and responsible use of critical mineral resources for developing low-carbon technologies, this report focuses on innovative circular business models throughout the mineral lifecycle.

The report investigates the applicability of a circular business model to vanadium all along its extraction and transformation value chain, assessing its potential scalability to other critical minerals while minimizing environmental impacts. Hence, the report explores innovative business models for vanadium, with a particular focus on the leasing model for VRFBs. The project encompasses eight major tasks, including vanadium battery market analysis, vanadium leasing model assessment, vanadium supply and demand dynamics analysis, economic and financial evaluation, regulatory and legal review, macroeconomic and fiscal analysis, environmental and social impact assessment, and a roadmap for circular business model expansion. The report is designed to provide policy advise to: vanadium extraction countries, countries where it is transformed, or countries where VRFB is utilized.

While the leasing model stands out as a promising avenue for VRFB deployment, it is important to acknowledge that this innovative solution will need to be proofed and is not standalone. Factors beyond the report's scope may influence the practical scale up of VRFB adoption.

Approach and Methodology

To thoroughly assess the feasibility and potential impact of a proposed circular vanadium business model, the analysis adopted a comprehensive and multi-dimensional approach.

First, market research was conducted to evaluate the market potential and cost economics of VRFB-based energy storage solutions, while acknowledging that other studies assessed this potential in a more detailed manner, using analysis of load flows in selected power systems. South Africa was used as a case study and a complete supply and demand analysis was also performed, utilizing subject-specific data to identify key opportunities for local stakeholders.

Second, a detailed analysis of the entire vanadium-VRFB value chain was conducted, encompassing mining, manufacturing, and recycling[2]. Insights from leasing and rental models of other metals were incorporated to refine the proposed vanadium leasing model.

1 Unlike other type of grid-scale battery technologies, VRFB does not have other energy storage application driving the technology cost down, hence the essential need to differentiate the asset through its lower footprint and longer lifetime.
2 This is a value chain assessment which excludes operating cost and maintenance of VRFB.

Third, a cost-benefit analysis (CBA) was employed to assess the costs and benefits associated with both the current state and the proposed circular vanadium business model. This holistic approach provided a comprehensive understanding of the case study's potential economic impacts across various stages of the value chain.

Next, the South African vanadium value chain and regulatory framework was reviewed to ensure it facilitates sustainable mineral extraction and supports the global low-carbon transition. A high-level mineral rental model utilizing a Special Purpose Vehicle (SPV) was proposed to maximize the study case's benefits.

The subsequent step of the analysis included a macroeconomic impact assessment (MEIA), which was conducted to quantify the estimated economic net benefits of the proposed case study. This analysis highlighted its macroeconomic and fiscal impact by demonstrating industry interdependencies within different economic sectors.

To make the study exhaustive, a collaborative approach was adopted to address the environmental and social impacts of the case study. Key stakeholders were consulted on themes including inclusivity and equity in managing water use, land and air pollution, and waste/tailings management.

Vanadium Market Dynamics

Vanadium redox flow batteries are poised to become a promising energy storage technology with a growing market. By 2030, the global VRFB deployment is expected to reach 111 gigawatt hours (GWh) globally, driven by applications such as grid use (e.g., for renewable energy integration), or behind the meter power backup (e.g., for health centers in fragile power systems). VRFBs offer long-duration storage and minimal degradation – hence, longer lifetime than other battery energy storage systems (BESS), but their upfront cost is currently higher than competing energy storage options. Following similar trend than for other modular energy storage technology, the cost of VRFBs is expected to halve by 2030 due to technological advancements and economies of scale. The levelized cost of electricity (LCOE) is a better metric for evaluating the cost-effectiveness of VRFBs in commercial applications, as these assets have around twenty years lifetime and allow full recycling of the electrolyte minerals, the vanadium.

Over time, the demand for large volumes of stored energy will increase as a consequence of wind and solar photovoltaic power capacity development: VRFBs will be an adequate long duration energy storage, in cases where large pump hydropower is not feasible and other grid investments are too costly.

Vanadium Leasing Models: A Viable Option for VRFB Deployment

The substantial upfront cost of VRFBs poses a significant challenge to their widespread adoption. To address this hurdle, innovative business models, like vanadium electrolyte leasing, have emerged as promising solutions to accelerate VRFB commercialization. These models leverage the high recyclability of vanadium electrolyte, which can be recovered with over 99% efficiency after use in the battery, making it an ideal candidate for leasing.

Two business models for circular vanadium ownership have been proposed in this report, each with three different leasing scenarios:

Model		Scenario	
Model-1	Leasing Vanadium Electrolyte to VRFB Battery Manufacturer	Scenario A	Single long-term leasing
		Scenario B	Multiple short-term leasing
		Scenario C	Multiple short-term leasing in a focused geographical region
Model-2	Leasing Vanadium Electrolyte directly to End User	Scenario A	Single long-term leasing
		Scenario B	Multiple short-term leasing
		Scenario C	Multiple short-term leasing in a focused geographical region

In both cases the commodity is leased to an off taker (e.g., a VRFB manufacturer or end user) so both models offer several advantages:

- **Reduced Upfront Cost:** The user avoids the high upfront cost of purchasing the vanadium electrolyte, making VRFB deployment more affordable.
- I**mproved Resource Efficiency:** Leasing promotes resource conservation by extending the life of the electrolyte and reducing the need for new material extraction.
- **Enhanced Circularity:** Leasing aligns with the principles of circular economy by minimizing waste and maximizing resource utilization.

To further expose the potential of leasing models for VRFBs, a comparative analysis is drawn with platinum, another valuable metal with limited natural reserves. The successful implementation of leasing models for platinum has demonstrated their feasibility, suggesting that leasing could be an effective approach for VRFBs, which also face resource scarcity challenges.

Supply and Demand Dynamics

The current global vanadium market is dominated by steel and other metal production, with battery storage demand currently accounting for only 2% of total consumption. However, battery storage demand is expected to increase rapidly over the next decade, reaching 10% of total demand by 2030. This increase in demand will put upward pressure on vanadium prices.

To meet this growing demand, global vanadium supply will need to increase by 6.9% per year between 2022 and 2030. This level of growth is similar to the rates seen in the past decade, and it is achievable due to the reactive nature of vanadium producers.

Secondary production of vanadium from recycling industrial wastes will play a key role in meeting this increased demand. In particular, the upcoming changes in bunker fuel specifications will lead to an increase in the amount of spent catalyst generated by oil refineries, which can be recycled for vanadium production.

In conclusion, the vanadium market is expected to undergo significant changes in the next decade, with increased demand for battery storage driving up prices and stimulating secondary production.

Economic and Financial Implications of Leasing

The economic and financial implications of the leasing model are complex and depend on a number of factors, including the cost of vanadium, the lease duration, and the lease rate. For this report, an economic Cost Benefit Analysis (CBA) was carried out and it validates the economic viability of the 1MWh facility leasing model, demonstrating that the benefits outweigh the incurred costs. The economic CBA used a financial discount rate of 2.4% over a 20-year period. The summarized results in economic prices are presented as follows.

The net economic present value (NEPV), benefit-cost ratio (BCR), and internal rate of return (IRR) all suggest that the investment in the 1 MWh facility leasing model over the next 20 years is economically viable as it is expected to yield positive returns.	
Net Economic Present Value (NEPV), US$	6,751
Internal Rate of Return (IRR)	3%
Benefit -Cost Ratio (BCR)	1.02
Payback Period Years	20

Source: PwC's internal strategy and analysis

For the purpose of this report, the financial analysis employed the financial model provided by a company developing the circular vanadium business model (CVBM) to examine the proposed financing structure and assess key sensitivities associated with the proposed CVBM. The analysis centered on the Project IRR, which serves as a reference point for evaluating the proposed cost of financing or return levels expected by potential investors, and the levelized cost of storage, which benchmarks the model against alternative storage options.

The analysis revealed that the upfront cost of acquiring vanadium, along with lease duration and lease rate, significantly impacts the levelized cost of storage and Project IRR. A crucial factor in understanding the financial viability of the model will be the rates of return anticipated by prospective investors. In this regard, the report suggests that conducting a market sounding with potential investors and financiers would be beneficial to better assess the attractiveness of the projected returns.

In order to provide a comprehensive and accurate assessment of the regulatory, legal, macroeconomic, fiscal, environmental, and social implications of VRFB leasing models, this report focuses on South Africa as a case study. This country-specific approach allows for a more in-depth examination of the unique challenges and opportunities that exist within the South African context. By analyzing the specific regulatory framework, economic landscape, and environmental and social dynamics of South Africa, this report aims to provide valuable insights that can be applied to other countries considering the adoption of VRFB leasing models.

Regulatory and Legal Requirements for Enabling VRFB Leasing Models

South Africa's regulatory framework poses significant obstacles to implementing a circular vanadium business model and deploying large-scale VRFBs. Several key regulatory challenges hinder the development and adoption of VRFBs. Firstly, the absence of battery storage standards allows for the importation of substandard products, undermining the growth of the local battery storage industry. Secondly, the lack of specific incentives for BESS technologies impedes their uptake. Thirdly, the staggered rollout of energy storage capacity outlined in the IRP2019 is not conducive to fostering a battery storage industry capable of supporting a circular vanadium business model.

To address these challenges, the analysis suggests that South Africa needs to introduce BESS-specific regulations under the National Energy Act to promote VRFB deployment, establish environmental standards for VRFB project permitting and end-of-life processes, implement regulatory incentives to enhance VRFB competitiveness, and leverage emerging energy regulations to enable VRFB owners' participation in a liberalized electricity market incentivizing the increased deployment of VRFBs when compared to the current single -buyer electricity market.

Macroeconomic and Fiscal Impact

A macroeconomic impact assessment (MEIA) was conducted for a proposed vanadium redox flow battery (VRFB) leasing model in South Africa. The MEIA aimed to evaluate the economic contribution of the leasing model through capital expenditure and revenue generated from annual leasing fees and recycling of electrolytes.

In South Africa, the capital expenditure for preparing vanadium electrolytes for leasing is expected to contribute to increased tax collection and have long-term positive impacts on economic growth, employment, and poverty alleviation. The revenue generated from leasing fees and electrolyte recycling is also expected to have positive impacts on local communities and governments in terms of job creation, poverty alleviation, and public finance.

The overall economic contribution of the leasing model in South Africa is expected to be even greater than the quantified impacts, as some parts of the value chain, such as mining and transportation, were not included in the analysis. Additionally, the use of VRFB technology is expected to increase demand for vanadium, bringing further economic benefits to South Africa.

Environmental and Social Impact Analysis

Vanadium redox flow batteries (VRFBs) are a promising technology for energy storage, offering advantages such as long lifespan, safety, and scalability. However, the environmental and social impacts of the VRFB value chain need to be carefully considered to ensure sustainable development.

In South Africa, the lack of a regulatory framework for recycling VRFBs poses a challenge. The inclusion of VRFBs in the existing extended producer responsibility (EPR) regulation is essential to monitor the VRFB market and ensure proper recycling practices. Additionally, improving primary practices at the mining and processing stages of vanadium-bearing ores can mitigate environmental impacts associated with VRFBs.

The anticipated increase in demand for VRFBs could lead to expanded vanadium mining activities, potentially impacting regional environmental and social sensitivity and ecological resources. Thus, the primary practices at the mining and processing stages of vanadium bearing ores are key to reducing the associated environmental and social impacts.

In addition to the primary practices at the mining and processing stages of vanadium, strict monitoring mechanisms are also necessary to ensure proper treatment and disposal of waste products generated from vanadium mining, such as acidic effluent and calcine tailings. Considering the weight percentage distribution of VRFB components, 85% of the battery component is V-electrolyte, which is likely to be 100% recyclable. The other battery components (metallic, electrical, plastic) can also be easily recycled through mechanical separation, further reducing the environmental footprint in the VRFB value chain.

In terms of social impact, the analysis suggests that the growth of the vanadium battery market in South Africa presents opportunities for social development and economic empowerment.

The VRFB value chain, including recycling, electrolyte movement, and increased mining activity, can create gainful employment opportunities for women and economically disadvantaged communities. Expanding VRFB adoption can contribute to job creation and poverty alleviation.

Additionally, the analysis indicates that accelerating a circular business model for energy storage requires identifying skills-based jobs and upscaling short-term and long-term skills development among local communities. Investing in skills development programs can ensure that the workforce is equipped to meet the demands of the VRFB industry. Another conclusion driven from the analysis is that VRFB energy storage has the potential to benefit micro entrepreneurs and small to medium businesses in communities with weak grids, unreliable energy supply, inadequate infrastructure, and scarce employment opportunities. By providing access to reliable and affordable energy, VRFBs can empower these enterprises and stimulate economic growth in underserved areas.

Another major challenge highlighted in the report is the gender disparity along the VRFBs value chain. From the stakeholder consultations for the report, it was inferred that at present, women are underrepresented in the vanadium mining workforce. Therefore, gender inclusivity is yet to be prioritized in the VRFB value chain as women do not occupy an active position in the VRFB manufacturing process and (supply chain) operations. Addressing inequalities along the line of color, race, gender, and other factors can accelerate employment for local and economically disadvantaged communities in the country.

Roadmap to Scale Up Circular Business Model

Despite being available since the 1980s, the commercial application of VRFBs in the energy storage space is a relatively new concept. Our study identified several key challenges hindering the growth of VRFB technology, including low demand, relatively low consumer confidence, higher cost of energy storage for short durations, fluctuating vanadium prices and the absence of a regulatory framework for Battery Energy Storage Systems (BESS).

To overcome these challenges and scale up VRFB adoption, a roadmap was developed with major themes named Critical Success Factors:

- **Demand creation:** Stimulate demand for VRFB technology through awareness campaigns, education, and targeted incentives.
- **Supply growth:** Encourage the development of a robust VRFB supply chain, including domestic manufacturing and recycling capabilities.
- **Regulatory framework:** Implement a supportive regulatory framework that promotes the adoption of VRFB technology and addresses concerns related to safety, performance, and environmental impact.
- **Environmental and Social (E&S) Development:** Integrate sustainability principles into the VRFB value chain, ensuring responsible mining practices, minimizing environmental footprint, and promoting social equity.

Government intervention will play a crucial role in fostering the growth of the VRFB industry by providing incentives, creating favorable policies, and investing in research and development. South Africa serves as a valuable case study, demonstrating the approach required for governments to effectively support the growth of the VRFB market. By implementing a comprehensive regulatory and policy framework, considering economic and fiscal implications, and addressing social and environmental concerns, governments can pave the way for a thriving VRFB industry.

2 Analysis of the Vanadium Battery Market

2.1 Introduction

Several countries worldwide are prioritizing climate change, as unpredictable climate variations can pose a serious threat to global socioeconomic development and long-term poverty reduction goals. With commitments to reduce greenhouse gas (GHG) emissions and attain net-zero emissions, the world is transitioning from the use of fossil fuels to low -carbon technology measures in the electricity and transportation sectors (which currently account for approximately 40% of global GHG emissions). The application of battery energy storage is, therefore, gaining prominence in these sectors as well. Globally, energy storage has evolved a lot in terms of applicability, including the diverse range of advanced cell chemistries employed, to make efficient and reliable storage applications a reality.

For electricity grids to operate efficiently, supply and demand must always be balanced. The battery storage ecosystem makes a strong pitch to integrate renewable energy (RE) into the grid as it reduces intermittency and increases the flexibility of the overall system.

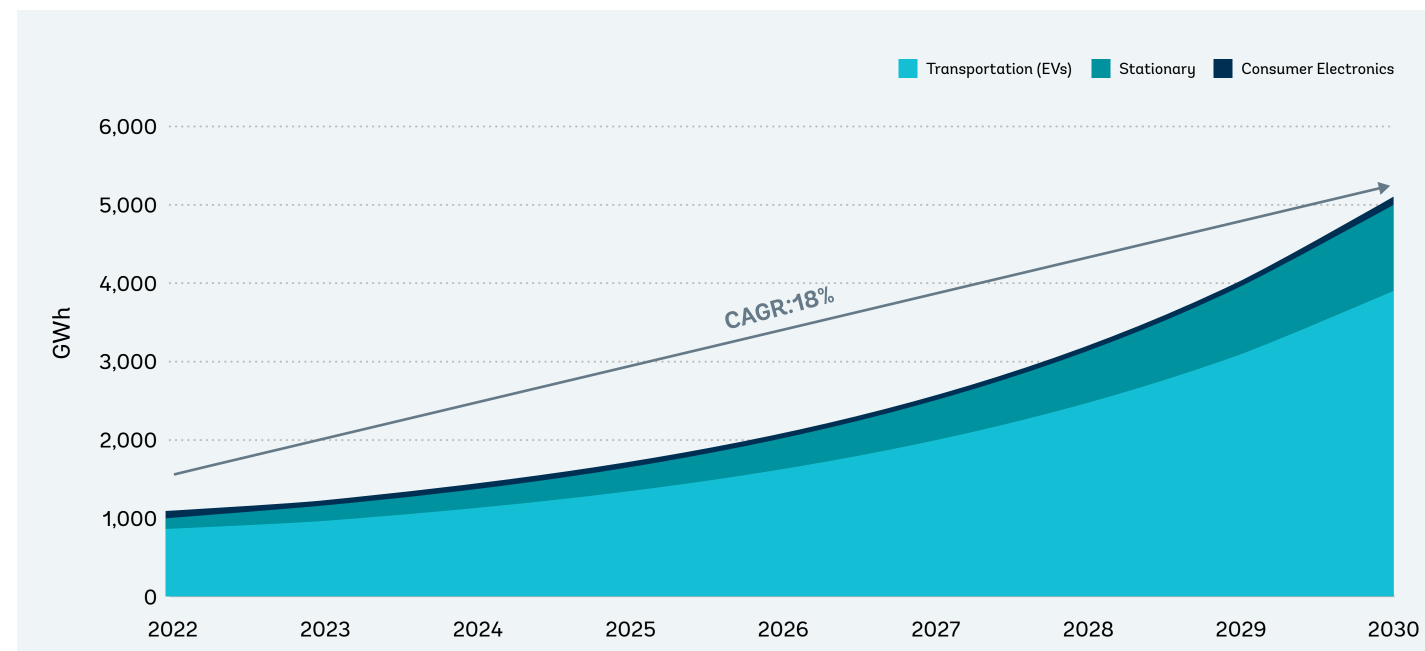
Apart from decarbonizing the transportation and electricity sectors, batteries also contribute directly and indirectly to achieving the United Nations Sustainable Development Goals (SDGs), supporting access to energy, productivity, health care, and livelihoods.

2.2 Global Energy Storage Market

There has been a drastic change in the global market of energy storage systems in the past couple of years, with countries moving toward net-zero carbon transition in electrification and mobility; the investments in and adoption of energy storage technologies have increased significantly.

In 2021, battery demand grew significantly, with lithium-ion batteries (LiB) dominating the market as its demand has grown by 70%, primarily boosted by electric vehicle (EV) sales globally. The global demand for batteries is expected to grow five-fold to reach an annual demand of about 5,100 GWh by 2030[1] from around 933 GWh in 2021. This surge in market deployments throughout the global electric and transportation sector is largely due to the

Figure 2.1: Global Advanced Battery Market in GWh, 2022-30



Source: PwC analysis based on BloombergNEF (BNEF), International Energy Agency (IEA), Interact Analysis 2022, and World Economica Forum (WEF).

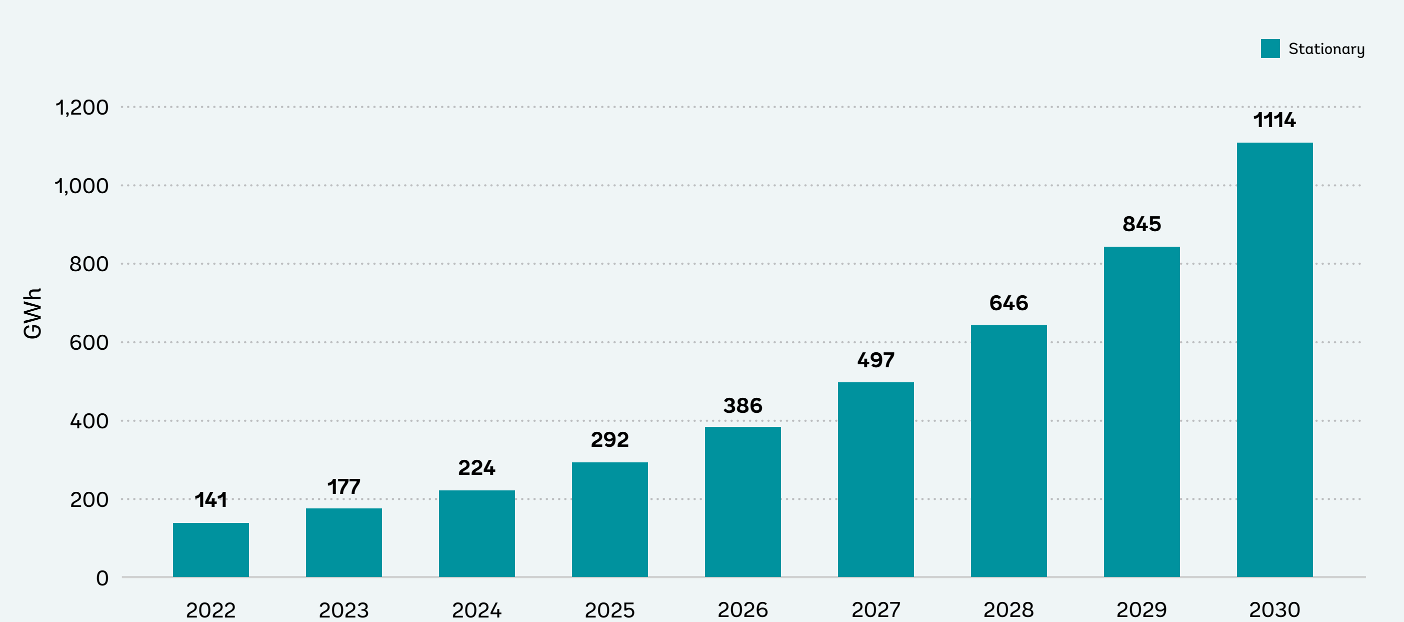
1 Interact Analysis (2022), Lithium-Ion Battery Market Is Moving into Surge Mode https://www.interactanalysis.com/lithium-ion-battery-market-is-moving-into-surge-mode/

integration of electric vehicles, lower battery storage prices, and increased variable renewable energy generation. Figure 2.1 depicts the global demand projection for advanced battery chemistries, such as lithium-ion flow batteries, across multiple applications up to 2030, based on market research and projections.

There are three main potential uses of battery energy storage: consumer electronics, stationary storage, and e-mobility. Globally, e-mobility applications, primarily EVs, account for the majority of the battery demand; however, similar momentum is emerging in stationary energy storage applications. The stationary energy storage system can provide up to 17 different services to stakeholders at all levels of the electricity system,[2] including utilities, grid operators, and other end-use applications. In 2021, the annual demand for stationary applications was about 116 GWh and is projected to reach around 1,114 GWh by 2030.[3] The demand for stationary energy storage is currently led by industrial applications such as forklifts, followed by UPS, telecom applications, and data centers. Figure 2.2 shows the projected demand for battery energy storage across all stationary applications, including grid storage, behind-the-meter applications, railways, and other uses.cations, and data centers. Figure 2.2 shows the projected demand for battery energy storage across all stationary applications, including grid storage, behind-the-meter applications, railways, and other uses.

With the increasing demand for stationary energy storage, the global investments made in this sector are expected to continue at a rapid pace, reaching more than US$ 30 billion by 2030. Furthermore, this huge market for stationary applications is anticipated to have a bigger share of grid-level storage by the end of this decade and is expected to be dominated by lithium-ion batteries, as its demand for such applications is projected to increase from 56 GWh in 2021 to almost 1,028 GWh by 2030. This, in turn, also creates huge market potential for VRFBs in the future as vanadium redox flow batteries have superior performance in the grid and other long-duration stationary storage applications (as discussed in later sections) compared to LiBs.

Figure 2.2: Global Stationary Application Energy Storage Market



Source: PwC analysis based on BloombergNEF (BNEF), International Energy Agency (IEA), Interact Analysis 2022, and World Economica Forum (WEF).

2 Energy Storage World Forum, 2022. About Us. https://energystorageforum.com/energy-storage-technologies/applications-of-energy-storage
3 BNEF (2021), Global Energy Storage Market Set to Hit One Terawatt-Hour by 2030 https://about.bnef.com/blog/globalenergy-storage-market-set-to-hit-one-terawatt-hour-by-2030/

2.3 Business Case for the Adoption of VRFBs

It has become increasingly important for the power industry to have energy storage, and while Li-ion batteries have been used in many places, vanadium flow batteries have a lot to offer in long-term applications and situations that require regular battery cycling. Several different factors should be considered when comparing VRFBs and LiBs. Table 2.1 depicts the advantages of VRFBs over Li-ion batteries in utility-scale storage systems for long-duration use cases.

Table 2.1: Comparative Assessment of Li-ion Batteries and VRFBs

Longer Asset Life:
Vanadium flow batteries discharge at —100% throughout their lifetime whereas lithium-ion batteries decay and loose capacity of time

Flexibility:
In contrast to lithium-ion batteries, VRFBs can operate at a wide temperature range without any adverse effects in its performance

Scalability:
The kWh and kW capacity of VRFBs can be scaled independently, whereas the capacity of lithium-ion batteries cannot be added incrementally

Lower operating cost (LCOS):
VRFBs typically have a much longer lifespan, which means they have lower LCOE in comparison to lithium-ion batteries if used daily at least once

Safety:
While Li-ion batteries have inherent safety risks due to overheating and thermal runaway, VRFBs are non-flammable, non-toxic, and have no explosion risk

Recyclability:
Liquid electrolyte used in VRFBs can be nearly i00% recovered and, with minimal processing steps and cost, reused in another battery application

Source: PwC Analysis

Table 2.2 compares various characteristics of both battery types.[4]

Table 2.2: Comparison of Characteristics of Battery Types

Parameter	Lithium-ion Battery	Vanadium Flow Battery
Energy Density (Wh/L)	200–400	20–70
Specific Energy (Wh/Kg)	100–265	10–30
Discharge Time (hours)	0.02–8	4–12
Lifetime (cycles)	1,000–12 000	20,000–30,000
Efficiency (%)	85–95	70–85

Source: PwC Analysis

There are several cases that favor the adoption of VRFBs as they offer many advantages, including their nearly unlimited energy capacity merely by utilizing larger electrolyte storage tanks and the fact that they can be left completely discharged for long periods without adverse effects. Thus, it is a unique technique for energy storage that has an enormous impact on stabilizing and regulating renewable energy. The major consumer of VRFBs in the short and long term will be stationary applications involving longer -duration grid storage, along with other use cases as mentioned below.

a) Grid-Scale Uses

Although Li-ion batteries have a higher energy density, VRFBs are being targeted for stationary applications involving longer -duration grid storage for the following reasons:

- In grid congested areas, VRFBs can alleviate stress without the same capital investment and environmental disruption required to build out new transmission and distribution lines
- VRFBs while acting as a backup generator can increase grid resiliency without the harmful air pollution effects associated with diesel generators, such as microgrids for remote communities
- In large industrial applications such as manufacturing processes, VRFBs can be used to shift energy-intensive processes to off-peak hours to relieve strain on the grid

Source: PwC Analysis

4 Market Intelligence Reports, Technology Specification Brochures of Battery Players.

Table 2.3: Battery Technology suitable for Grid Use Cases[5]

	Energy Arbitrage	Primary Response	Peaker Replacement	Secondary Response	Distribution & Transmission Deferral
Battery Types	Regional Transmission Operator (RTO)			Utility	
Current Li-ion	Medium Suitabity	Highly Suitabity	Medium Suitabity	Medium Suitabity	Medium Suitabity
Advanced Li-ion	Highly Suitabity	Highly Suitabity	Highly Suitabity	Medium Suitabity	Medium Suitabity
Flow	Medium Suitabity	Medium Suitabity	Highly Suitabity	Highly Suitabity	Highly Suitabity
Zinc	Medium Suitabity	Low Suitabity	Medium Suitabity	Highly Suitabity	Highly Suitabity

Highly Suitabity | Medium Suitabity | Low Suitabity

Source: Rocky Mountain Institute

b) Arbitrage (Ancillary Services)

Depending on the power market, arbitrage might be the best use case for flow battery capacity as flow batteries can provide power within milliseconds, depending on the load, and can be recharged quickly from many different power sources. Particularly during peak seasons, as power costs spike, the capacity available from large-scale flow battery configurations can become economical. By synchronizing flow battery capacity to be available quickly and with durations of six to eight hours or more, while prices per kilowatt are at a peak, significant revenue can be realized. In addition to this, VRFBs are also used to provide ancillary services, such as balancing and frequency response. Table 2.3 compares the suitability of various battery types for different grid use cases.

The primary response includes applications such as frequency regulation and control. The secondary response includes applications such as following reserve, spinning, and non-spinning reserve, and renewables integration. Peaker replacement refers to a system capacity mechanism to meet peak demand.

c) Other Uses

VRFBs can be paired with solar photovoltaic (PV) systems to form standalone charging systems. They can also be added to existing charging infrastructure in urban areas because of their ability to be cycled frequently without experiencing capacity degradation. In fact, two trial projects have already been announced where VRFB energy storage systems will support electric vehicle charging solutions, one in South Korea and the other in Australia.

2.4 Overall Market Potential for VRFBs

VRFB technology is a leading energy storage option as it continues to find a market because of its advantages in providing long-duration energy storage. In addition to the benefits of the technology, synergies across industries are helping drive the development of flow batteries. As of April 2022, the cumulative global deployment of vanadium redox flow batteries is around 289 MWh,66 with China deploying about one third of the total capacity.

5 Rocky Mountain Institute, 2020, Breakthrough Batteries: Powering the Era of Clean Electrification, https://rmi.org/insight/breakthrough-batteries/
6 Vanitec 2022, Global VRFB Installations Database & Map, https://vanitec.org/vanadium/map?q=&country=&manufacturer=&status=Operational

2.4.1 Market forecasts

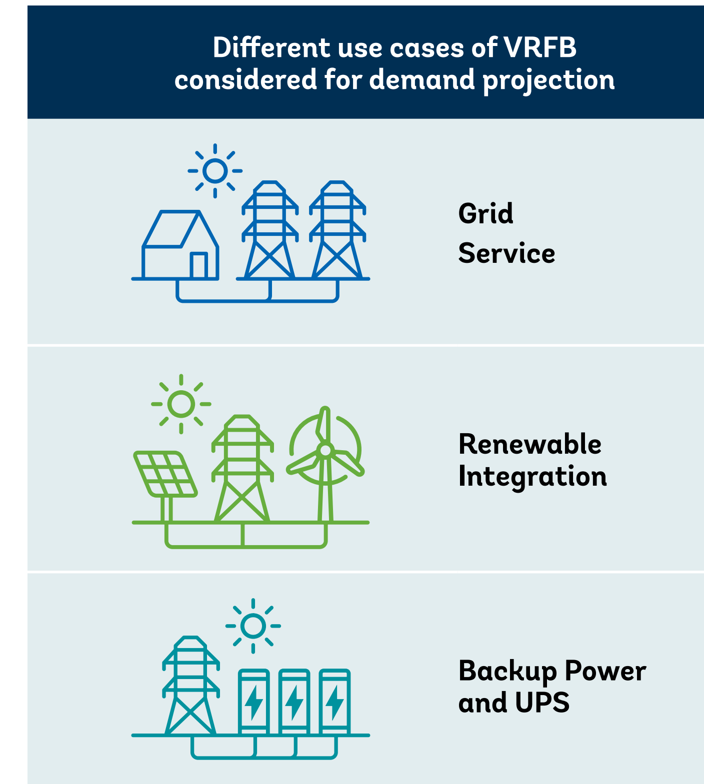
For the market potential assessment exercise, a thorough literature review was conducted that included in-depth secondary research on reports[7] to project the global demand for vanadium redox flow batteries for energy storage.[8]

Figure 2.3: Methodology for Demand Projections

- **Sector Based Research:** Data is based on extensive desk research to identify most relevant secondary information
- **Data Validation** includes review of existing reports, penetration levels, and correlation with our global stationary storage demand projections
- **Analysis and forecast model generation:** Based on data collected, our in-house subject matter experts convert them into critical insights
- Three cases have been considered to estimate market growth, namely **base case, conservative case** and **optimitic case**
- **Annual demand** for vanadium flow batteries for stationary storage applications is determined based on the projections from the above segments

Source: PwC Analysis

A variety of factors and assumptions were considered to understand and accurately assess the market of interest, with the main assumption being that the redox flow battery energy deployment capacity is only suitable for stationary storage applications, including grid use, renewable integration, backup power, and UPS as shown in the following figure.



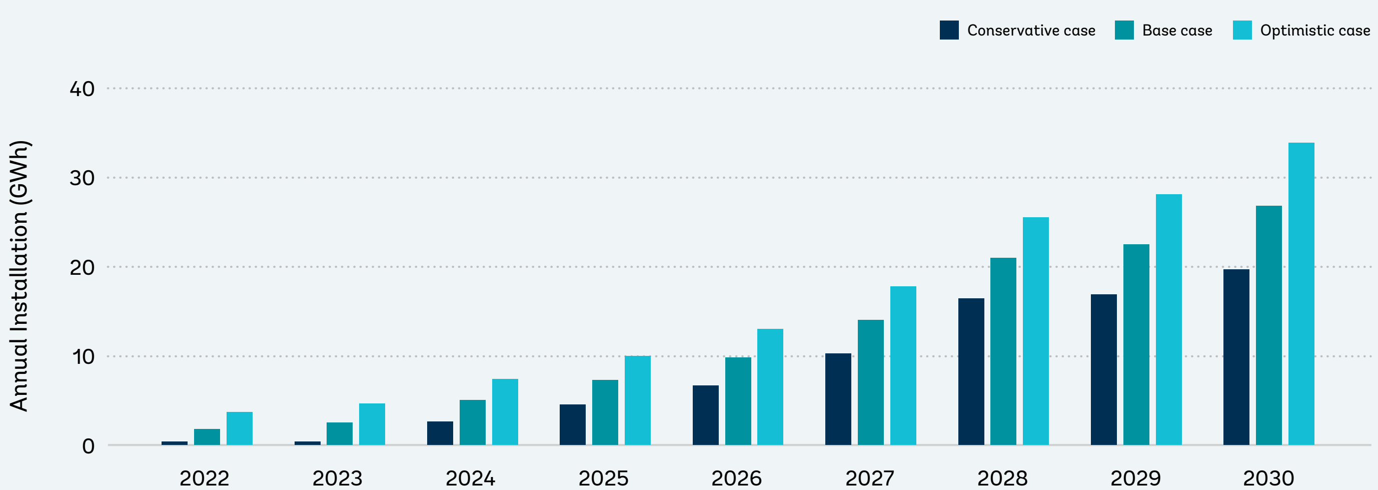
Source: PwC Analysis

Other assumptions and factors included the competitiveness of energy storage against alternatives, the percentage penetration of VRFB technology in the energy storage market, and the overall stationary storage demand in the market. Moreover, while projecting the addressable market, the average system duration of the vanadium flow batteries was assumed to be greater than 4 hours, and thus if shorter duration systems are feasible in the future with further research and development, then the addressable market would be larger.

From an optimistic perspective, the market is forecasted to grow at a higher rate than the base case (to depict an aggressive market, a 2.5% increase in the penetration level of VRFB across the entire period is assumed) and vice-versa for the conservative case. Figure 2.4 demonstrates the projected annual installed VRFB deployment capacity.

7 U.S. Department of Energy 2022, Grid Energy Storage: Supply Chain Deep Dive Assessment, https://www.energy.gov/sites/default/files/2022-02/Energy%20Storage%20Supply%20Chain%20Report%20-%20final.pdf
8 Guidhouse Insights 2022, Vanadium Redox Flow Batteries: Identifying Market Opportunities and Enablers, https://vanitec.org/images/uploads/Guidehouse_Insights-Vanadium_Redox_Flow_Batteries.pdf

Figure 2.4: Global Annual Installed VRFB Deployment Capacity (GWh), 2030



	2022	2023	2024	2025	2026	2027	2028	2029	2030
Conservative case	0.35	0.38	2.63	4.53	6.63	10.23	16.45	16.88	19.70
Base case	1.75	2.50	5.00	7.25	9.80	14.00	21.00	22.50	26.80
Optimistic case	3.68	4.63	7.38	9.98	12.98	17.78	21.55	28.13	33.90

Source: Vanitec and Market Reports and PwC Analysis

Based on the preceding forecast, the cumulative global demand of VRFB by 2030 is around 111 GWh, with annual demand of about 27 GWh, or 2.4% of the total required stationary storage capacity for that year. This presents significant growth, with a CAGR of 41% from 2022 to 2030. The preceding forecast illustrates that the VRFB market is poised for steeper growth in the coming years, especially as demand for long-duration storage capabilities increases.

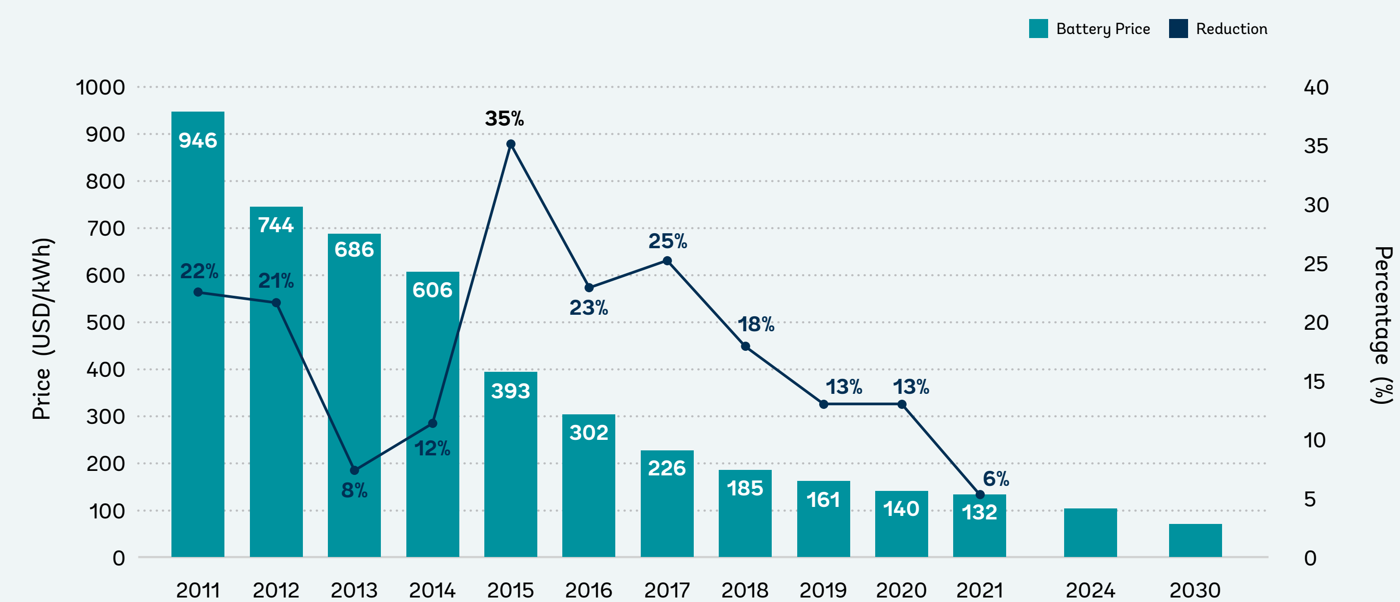
Furthermore, based on several market reports, it is estimated that the Asia -Pacific region will reach around 14.5 GWh of annual VRFB energy capacity by 2031, with China accounting for 60% to 80% of this capacity. BloombergNEF(BNEF) predicts that if all the redox flow batteries were grouped, the annual demand could compete with lithium-ion for up to 69 GWh capacity in 2030.

2.5 Cost Analysis

The commercialization of VRFB battery technology globally has been hampered to a large extent by cost economics, which places it among the costlier options for deployment in stationary storage applications. The current pricing for VRFB -based solutions (>US$300/kWh) is much higher than its counterpart Li-ion - based technology (<US$200/kWh), which has witnessed a drastic fall over the past decade, from US$1,200/kWh in 2010 to US$132/kWh in 2021.[9] Another prominent Li-ion-based chemistry option, Lithium Iron Phosphate has been widely deployed in mature markets such as China, is further currently priced 30% lower than Li- Nickel Manganese Cobalt technology. The fall in lithium-ion battery chemistry can be largely attributed to the economies of scale, with increasing deployment in other critical areas, such as the EV segment. Additionally, targeted R&D efforts in battery cell chemistries to reduce the content of expensive raw materials, such as nickel and cobalt (NMC-111 to NMC-811), have significantly reduced lithium-ion battery prices.

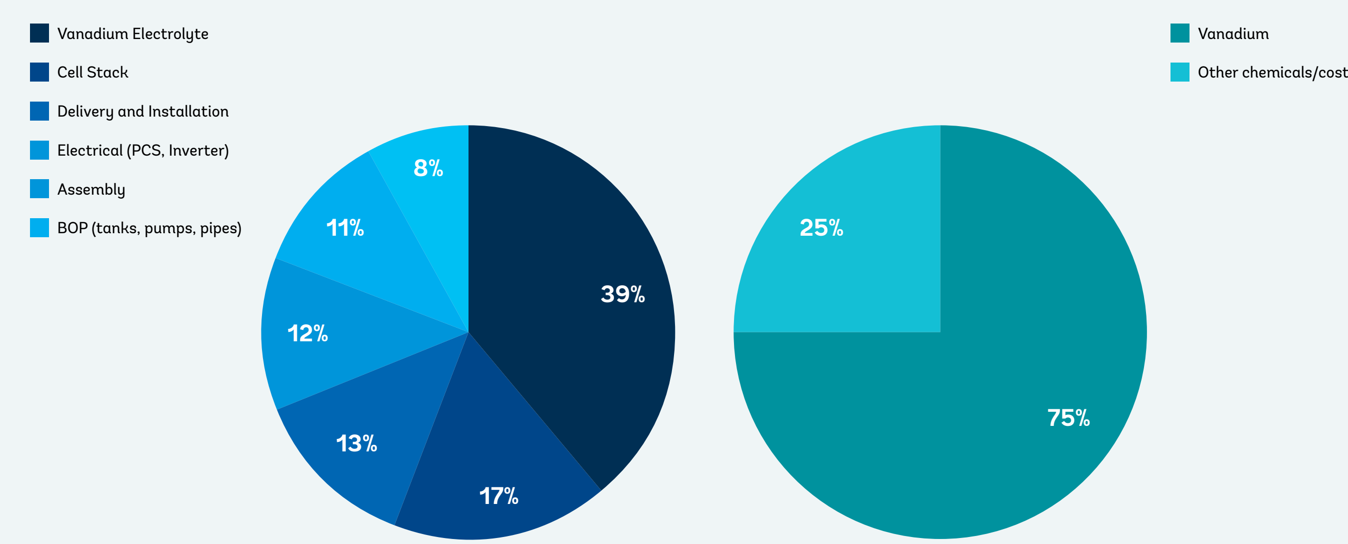
9 BNEF, 2021, Annual Battery Price Survey, https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite/

Figure 2.5: Lithium-ion Battery Cost Trajectory



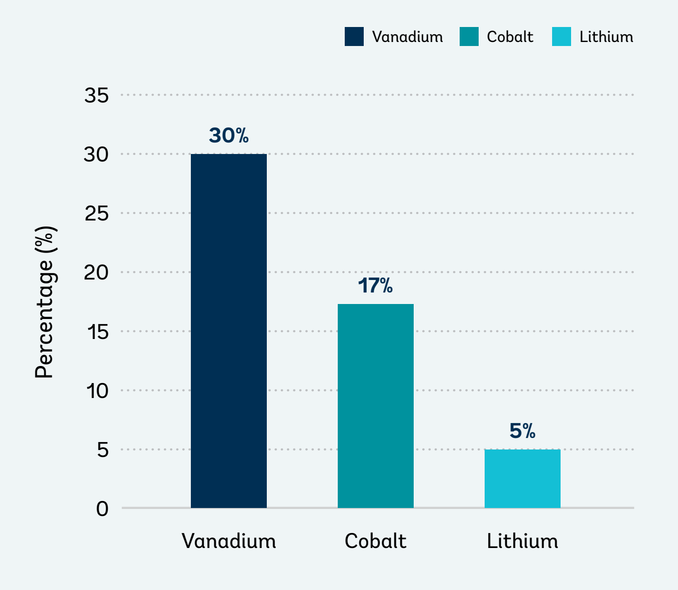
Source: BloombergNEF

Figure 2.6: VRFB Cost Breakdown



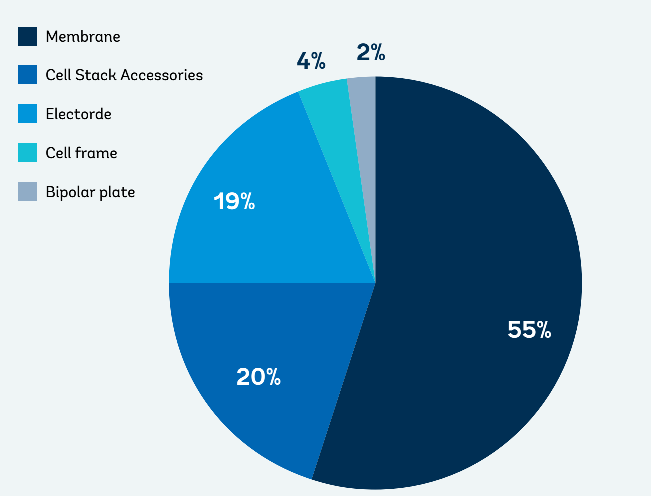
Source: Bushveld Minerals

Figure 2.7: Mineral Cost Contribution, by battery type (%)



Source: Bushveld Minerals

Figure 2.8: Material Cost Distribution, by component for stack (%)



Source: California Energy Commission

However, the recent surge in prices of critical components of Li-ion cell chemistry, such as nickel and cobalt, due to rising geopolitical tensions may soon have a strong bearing on the overall cost economics. The economic sanctions on Russia (primary supplier of Class 1 nickel used in Li-ion chemistry) have resulted in supply chain pressures, affecting the global prices of nickel. This represents an enticing opportunity for VRFB to gain market share.

For VRFB technology to make a strong business case commercially, continued investment in R&D along with capacity expansion across the supply chain are needed over the next decade.

A careful analysis of the VRFB material cost distribution in a typical battery assembly point to "electrolyte" and "stack" as the key contributors to overall system costs. The detailed breakdown is presented in Figure 2.6.

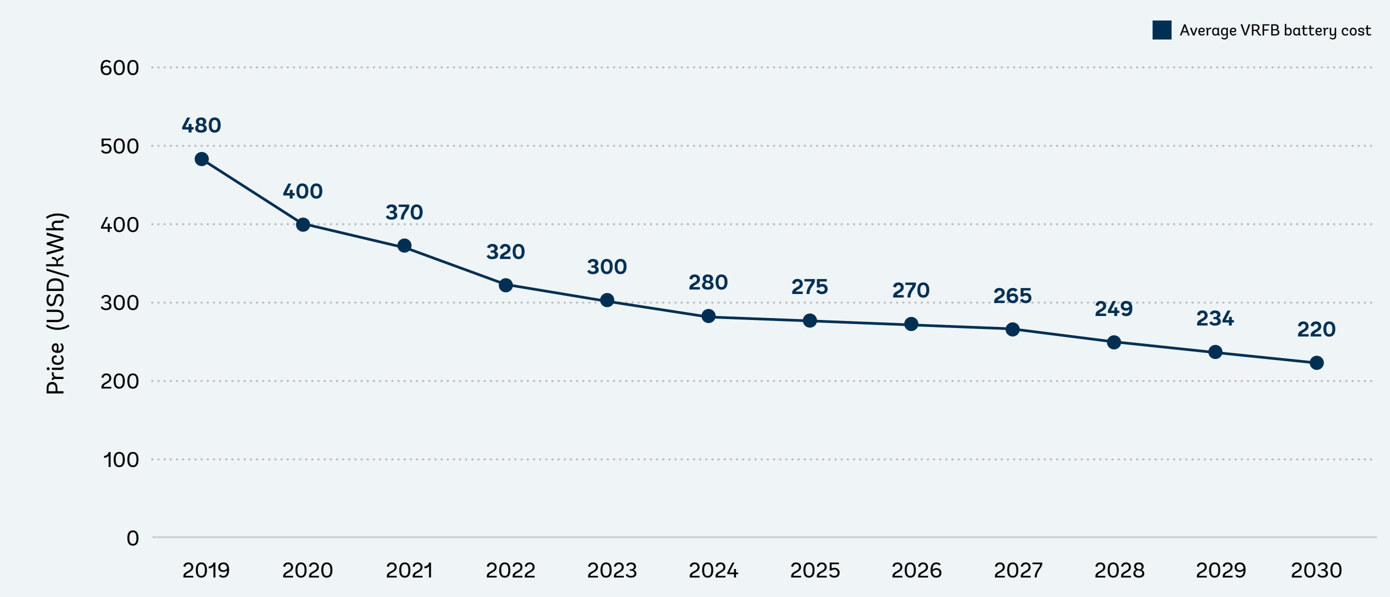
Vanadium in the form of electrolyte (V_2O_5) contributes approximately 40%[10] of the cost of the total VRFB battery system for a typical four-hour energy storage requirement. This cost contribution for the electrolyte can reach as high as 80%, as the relative contribution of vanadium increases for a larger VRFB system, such as with a 10-hour energy storage requirement.

However, it is important to note that 100% of the vanadium is reusable at the end of the lifespan of the battery. Since vanadium's contribution to VRFB is greater than with other battery technologies, strategies to counter the high prices of vanadium will be critical for the sustained commercial success of VRFBs.

Like any other commodity, the price of vanadium is tied to demand and supply. Over the past eight years, the price of vanadium metal has fluctuated considerably, going as low as approximately US$15/kgV in September 2015 to as high as US$135/kgV in September 2018, and finally tapering to around US$40/kgV in Sep 2021. The demand for vanadium is propelled not only by the increasing share of VRFB deployments, but also by the rising demand in the steel industry—which accounted for over 90% of the consumption in 2019, whereas less than 10% was reported for electrolyte manufacturing. As per Roskill forecasts,[11] the demand from the steel market is expected to grow by 2.7%, whereas from VRFB, it is expected to grow at a CAGR of 56.7% by 2030.

10 Bushveld Energy, 2021, Energy Storage Manufacturing- A South African Approach, PowerPoint Presentation (bushveldenergy.com)
11 Bushveld-Minerals, 2021, Half Year Results, https://www.bushveldminerals.com/wp-content/uploads/2021/09/Bushveld-Minerals-_Half-Year-2021-Results-Final_27.09.2021.pdf

Figure 2.9: Average Cost of VRFBs (US$/ kWh)



Source: PwC analysis based on Bushveld and US DOE reports

The other major cost contributor to the upfront capital cost in the VRFB battery system is the cell stack. Along with the electrolyte, its power output determines the efficiency and cost of VRFB -based storage. The cell stack comprises many sub-components, the material cost distribution of which is indicated in Figure 2.8.[12]

A key decision point when evaluating VRFB costing is the Levelized Cost of Electricity (LCOE) versus capital expenditure. A VRFB battery system is typically effective over a long duration, offering minimal degradation and easy scalability features, although the upfront capital requirement is significantly higher compared to other battery chemistries. Hence, LCOE is a better metric for justifying the commercial adoption of VRFB.

In terms of cost projections for future for VRFB technology, the average cost per kilowatt-hour is expected to drop by 50% from 2020 to 2030.[13] The average cost primarily represents the cost of the storage block, which has two components, namely power and energy. The power cost is associated with stack, pumps, and piping, while energy costs are associated with electrolyte and tank costs. For a high E/P ratio, since electrolyte costs contribute a significant portion, the power density would be adjusted downward to improve efficiency and, thus, reduce electrolyte cost. This results in a lower cost per kilowatt-hour for the energy component (electrolyte) and a higher cost per kilowatt-hour for the power component (stacks).

However, the average cost is still not comparable to Li-ion based chemistries, which is expected to reach US$58/kWh[14] by 2030. To a large extent, the cost for VRFB will depend on the demand-supply dynamics of vanadium and its pricing. Some of the key factors responsible for VRFB cost reduction have been analyzed below:[15]

- **Cost reduction in key components:** Cell stack and electrolyte are the chief contributors to the high price of a VRFB system; hence, strategies to effectively reduce the pricing of these components are expected to play a critical role in reducing the overall upfront capital expenditure.

12 California Energy Commission, 2021, Life Cycle Assessment of Environmental and Human Health Impacts of Flow Battery Energy Storage Production and Use, https://www.energy.ca.gov/sites/default/files/2021-12/CEC-500-2021-051.pdf ; Cell stack accessories consist of current collector, gaskets, end plates, and stack shell
13 Bushveld Presentation-Grid Energy Storage Technology Cost and Performance (Navigant Research) and Department of Energy (DoE), USA- https://www.pnnl.gov/sites/default/files/media/file/RedoxFlow_Methodology.pdf
14 BNEF, 2020, Annual Battery Price Survey, https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/
15 Department of Energy, USA, 2022 Grid Energy Storage Technology Cost and Performance Assessment

- Cost reduction in electrolyte: The cost of electrolyte accounts for a significant portion of the overall cost (30-50%) of VRFB batteries and is largely driven by the pricing of vanadium pentoxide. By reducing the cost of vanadium supplied through low-cost processing and bulk procurement, the overall cost can be reduced. Furthermore, the cost of electrolyte manufacturing is expected to fall on account of a reduction in the conversion cost through the development of cheaper facilities, higher production volumes, and a new, innovative process design. R&D efforts focused on developing cheaper alternatives to materials/reagents and improvements in power density are also expected to contribute significantly to cost reduction. Recent efforts to use low-metallurgical -grade vanadium pentoxide, coupled with operation in the 10%-90% State of Charge (SoC) range, enables a reduction in the cost of electrolyte from US$180/kWh to US$105/kWh (approximately 40% reduction) for mixed -acid electrolyte.
- Cost reduction in stack: The stack is composed of many subcomponents (membrane, electrode, etc.), which offer significant cost reduction potential through R&D by using cheaper materials and improved design processes. Cost reduction in electrode and membrane costs are expected as demand increases. Research[16] into the development of cost-effective semipermeable membrane and cell design is expected to result in lower transport losses. It is anticipated that up to 18% of the total stack cost can be reduced by using less expensive and fewer passive components. Newer designs employing thinner active material and microporous separators are further expected to support cost reduction.

- **Improved efficiency in processes:** Automation of processes is a key driver in the cost reduction trajectory for VRFBs. Improvement in performance is expected to increase the power density, allowing for the use of fewer stacks to provide the same power, reducing the cost. Using automatic welding or gluing of stacks rather than a manual process is also expected to reduce the cost. In addition, an increase in the overall production volumes of key components (such as stack) will also help drive down costs.

Along with automation, it is expected that players will opt for vertical integration where vanadium supply, electrolyte, and other component manufacturing are all under the same corporate structure to build manufacturing and logistical efficiencies. For example, VRB Energy manufactures stacks in China. It leverages vanadium resources in central China, with a 100 MW, 500 MWh system using 2 MW, 12 MWh systems as a repeat unit planned for construction in the Hubei Central District as part of a Giga Technology requirement from the local government.

- **Economies of scale:** As mentioned earlier, the limited number of deployments, (currently less than 2% deployment in the battery market) remains one of the key barriers for VRFB implementation relative to Li-ion chemistries. However, as demand for long-duration storage capability grows, deployment of VRFBs is expected to increase which would help VRFBs achieve economies of scale and become more cost effective.

- **Other key factors**
  - State of Charge (SoC): Operation at an extreme SoC and temperature can lead to degradation of electrolyte. Recent R&D efforts aimed at restricting the SOC range to 20%–75% for conventional sulfuric-acid electrolyte and to 10%–90% for mixed-acid electrolyte by adding additional electrolyte have also yielded efforts. An additional benefit of operating in such a narrow range is that the maximum span for voltage during a full charge-discharge cycle is limited to 30%, avoiding the need for a DC-DC converter and further reducing overall costs.
  - Improvement in power density: Improvements in power density owing to R&D generally occur within a few years of technology penetration. The same has been the case with popular Li-ion chemistries—NMC, Lithium Nickel Cobalt Aluminium oxides, where a significant increase of as high as 100% has been achieved. Hence, improvements in charge density over time for VRFB are expected to further support commercialization.

16 Research Paper (Science Direct), 2018, Passive Components limit the cost reduction of conventionally designed vanadium redox flow batteries.

2.6 Risk and Opportunity Assessment

As with any advanced battery technology solution in its inception phase, the acceptance of VRFB as a techno-commercially viable alternative to some of the other leading cell chemistries requires an in-depth risk profiling exercise to ascertain the major risks and associated countermeasures. These risks can be broadly grouped into five categories.

Market-Related Risks

Supply Chain Risks

Cost Economic and Pricing Risks

Financial Risks

Miscellaneous Risks

- **Market-Related Risks**

  The penetration of VRFB technology to a large extent depends on the stationary storage market dynamics, wherein Li-ion battery has currently been deemed a more feasible option, specifically for short-duration, grid-scale applications (less than four hours) owing to favorable cost economics. Additionally, the lower power and energy density of VRFB technology implies that such systems are physically larger and heavier than alternative battery chemistries (LFP and Li-NMC) of comparable specifications, significantly impacting its deployment in EV and consumer electronics-based applications.

  Thus, the limited applicability of a VRFB solution restricted to stationary storage segments and stiff competition from Li-ion-based chemistries creates concerns related to VRFB offtake and future market share. This situation is expected to improve with growing economies of scale and technology maturity as deployment increases.

- **Cost Economics and Pricing Risks**

  One of the most pressing issues in large-scale VRFB adoption is the cost attribute that makes it commercially less attractive to potential investors than alternatives. As per the capital material distribution for a typical VRFB system, vanadium alone can contribute over 30% of the system cost, depending on the amount of electrolyte used, more than any single mineral in other comparable battery technologies. Hence the battery cost will be impacted by the pricing of vanadium, which has historically fluctuated significantly in response to changes in global demand supply.

  In addition, misconceptions about costs and comparisons based purely on capital expenditure rather than the cost of energy are another major information gap affecting market perception. Over the long term, VRFB systems can be more cost-effective, owing to the low degradation and easy recyclability of the electrolyte.

- **Financing Risks**

  The availability of low-cost financing may be an issue for smaller vendors willing to enter the VRFB supply chain. Banks and financial institutions (FIs) may be reluctant to provide loans for a new technology because of a lack of technical expertise, standard evaluation templates, and deployments in the market. The lack of assured offtake or a guaranteed market may further aggravate the issue of financing, as evidenced by bankruptcies among prominent flow battery players, including Imergy, EnerVault, and EnStorage.

  In addition, many VRFB players may be reluctant to invest in the early stages of technology adoption and may enter the market at a later stage with the competitive edge of being an "informed investor," learning from past experiences and mistakes.

- **Supply Chain Risks**

  Although there are several established suppliers for each part of the VRFB value chain, it is still a new ecosystem and may not be as resilient as Li-ion battery supply chains in the face of technology disruptions. There are still industry apprehensions regarding the bankability and financial strength of most VRFB vendors operating in the segment. In terms of technical expertise, there is a limited number of players with the requisite infrastructure and processing facilities to produce vanadium that complies with the specifications to be used in electrolyte manufacturing for VRFBs. Moreover, China has a significant influence on the global vanadium supply chain, thus leading to a strong dependency on a single country for future raw material sourcing.

The availability of vanadium for VRFB manufacturing is also subject to its competitive uses in other sectors, such as the steel industry; hence, challenges related to supply may emerge, owing to increased demand for steel.

- **Miscellaneous Risks**

Apart from the risks flagged in the preceding subsections, there are additional risks, which may not be prominent currently, but may require future intervention efforts.

- Policy and Regulatory Risk: At present, there are no significant policy and regulatory impediments to VRFB market growth as different countries have not developed a specific policy for energy storage involving VRFB components. However, the lack of a concrete policy roadmap with targets affects market sentiment as demand creation itself is subject to the vagaries of policy and regulatory decisions. In addition, the standards and technical specifications for VRFB deployments must be developed to prevent substandard and uncertified products from being circulated in the market.
- Economies of Scale: Although VRFBs are more economical over the project lifecycle, reaching economies of scale globally will be critical for further lowering upfront capital investment and making this technology more conducive to investors at the outset.
- Health, Environment, and Safety Risks: Recent research conducted by the California Energy Commission indicates that among flow batteries, production of VRFBs had the greatest potential to exacerbate global warming, ozone depletion, particulate matter, acidification, and cumulative energy demand. In addition, for air emissions in the production phase, the VRFB exhibits the highest impact on disability-adjusted life years per kilowatt-hour of battery capacity through global warming, ozone depletion, and particulate matter emissions largely because of the production of the vanadium pentoxide electrolyte.

Figure 2.10: Severity Assessment of Risks associated with VRFBs

Risk Assessment	Severity				
	1	2	3	4	5
Market-Related Risks		■			
Supply Chain Risks	■				
Cost Economic and Pricing Risks			■		
Financial Risks		■			
Miscellaneous Risks					■

Source: PwC Analysis

Note: 1 indicates most severe, while 5 indicates least severe

2.7 Opportunity Assessment

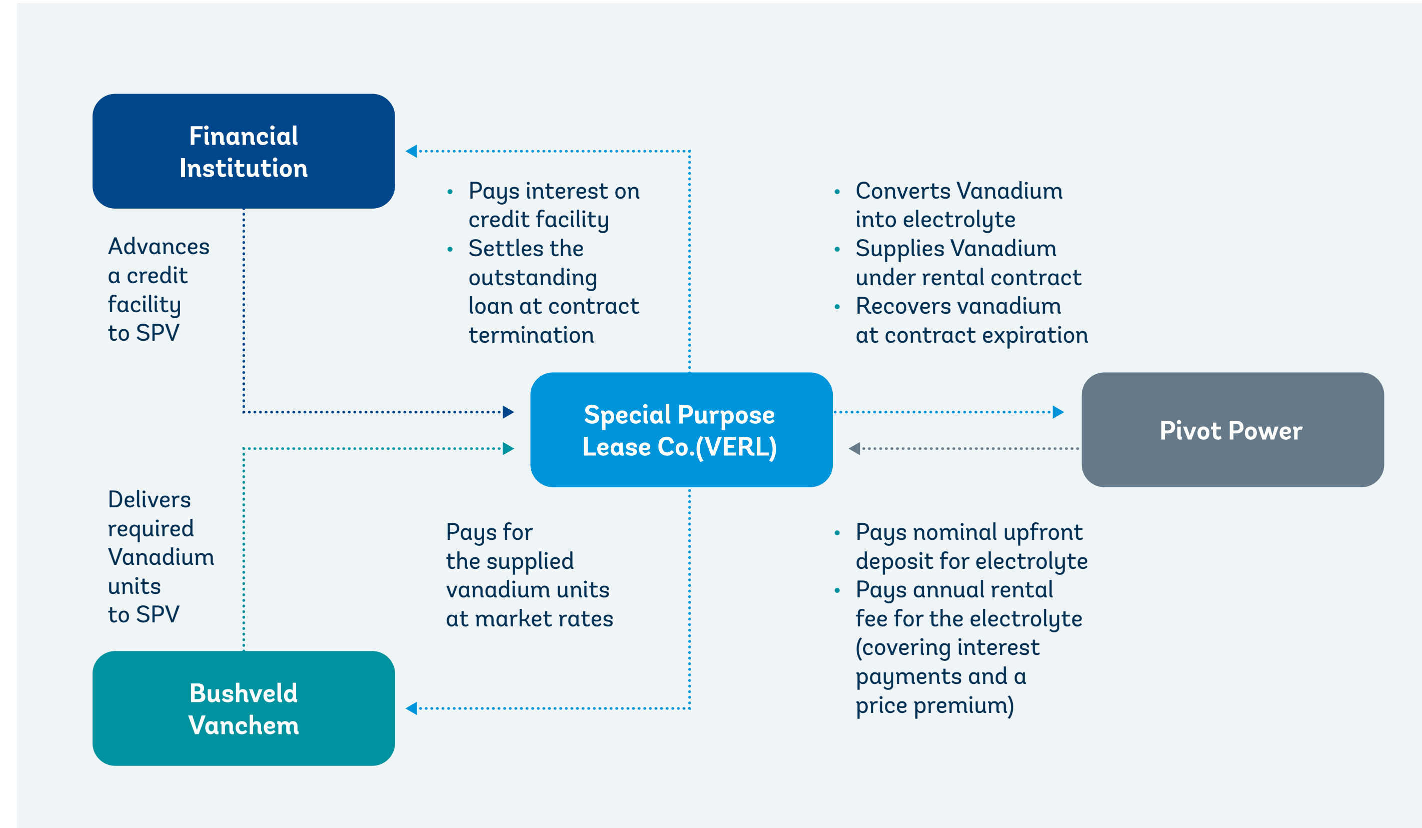
The VRFB market provides a plethora of opportunities across the entire value chain for diverse stakeholders to participate and develop an enabling ecosystem for further growth and development. These opportunities can be leveraged through increased collaboration and R&D efforts, technology partnerships, innovative financing measures, scaling up domestic manufacturing capacities , business model development, and GDP and employment generation.

2.7.1 Domestic value capture

Localization of the supply chain in terms of value capture presents a lucrative opportunity for domestic players to reduce reliance on imports and undertake innovation and R&D to develop cost-effective, in-house solutions. The presence of a vertically integrated value chain provides a significant incentive for exports, allowing local players to provide a complete range of VRFB solutions. A robust domestic supply chain creates manufacturing and logistical efficiencies, bringing down overall transportation costs.

The indigenization of the value chain further unlocks opportunities for increased collaboration in the sector. Local players must aim to form joint ventures (JVs) or partnerships with international players to get access to patented technology and critical raw materials to establish a local VRFB supply chain. Knowledge dissemination and awareness-building activities also need to be undertaken

Figure 2.11: Electrolyte Rental Model between VERL and Pivot Power, UK



Source: Bushveld Minerals

by technology experts to make utilities and other customers understand potential end use cases for VRFB in stationary applications, emphasizing the overall value proposition for greater deployments. It is essential to undertake capacity -building activities to differentiate between use cases for Li-ion and VRFB technology benefits, including cost comparisons on the LCOE basis and not only on upfront capital costs.

2.7.2 Innovative business model for mineral financing

The capability of vanadium-based electrolytes to be redeployed completely at the end of battery life unlocks opportunities for market players to develop innovative business models to reduce the upfront costs of the battery, including levelized costs for VRFB customers. In this context, electrolyte leasing or renting models are gaining popularity by creating a win-win proposition for both consumers and suppliers. Under such a business model, vendors are offering solutions to reduce the risk to customers by shifting a portion of their upfront investment in favor of a manageable annual fee, reducing the cost of ownership and allowing the vendor to recycle the electrolyte for future projects. Figure 2.11 [17] shows the electrolyte rental design model between VERL and Pivot Power, UK.

The high upfront capital cost of VRFBs versus Li-ion batteries further illustrates the need for adoption of such electrolyte -based models, which are expected to gain popularity over the next decade. In addition, the adoption of such a business model will enable utilizing the circularity of vanadium and ensuring that the chemistry in the battery is recycled.

17 Bushveld Minerals, 2021, Corporate Presentation http://www.bushveldminerals.com/wp-content/uploads/2021/03/Bushveld-Minerals-February-Corporate-Presentation.pdf

2.8 Case Study: South Africa

The global analysis reveals considerable market potential for VRFB technology, including a strong value proposition for adoption in stationary storage. The same is the case in South Africa, where VRFB technology is expected to play a dominant role given the overall market demand, broad availability of vanadium, the existence of innovative business models (such as players engaging in electrolyte leasing), and the overall business environment.

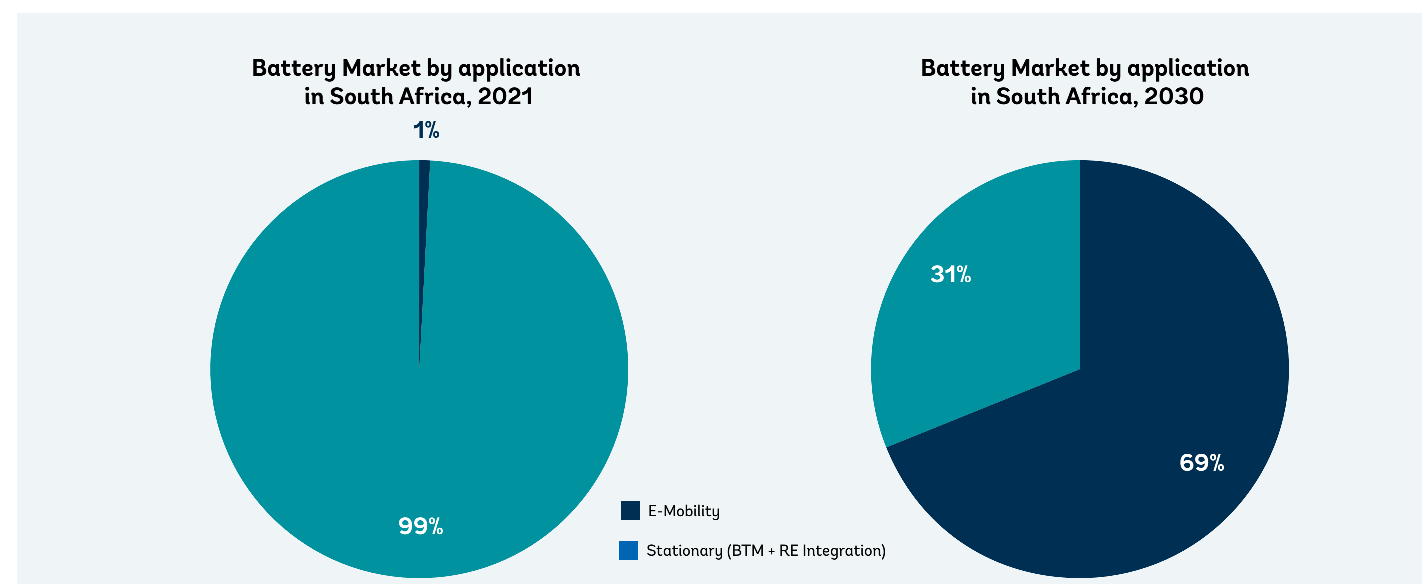
2.8.1 Energy storage market in South Africa

The battery storage market in South Africa comprises mainly stationary, storage-based applications covering behind-the-meter (BTM) use cases, such as UPS, telecom, rooftop solar, solar home lighting systems, and microgrids. It is expected that the BTM market,[18] which is currently dominated by lead-acid batteries in South Africa, will provide opportunities for advanced battery chemistries as lithium-ion batteries are already being adopted in telecom towers and solar home lighting systems. Figure 2.12 depicts the battery demand split in South Africa in 2021 and 2030.[19]

The demand for large-scale grid energy storage in South Africa is evolving rapidly and is likely to go beyond the 2 GW grid-scale battery storage target mentioned in the Integrated Resource Plan (IRP). In terms of other applications, such as e-mobility, South Africa has not yet developed an EV policy aimed at accelerating the uptake of electric transportation. However, falling battery prices and rapidly improving economic conditions in this market will drive demand post-2025, with EVs potentially representing the biggest opportunity for the country's battery market, particularly for advanced battery technologies such as NMC and NCA, among others.

Figure 2.13 shows the current and the projected technology split in the battery market in South Africa. Total battery demand is expected to increase at a CAGR of 24% from 2022 to reach an annual demand of around 9.58 GWh in 2030. In terms of technology, lead-acid chemistry drives the market currently, given that the penetration of lithium-ion chemistry in the BTM segment was less than 10% in 2021. However, lithium-ion penetration is expected to increase up to 60% by 2030 in the BTM segment. Additionally, the e-mobility segment is expected to make up nearly 70% of lithium-ion battery demand in South Africa.

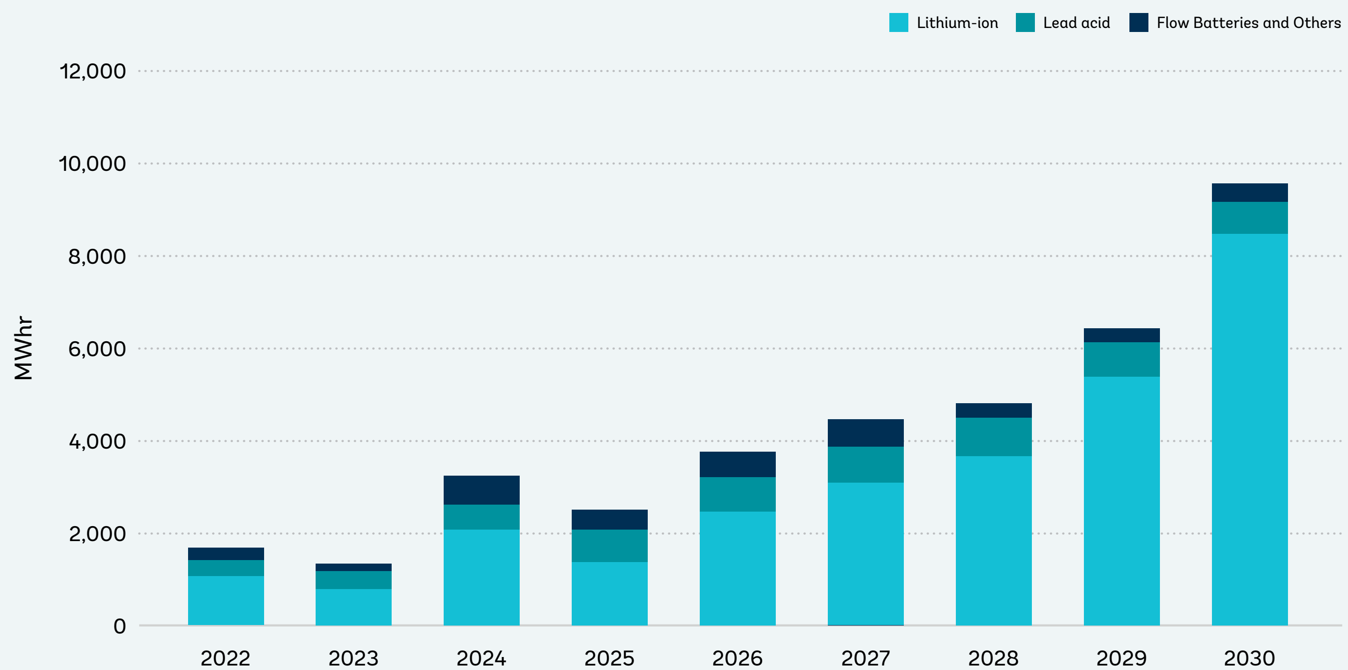
Figure 2.12: Battery Market in South Africa, 2021 and 2030



Source: South Africa & Southern Africa Battery Market & Value Chain Assessment Report, World Bank.

18 BTM segment includes the following applications – Embedded generation, Telecom, UPS, Inverter backup, Rural electrification, Diesel displacement optimization.
19 World Bank Report 2022, South Africa & Southern Africa Battery Market & Value Chain Assessment Report.

Figure 2.13: Total Battery Technology Split, South Africa, 2022-2030



Source: South Africa & Southern Africa Battery Market & Value Chain Assessment Report, World Bank (2022).

2.8.2 Competitiveness in the production of VRFBs over Li-Ion Batteries in South Africa

The following factors are taken into consideration when assessing South Africa's competitiveness in the production of Li-ion batteries:

- **Raw material availability:** There are certain obstacles to the wide -scale adoption of lithium-ion technology in South Africa based on the mineral requirements of the various chemistries of lithium-ion cells and the processing technologies available. Key lithium-ion battery minerals such as nickel and cobalt are produced as a by-product of Platinum Group Metals (PGMs) mining and, hence, its supply depends on the PGM market. Moreover, because of the lack of reserves, refining, and precursor processing capabilities, lithium ranks low among the battery materials available in South Africa. Because of these inherent gaps, lithium-ion cells are largely imported, which makes it difficult to get them at competitive pricing and quantities. But in terms of the availability of raw materials for VRFBs, South Africa has one of the world's largest vanadium reserves (approximately 15%). In addition, the country has high potential for localization and developing an in-house, vertically integrated VRFB value chain.
- **Demand:** The demand for large-scale grid energy storage in South Africa is growing rapidly to support the grid and facilitate the addition of 26 GW of renewable energy by 2030. This creates a sizable market for advanced battery chemistries such as VRFBs. Additionally, the frequent power outages in the country have created a significant demand for distributed power generation systems. This rapid development of the grid-tied energy storage market is leading to an increased need for longer-duration energy storage (greater than four hours), which fits the VRFB profile. A strong economic climate already exists around utility storage, as evidenced by the fact that over 1,400 MW of utility-scale storage was contracted in South Africa alone in 2021 and will most certainly be deployed during 2022.

- **Business environment:** A constrained electricity supply and rapidly rising electricity prices in South Africa, coupled with a lack of well-developed power infrastructure across regional countries within southern Africa, are hindering the expansion of the lithium-ion battery industry in the country. Furthermore, the local lithium-ion battery manufacturing industry is quite limited in terms of both scope and scale, as a large proportion of the market is served by imports. In addition, there are hardly any supply chain or market players operating in the region for the development of Li-ion technology, as compared to VRFB, where significant progress and activities related to mining, processing, refining, and recycling are being undertaken by players in South Africa.
- **Government policies:** From a policy standpoint, the lifting of the license threshold that permits grid integration of renewable plants up to 100 MW is expected to have a substantial impact on the penetration of storage in distributed generation. Additionally, stationary storage policies (such as Rural Electricity Policy) and targets set by the government are aimed at increasing distributed renewable energy generation in the country. However, there is no such explicit goal or objective concerning EVs, and the fact that EVs account for the vast majority of lithium-ion battery use further restricts their market penetration. The lack of government support and incentives to scale-up the battery industry is one of the main factors affecting the production of LiB in South Africa.
- **Infrastructure or manufacturing capabilities:** As mentioned, lithium-ion battery technology currently ranks low in terms of overall techno -commercial viability for adoption because of the lack of refining and precursor process and mining capabilities. Vanadium ranks highly because of South Africa's emerging status relative to established precursor producers. South Africa is already well placed to maximize the economic value of the vanadium with state-of-the-art smelting facilities, processing, and manufacturing units based on homegrown technology. In terms of battery assembly and supply, Bushveld Energy is already emerging as a vertically integrated player covering the entire battery value chain in South Africa.
- **Skilled workforce/expertise:** Because of competition from other industries where wages are high and unaffordable for battery manufacturers, finding experienced professionals, particularly firmware and software engineers, is one of the major challenges cited by South African lithium-ion manufacturers. That there is little to no prior experience or expertise in commercial-scale LiB cell production is another barrier to local battery production. The certification of local goods and battery market potential is further hampered by a lack of local battery pack testing, certification, and R&D facilities and constrained workforce allocation for the refining of key battery minerals and material production. Moreover, the lack of processing plants with the technical expertise of NMC cathode materials and proper R&D funding for the refining of key battery minerals and cathode material in South Africa makes it difficult for the current battery manufacturers to access the competitive financing needed to scale production and exports.
- **Miscellaneous:** Although several techniques have been developed for the recycling of LiB, there is currently no business case for constructing a commercially viable recycling facility in South Africa; hence, LiB recycling is still in its infancy as an industrial process. However, as large-scale LiB applications in EVs and stationary storage systems rapidly expand, this value chain stage will become crucial for both commercial and environmental reasons.

Figure 2.14 demonstrates how leveraging regional strengths and a strong domestic value chain can make VRFB technology a game-changer for the stationary storage market in South Africa.

Figure 2.14: Business Case for the Adoption of VRFBs in South Africa

Source: PwC analysis based on market reports

2.8.3 VRFB market potential in South Africa

Based on the analysis of multiple market studies and considering a similar rise in the penetration of VRFB in the stationary storage market as observed in the global scenario, we estimate that by 2030, the annual demand for VRFBs in South Africa will be around 270 MWh, from a present deployment of around 0.67 MWh.[20]

- **Key Opportunities in South Africa**

  There are several enticing opportunities in the VRFB space, that South Africa can explore to maximize benefits.

  - Localization: With dedicated efforts to indigenize mining operations, metal processing, electrolyte manufacturing, and battery assembly, a localization content of 80%-90%[21] can easily be targeted in South Africa. This will further help improve the commercial viability of VRFB in the country.
  - Production revenue potential: A recent study conducted to assess the South African battery market value chain revealed that the expected production revenue representing upstream, midstream, and downstream opportunities across the value chain for VRFB up to 2030 is estimated at R 6.47 billion.

Table 2.4: Opportunities across the VRFB Value Chain[22]

Opportunity	Estimated Market Growth (2030)	Production Revenue pa for 2030 potential (2021 prices, US$1=R13.5)
Upstream —Mining of Vanadium ore (Pentoxide)	18,000 metric tons	R 4.47 billion
Midstream—Manufacturing of Vanadium Electrolyte	16 ML	R 1.23 billion
Downstream—VRFB Manufacturing and Assembly Activities	270 MWh	R 0.77 billion
Total		R 6.470 billion

Source: Pwc analysis based on CES Flagship Report - South Africa and Southern Africa Battery Market and Value Chain Assessment Report

- GDP and employment: Vanadium electrolyte and VRFB battery manufacturing for stationary applications are expected to be key contributors to employment and GDP in the battery value chain. Table 2.5 indicates the expected job growth and direct GDP contribution up to FY 2030.

Table 2.5: Impact on GDP and Employment

Opportunity	Estimated production volume pa at peak by FY 2030	Production revenue pa (Rm)	Direct GDP (Rm)	Direct labor (FTE)	Indirect labor (FTE)	Total labour (FTE)
Manufacturing activities (Midstream)						
Vanadium electrolyte	16 ML	1230	262	220	2888	3108
Manufacturing and assembly activities (Downstream)						
VRFB battery for stationary applications	270 MWh	770	137	125	1,876	2001

Source: Pwc analysis based on CES Flagship Report - South Africa and Southern Africa Battery Market and Value Chain Assessment Report

20 Vanitec, https://vanitec.org/vanadium/map?q=&country=South+Africa&manufacturer=&status=Operational The current operational capacity of VRFBs in South Africa has reached 0.745 MWh as of August 2022, however for making future projections up to 2030 we have considered Dec 2021 as the base year (calendar year), with a cumulative capacity of 0.665 MWh installed at that time.
21 Engineering News Research Article, 2022, Bushveld Energy Pushing for Localisation of VRFB, Bushveld Energy pushing for localisation of VRFB technology (engineeringnews.co.za)
22 World Bank CES Report 2022

3 Analysis of the vanadium leasing model

The objective of this study is to analyze the technical and economic barriers associated with vanadium leasing based on the current state of the vanadium supply chain in the VRFB sector, and accordingly, suggest the way forward to implement the circular business model in the vanadium–VRFB value chain. The diagnosis will include details of each step of the vanadium–VRFB value chain, from mining vanadium to manufacturing VRFB and recycling vanadium from VRFB. PwC studied and incorporated inputs from leasing and rental models of other commodities into proposed vanadium leasing models, as applicable on the best-efforts basis through secondary research and stakeholder consultations.

The growing global demand to reduce carbon emissions, mitigate climate change, and improve renewable power generation and storage since the Paris Agreement in 2015 has increased the focus on cleaner and environmentally sustainable forms of power generation. Today, the addition of renewable power capacity in many countries is exceeding that of traditional coal and gas. Propelled by the falling prices of solar PV and wind energy technologies, electricity from renewables has breached grid parity and is cheaper than traditional electricity generation in many parts of the world.

This shift toward renewables has brought into focus the intermittency and variability of renewable power generation technology and its dependence on nature's forces. The rapidly evolving technology landscape has provided energy storage solutions that could stabilize the infirm nature of renewables; these developments only applied to certain geographies and applications because of the high costs and complexity issues. However, this has changed over the past decade: the falling prices of battery technologies triggered by advancements in battery chemistries and the need for better batteries from consumer electronics and electric vehicles has brought energy storage to the center stage.

With these conditions in place, batteries are on the cusp of enabling a major paradigm shift in decarbonizing transportation and power generation by connecting and coupling both sectors through renewable energy as the source of power.

According to the World Bank report, "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition," there is growing global demand for clean energy technologies, and the demand for vanadium, specifically, shows a foreseeable increase of nearly 200% by 2050. This is largely because of the growing need for steel and titanium around the world, the change in specific vanadium consumption (as per the government regulations) in steel manufacturing, and demand from the energy storage sector. According to the report by Roskill[23] .Vanadium demand from VRFBs is expected to grow at a CAGR of approximately 56.7% through to 2030. This clearly shows the importance of vanadium as a critical mineral and the need to have a circular economy to restrict the exploitation of vanadium for its sustainable utilization. This section of the report discusses the opportunity to employ the circular economic model to vanadium in the VRFB value chain.

3.1 Overview of Vanadium

Vanadium is a medium-hard, steel-blue metal. It is quite valuable in the manufacturing industry because of its malleable, ductile, and corrosion-resistant qualities when alloyed with steel.

Despite being available abundantly, it is very hard to find vanadium as a free element in nature because of its highly reactive nature. It can be found in chemically combined forms with about 65 different minerals[24] including magnetite, vanadinite, carnotite, and patronite. Vanadium can also be found in phosphate rock and some crude oils. It is estimated that vanadium comprises around 0.02% of the Earth's crust.

Vanadium compounds are not considered a serious health hazard; however, too much uptake of vanadium may have some ill effects on the lungs, eyes, throat, and nasal cavities. Furthermore, it may cause damage to the cardiac, vascular, and nervous systems, along with skin rashes, headaches, and stomach diseases.

The important features of vanadium are that it has good ductile and structural strength; it can resist corrosion and shows resistance to hydrochloric acid, sulfuric acid, and saltwater; and it has a low fission neutron cross-section and oxidizes readily at a temperature of more than 660°C.

23 Source: Vanadium: Outlook to 2029, 18th edition, Roskill
24 https://www.livescience.com/29155-vanadium.html Source: Live Science, Traci Pedersen-August 01, 2017

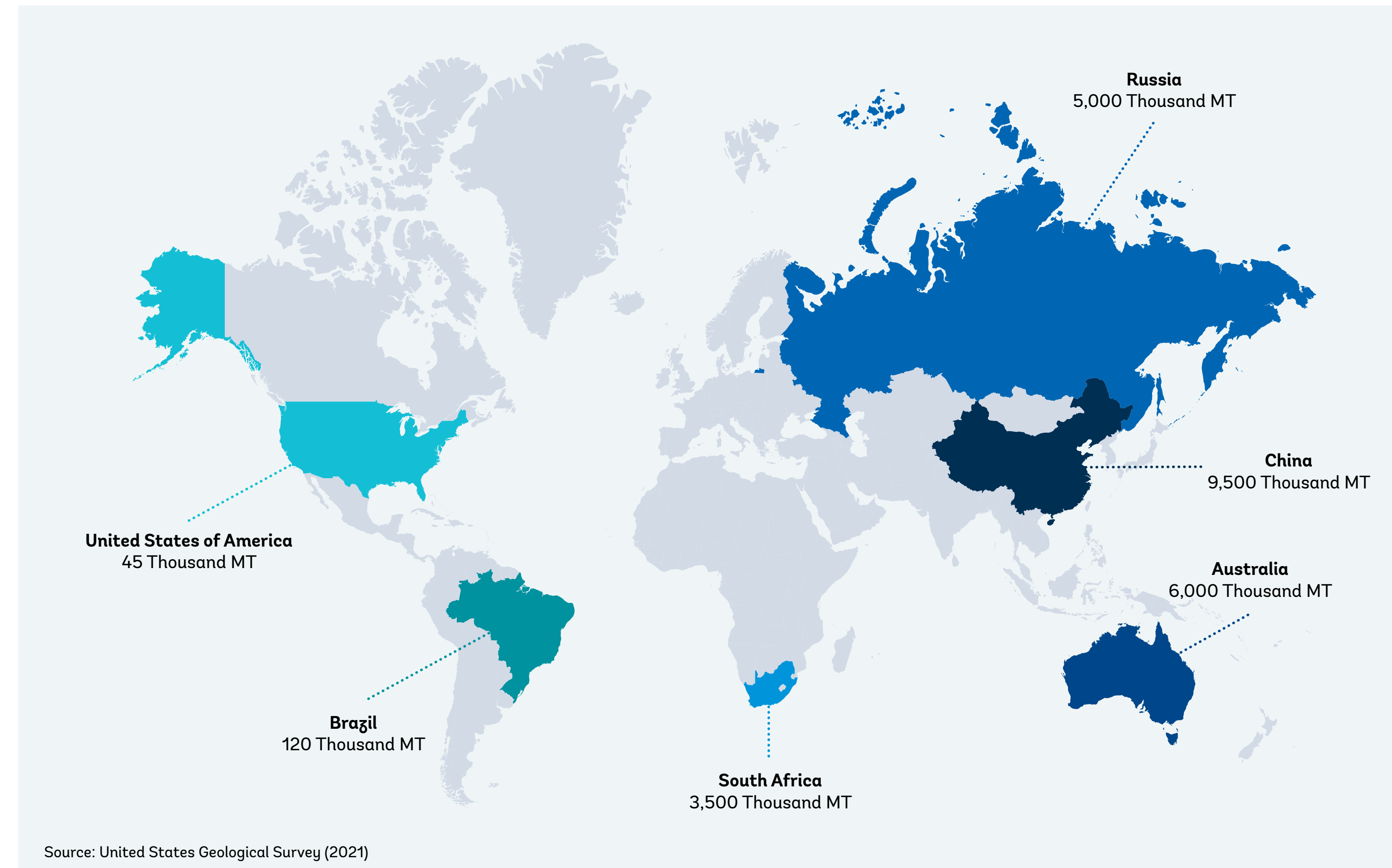
Most vanadium is extracted from the vanadiferous ores, slags, and residues and converted into vanadium pentoxide or trioxide. Most pentoxide is converted into ferrovanadium, an iron-vanadium alloy. Most of the world's supply of vanadium comes from steelmaking slags, where the steel has been produced from vanadiferous titanomagnetite. Over 90% of vanadium is consumed by the steel industry for high -strength steel manufacturing as it acts as a hardening agent. Using vanadium improves the strength, toughness, and resistance to wear of steel, which are required for high -strength, low -alloy steels. As the steel industry is the largest consumer of vanadium, the vanadium market is forced to follow the steel market. Apart from the steel industry, vanadium is consumed for manufacturing catalysts, ceramics, electronics, and other vanadium-based chemicals, including vanadium electrolyte.

3.2 Vanadium Reserves and Resources

Vanadium occurs mainly in four types of mineral deposits as a major constituent. Fossil fuels are also important sources of vanadium, and itis estimated that world resources of vanadium exceed 63 million metric tons. Vanadium deposits can be categorized as follows:

- **Vanadiferous titanomagnetite deposits (VTM):** VTM deposits are found throughout the world and are the principal sources of vanadium. The VTM deposits contain magmatic accumulations of ilmenite and magnetite. In most of the cases, they commonly contain 0.2% to 1% V_2O_5, but some zones contain greater than 1.5% of V_2O_5. VTM deposits are hosted mainly within mafic and ultramafic igneous rocks, most commonly anorthosite and gabbro.
- **Sandstone Shale-hosted vanadium deposits (SSV):** Sandstone-hosted uranium deposits have been identified and are available on all continents, and many of them contain vanadium in considerable amounts. These deposits of vanadium- and uranium-bearing sandstone (known as sandstone-hosted vanadium deposits) have an average resource and ore grades that range from 0.1 to 1 weight percent vanadium. On a global scale, the United States has been the main producer of vanadium from SSV deposits.
- **Shale-hosted vanadium deposits:** Vanadium-rich metalliferous black shales occur primarily in late Proterozoic and Phanerozoic marine successions. The shale includes a range of carbonaceous rocks that comprise marls and mudstones. These fine-grained sedimentary rocks were deposited in epeiric (inland) seas and on continental margins. They typically contain high concentrations of organic matter (>5%) and reduced sulfur (>1%), as well as a suite of metals, such as copper, molybdenum, nickel, PGEs, silver, uranium, vanadium, and zinc. Generally, the concentration level exceeds 0.18% V_2O_5 and can go up to 1.7% V_2O_5.
- **Vanadate deposits:** Vanadates of lead, zinc, and copper (vanadinite and minerals of the descloizite-mottramite series) form in the oxidized zones of base-metal deposits, especially in areas of arid climate and deep oxidation.

Map 3.1: Major Global Vanadium Reserves



Source: United States Geological Survey (2021)

- **Other magmatic-hydrothermal vanadium resources:** Some magmatic-hydrothermal niobium-titanium deposits contain elevated concentrations of vanadium.
- **Fossil fuels:** Vanadium closely correlates with organic carbon, and, therefore, is enriched in many oil shales. Significant amounts of vanadium are available for commercial use as a by-product of petroleum, and minor amounts are produced as by-products of coal and tar sands. Heavy crude oil contains the highest concentration of vanadium, and most of the heavy oil and vanadiferous petroleum resources are located in Venezuela.

According to the data published by the United States Geological Survey (USGS), total worldwide vanadium reserves stand at about 24.16 million metric tons, where China holds 39% of total reserves at about 9.5 million metric tons. Australia has the second -largest vanadium reserve in the world, with about 25% of the total reserve, followed by Russia (21%), and South Africa (15%). Brazil and the United States have small reserves of vanadium, at 0.12 million metric tons and 0.045 million metric tons, respectively. As only about one fifth of the total vanadium produced is from primary sources, the rest of the vanadium is recovered as a by-product or co-product. Thus, the demonstrated world resources of the element are not fully indicative of the available supply as most of the vanadium is being produced as a by-product or co-product.

3.3 Vanadium Production

There are three different sources of vanadium production: primary, secondary and co-production.

- **Primary production:** Vanadium produced from its ores by salt-roasting, water leaching, filtration, desilication and precipitation. This accounted for 18% of the global vanadium supply in 2020.
- **Secondary production:** Vanadium produced from fly ash, petroleum residues, alumina slag, and from the recycling of spent catalysts used in crude oil refining. It accounted for approximately 10% of the global supply in 2020.
- **Co-production:** As co-production slag produced in iron ore processing for steel production. Accounting for 72% of the global supply in 2020.

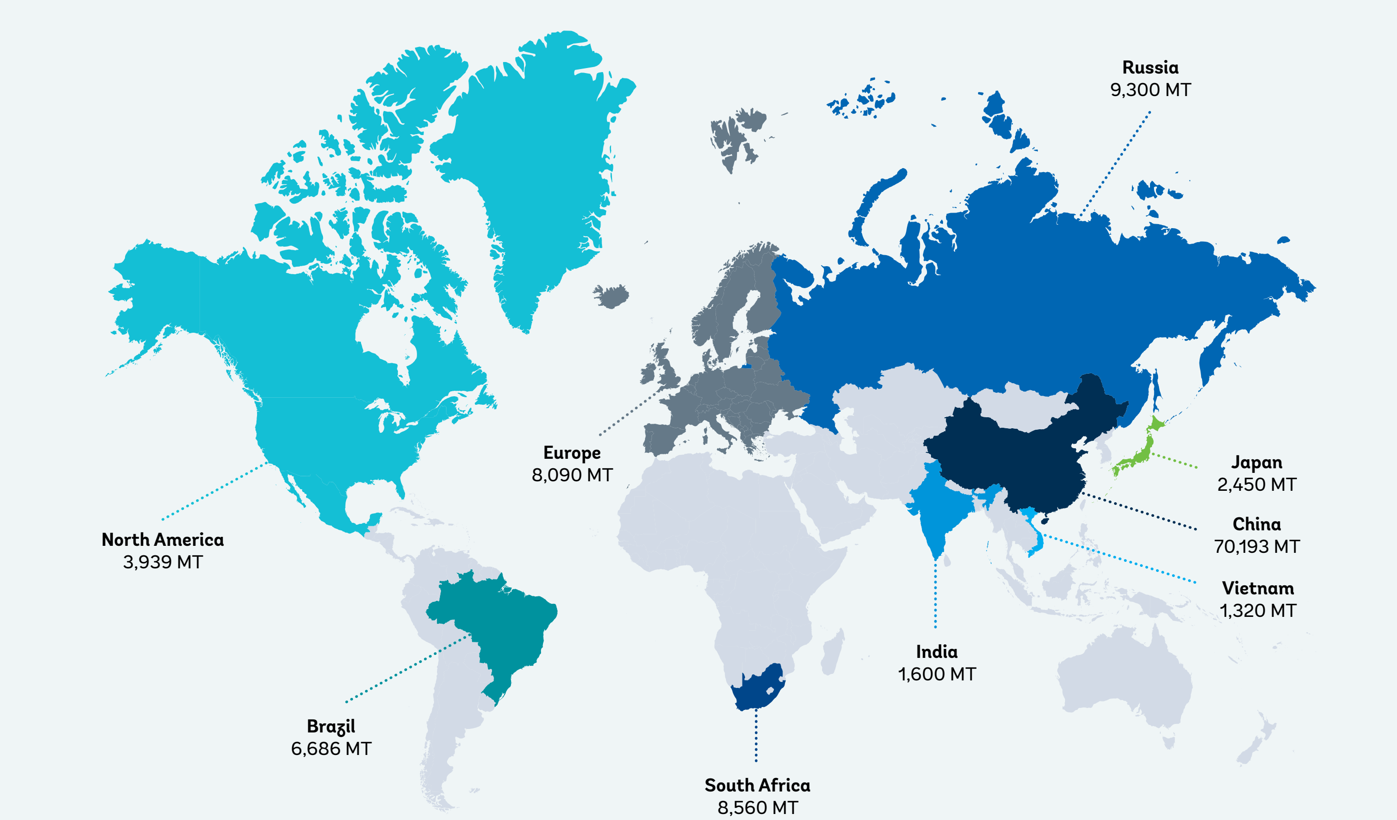
Most of the vanadium is produced as a co-product and as a by-product from different sources. Primary production only contributes to about 18% of total worldwide production.

China is the major producer and contributes around two thirds of worldwide vanadium production. Most of the production in China is from slag generated in the production of steel from vanadium titanium magnetite (VTM). Other major producers of vanadium are Russia, South Africa, Brazil, India, and Vietnam. The top five producers in the world contribute 90% of the total vanadium production worldwide. South Africa and Brazil were the major primary producers of vanadium in 2020.

Vanadium is produced from different minerals through various routes, with some common major steps (Figure 3.1).

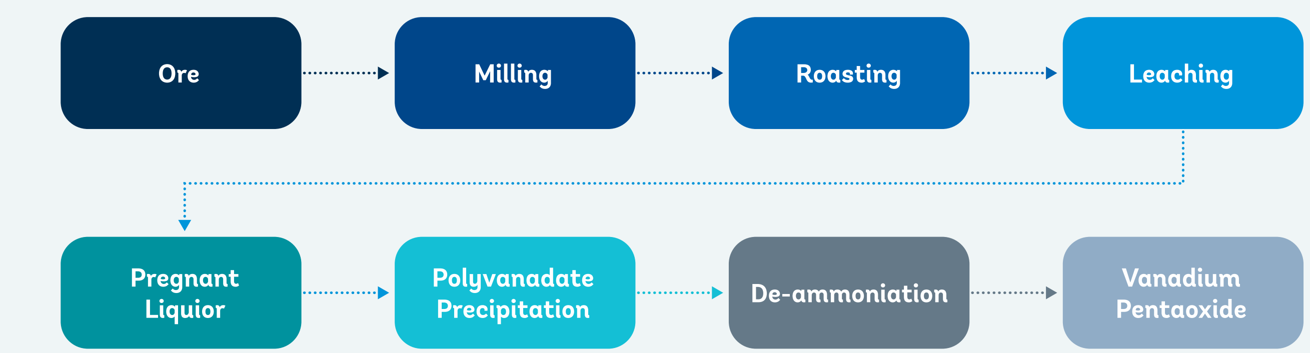
The process for preparing sodium hex-vanadate, producing vanadium pentoxide, and reducing the vanadium pentoxide to

Map 3.2: Global Vanadium Production (2020)



Source: TTP Squared, Inc. VANITEC 9th Energy Storage Committee Meeting, July 13, 2021

Figure 3.1: Steps for Processing Vanadium Ore to Vanadium Salts



Source: EPA, metallurgist.com

metal involves different steps and routes. The ore is sent for milling and then roasting. The vanadium slag resulting from the roasting process is also processed for further use. Leaching is the next step after roasting and the vanadium pentoxide is prepared after the de-ammonization step.

Vanadium from the titaniferous magnetite ores is extracted as a co-product in steelmaking. The V_2O_5 is extracted from the slags through a roast-leach process. Kilns or in multi-hearth furnaces with sodium carbonate, chloride, or sulfate are used to roast the slags. This produces sodium vanadates, which are leached into an aqueous phase with water. Ammonium vanadates are precipitated from this solution by the addition of ammonia and sulfuric acid to control the pH.

The ammonia is removed by de-ammonization and the vanadate is converted to various oxides by heating under controlled conditions and may vary based on the oxide required. Fused flake V_2O_5 is produced by decomposing the vanadates in a furnace and melting the resulting V_2O_5 into a liquid phase and then casting onto a chilling wheel.

Vanadium from the Colorado carnotite ore is extracted as a co-product during uranium production. The ore from the mines is treated with sulfuric acid to dissolve the vanadium and uranium. Then the uranium and vanadium are separated from the liquid by solvent extraction, followed by a liquid-liquid ion exchange process, which separates the uranium, leaving the vanadium in the acid solution. This is subsequently oxidized and removed from the organic salts with soda ash. Vanadium polyanadate is precipitated by the addition of ammonium sulfate.

Vanadium can also be obtained by various routes from oils in which it is present. Vanadium-bearing oil-based fuels are burned in the boilers of electric power -generating plants, and vanadium is left in the fly ash and boiler slags. There are certain metals present in the ashes and slags, which are recovered by various methods.

As discussed earlier, most of the vanadium is produced in China (62%) and Russia (8%) from steel slags as co-production (72%). This creates precarity in the vanadium supply chain and results in volatility in supply and prices of vanadium.

According to the World Bank report[25] Vanadium demand is expected to increase by around 200% by 2050. A similar trend can be expected in vanadium production, which is estimated to increase by 45% by 2025. As existing capacity is fully utilized, it will allow for continued extraction of vanadium from sandstone and coal deposits in China, and significant growth in vanadium production from secondary sources is assumed to increase as a result of changes in bunker fuel specifications impacting the amount of spent catalyst generated by refineries, and the general focus on recycling industrial wastes.

25 Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition

3.4 Vanadium Consumption

In the current market scenario, over 95% of the vanadium is being used in the ferrous and non-ferrous alloying industry to produce high -strength steel and other alloys. Vanadium is also used in the ceramic industry and chemical industry, as a catalyst, in superconducting magnets, and as a vanadium electrolyte in VRFBs. Currently, the energy storage sector consumes less than 2% of the total vanadium produced. Region wise, China accounts for over 60% of worldwide consumption followed by Europe (12%), North America (10%), Japan (4%) and India (3%).

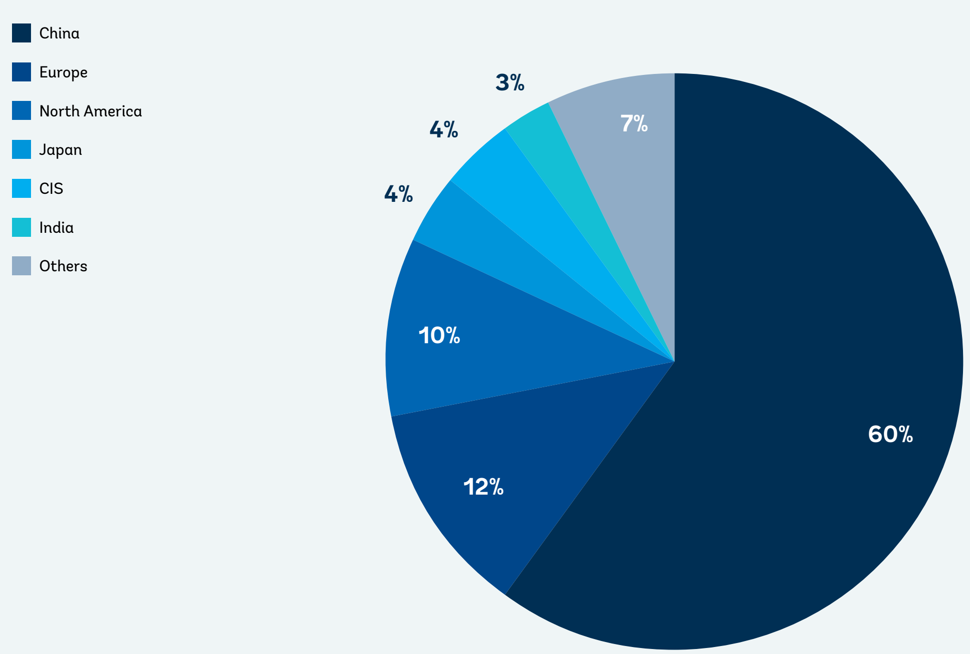
3.5 Vanadium Production Drivers and Challenges

There are various factors influencing the demand and supply of vanadium in the coming years. The following are some of the major factors expected to boost the demand for vanadium:

- increase in specific vanadium consumption in steel by the Chinese steel industry
- increasing demand for steel globally
- high demand for the battery manufacturing energy storage industry
- increased crude steel production
- high seaborne iron ore prices

Production from primary sources and co-production are expected to increase, but secondary production is expected to face challenges. Secondary production is more costly than primary and co-production and will also face the challenge of the availability of the necessary feedstock. In addition, most of the recent greenfield projects announced for development are associated with co-production or multi-commodities. They are also hampered by low grades and significant capital requirements and a relatively stable and higher price outlook than recent prices indicate.

Figure 3.2: Regional Vanadium Consumption (2020)



Source: TTP Squared, Inc. VANITEC 9th Energy Storage Committee Meeting, July 13, 2021

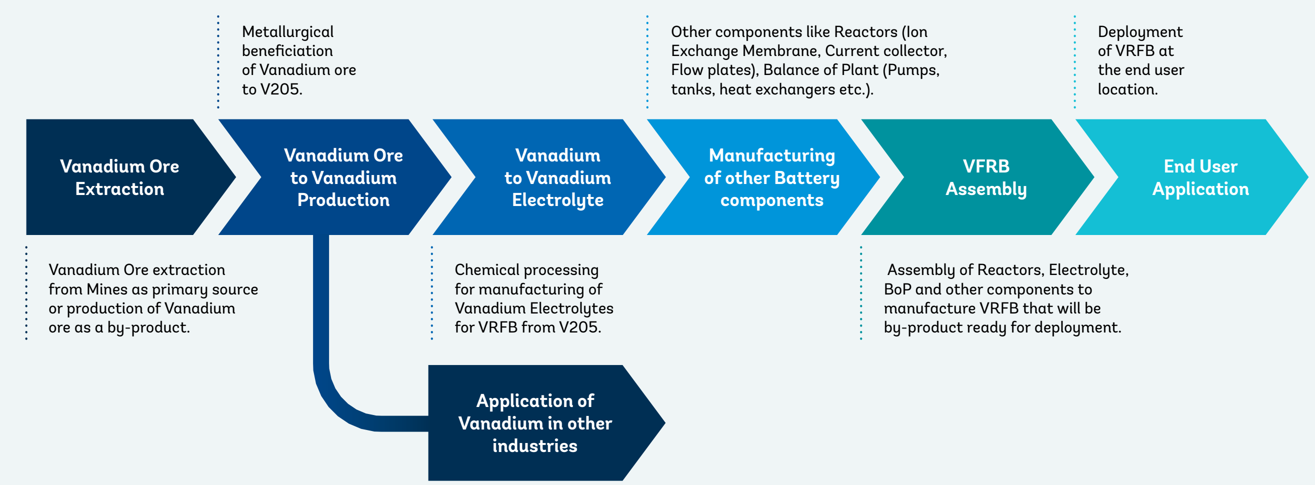
3.6 Vanadium–VRFB Value Chain Analysis

To prepare a robust business model for any commodity or product, it is important to analyze the entire value chain involved. The current state of the value chain is linear and involves five steps of value addition, from the mining of vanadium to deployment of VRFBs.

In the current market situation, the biggest cost involved in manufacturing a VRFB battery is VE, which is becoming one of the major roadblocks in the growth of VRFB applications. Additionally, given the finite resource availability and significant growth forecasted for the use of vanadium in VRFBs, it is imperative that we identify opportunities for the circularity in the vanadium-VRFB value chain. Figure 3.3 illustrates two options for achieving this.

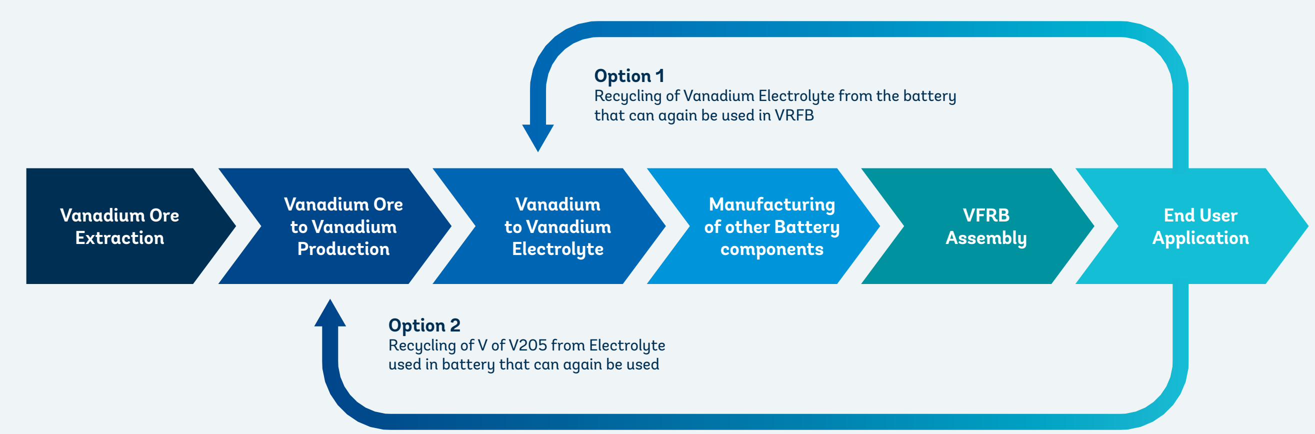
1. Recycling of VE that can be re-used in VRFBs
2. Reprocessing of vanadium from VE

Figure 3.3: Existing Value Chain for Vanadium to VRFB



Source: PwC Analysis

Figure 3.4: Recycling of Vanadium in the Vanadium–VRFB Value Chain



Source: PwC Analysis

3.7 Vanadium Ore Extraction

Vanadium is extracted from several types of deposits composed of various minerals and from fossil fuels. Vanadate, Titaniferous, Magnetite (VTM) deposits are the principal sources of vanadium in the world and consist of magmatic accumulations of ilmenite and magnetite, containing 0.2 to 1 weight percent vanadium pentoxide (V_2O_5). Sandstone, Shale -hosted vanadium (SSV) deposits have average ore grades that range from 0.1 to greater than 1 weight percent of vanadium pentoxide. Concentrations of vanadium in black shales exceed 0.18 weight percent V_2O_5 and can be as high as 1.7 weight percent V_2O_5. Vanadium has also been produced from the alum shale and ferrophosphorus slag generated during the reduction of phosphate to elemental phosphorus in ore from shales of the phosphoric formation in some countries.

- **Mining**

  Titaniferous magnetite ore is mined and processed for vanadium extraction in most of the major producing countries. Titaniferous magnetite ore is also processed in steelmaking operations in China, Russia, and South Africa.

  Vanadium is present in crude oil in the Caribbean basin, parts of the Middle East, and Russia, as well as in tar sands in western Canada and coal in parts of China and the United States. When vanadium-bearing ash is generated as these energy sources are refined or burned, it can be further processed for vanadium recovery.

  Another minor contributor to current vanadium production is roscoelite, a mineral processed in alumina production, primarily in India, that yields vanadium-bearing sludge.

- **Extraction**

  The extraction processes differ based on the requirements and outputs. The iron from different operations contains about 1.5% vanadium, which is removed as slag by low-temperature treatment with oxygen. Different countries use different types of processes to extract vanadium.

  As briefed earlier, vanadium deposits having dedicated primary vanadium production are available mainly in South Africa, Brazil, and Australia only. Currently, South Africa and Brazil are the only major producers. In South Africa, Bushveld Vanadium produces vanadium ore from its mines at Vametco and Brits Resources. In Brazil, Largo Resources produces vanadium ore from its mining operation at Maracas Mechen Mine. In Australia, vanadium mines are in the development phase and production is expected to start as early as 2023-24.[26]

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3.8 Vanadium to Vanadium Electrolyte

VRFBs use electrolytes to store the energy as chemical energy. This electrolyte is based on the vanadium element. Vanadium has four stable oxidation states (V_2+, V_3+, VO_2+, VO_2+) making it ideal for manufacturing both catholyte and anolyte. This makes VRFBs unique compared to other redox flow batteries. Since both the anolyte and catholyte are based on the same material, electrolyte cross contamination does not render the electrolyte unusable.

Electrolyte used in the VRFBs is manufactured by dissolving vanadium ions in diluted sulfuric acid. The solubility of the vanadium ions strongly depends on the sulfuric acid concentration and the electrolyte temperature. For V_2+, V_3+ and VO_2+, an increase of the sulfuric acid concentration leads to a reduction of the solubility, but for VO_2+ the solubility increases with rising H_2SO_4 concentrations. The temperature dependence follows the opposite behavior: VO_2+ solubility decreases with increasing electrolyte temperature, while the solubility of the other vanadium ions is enhanced. The overall best total sulfuric acid concentration for a VRFB electrolyte is usually set to 2 mol/L to 2.5 mol/L. The optimum concentrations must be adapted to the ambient temperature of the VRFB site. Moreover, additives such as phosphoric acid or ammonium compounds are often added to the electrolyte as stabilizing agents, ensuring VRFB operability in a broader temperature range[27]

Vanadium pentoxide (V_2O_5) is the vanadium compound used most frequently to produce vanadium electrolyte because of its comparatively low prices and high availability as most vanadium produced is in this form. Other vanadium-containing compounds used for the production of the electrolyte are vanadium trioxide (V_2O_3) and vanadyl sulfate (VO_5O_4).

For production of vanadium electrolyte from V_2O_5, reduction of pentavalent vanadium ion is necessary to increase the solubility of the V_2O_5. This reduction process can be done by two methods: chemical reduction and electrochemical reduction.

In chemical reduction, the vanadium components are reduced with chemical reducing agents such as SO_2, oxalic acid C_2H_2O4, or hydrogen (H_2), while in electrochemical reduction, the vanadium ions are continuously reduced with the aid of electric current. Of the two methods, electrochemical reduction is widely used on a commercial scale due to its cost effectiveness and continuous production capability.

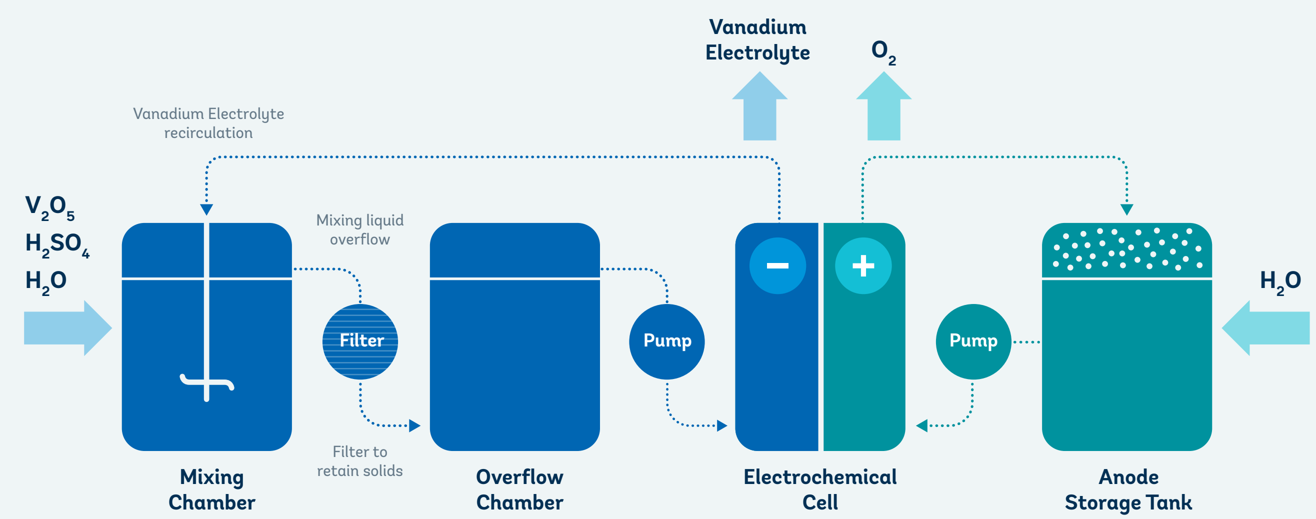
The electrochemical process for producing vanadium electrolytes consists of a stirred mixing vessel into which vanadium pentoxide and diluted sulfuric acid are continuously dosed. An overflow ensures the liquid transfer from the mixing vessel into a second tank. A filter is used between the two containers for complete solid retention. From the second tank, the solution is pumped into the cathode of the electrochemical cell and, after reduction, returned to the stirred mixing tank. A partial flow is continuously discharged as a product stream. The recirculation of the V_3+ ions, available in vanadium electrolytes produced in the electrochemical cell, causes an accelerated dissolution of the pentavalent vanadium ions in the mixing vessel because of chemical reduction. On the anode side, diluted sulfuric acid is conveyed through the cell from a storage tank. Because of the oxygen evolution reaction in the electrochemical cell, water has to be added continuously to the anode storage tank.

The cost of raw materials, i.e., V_2O_5 and H_2SO_4, is a major contributor to the production of vanadium electrolyte. V_2O_5 alone contributes approximately 75% of the total cost, hence sourcing inexpensive V_2O_5 becomes critical for the production of vanadium electrolyte.

As seen historically, the prices of V_2O_5 fluctuate significantly, which creates challenges for electrolyte manufacturers to source V_2O_5. Moreover, prices of V_2O_5 significantly depend on the steel sector as it is also used as a precursor to ferrovanadium in the production of steel alloys. It provides an advantageous position for vanadium producers to vertically integrate electrolyte production since (1) they are unaffected by vanadium price volatility, and (2) they benefit from unrestricted availability of vanadium. Most of the vanadium miners are entering the vanadium electrolyte manufacturing business, such as Bushveld minerals in South Africa and Largo Resources in Brazil. Australian Vanadium Limited will produce electrolytes at their mining and vanadium production facility.

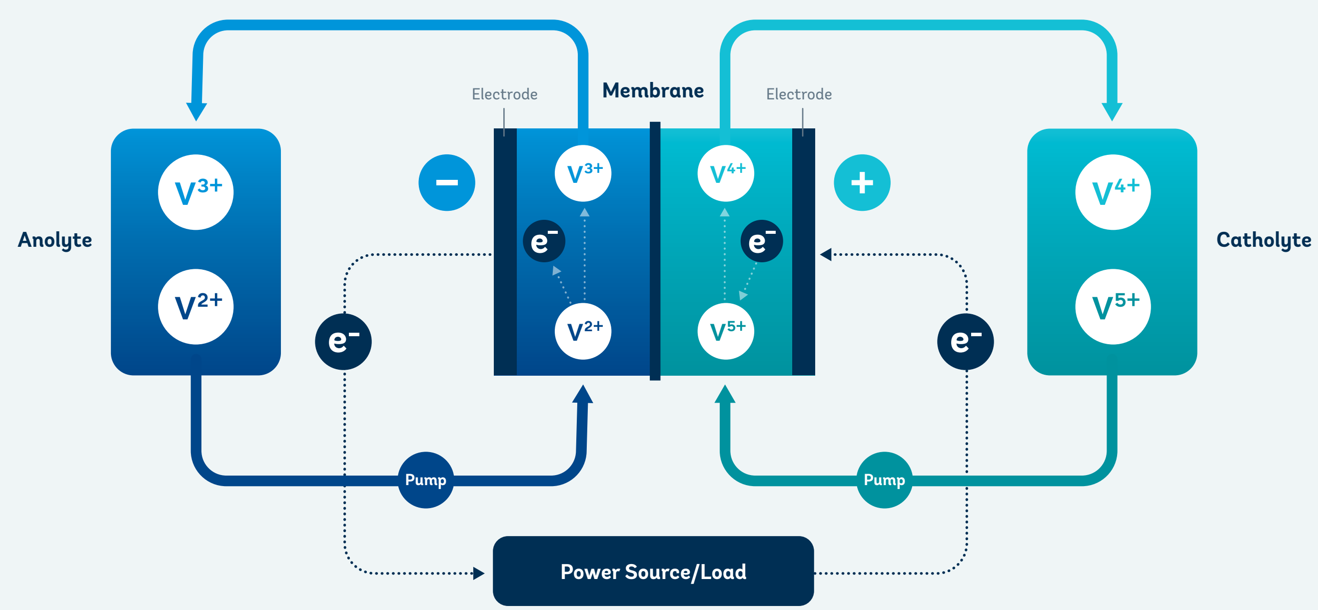
27 Preparation of Electrolyte for Vanadium Redox-Flow Batteries Based on Vanadium Pentoxide, Jan Martin, Katharina Schafner, and Thomas Turek

Figure 3.5: Process Map for Vanadium Electrolyte Manufacturing from V_2O_5



Source: EPA, metallurgist.com

Figure 3.6: Schematic Diagram of VRFB Battery



Source: PwC Analysis

3.9 VRFB Manufacturing and Assembly

A vanadium redox flow battery comprises an assembly of catholyte (electrolyte tank with V_4+ and V_5+ vanadium ion) and anolyte (electrolyte tank with V_2+ and V_3+ vanadium ion). These electrolyte tanks are connected to the power cell via a pump. In the power cell, there are two electrolytes separated by a proton exchange membrane, also known as an ion-selective membrane. Vanadium redox battery also consists of carbon-based electrodes. The most common types of electrodes are carbon felt, carbon paper, carbon cloth, and graphite felt.

3.10 VRFB Installed Capacity

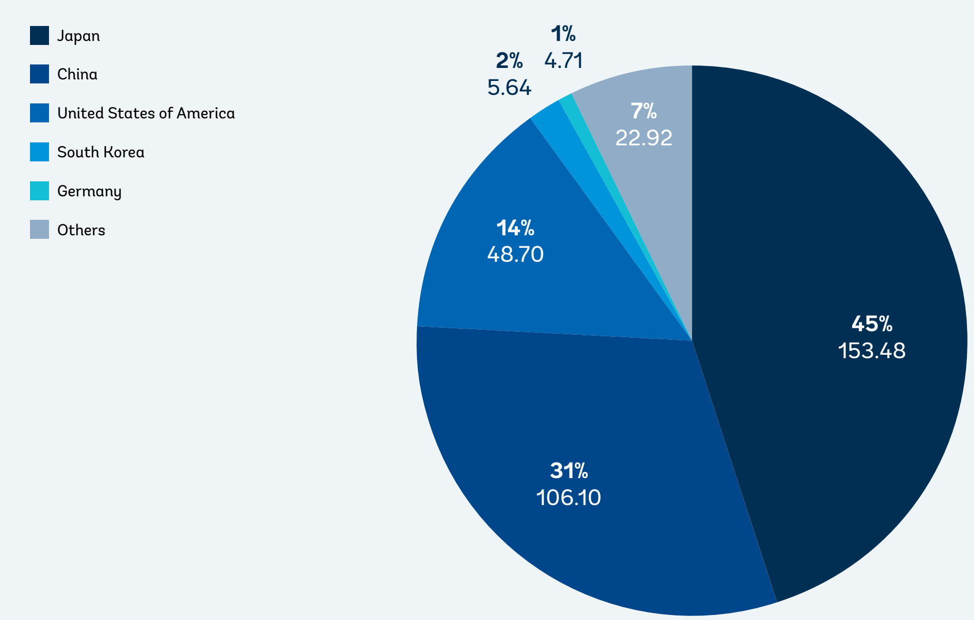
VRFB is currently used for stationary electricity storage in more than 35 countries, with an operational installed capacity of 341.55 MWh. The top five countries share more than 75% of the total installed capacity of VRFB, with Japan having 153.5 MWh of installed capacity, 45% of the total VRFB installed capacity worldwide. Japan is followed by China (31%), the United States (14%), South Korea (2%), and Germany (1%) in terms of VRFB installed capacity. A similar trend is observed among the top VRFB manufacturers, with the top five accounting for about 90% of current installed capacity: Sumitomo, a Japanese company manufacturing 163.75 MWh of VRFB, which is about 48% of total operational capacity; VRB Energy, Canada (15.61%); Rongke Power, China (12.71%); Shanghai Electric, China (8.5%); and UET, the United States (5%).

Table 3.1: Manufacturers of Operational VRFBs, 2022

Name of Manufacturer	Operational VRFB Capacity (MWh)
Sumitomo	163.75
VRB Energy	53.31
Rongke Power	43.42
Shanghai Electric	28.99
UET	17.33
Others	34.74
Total	341.55

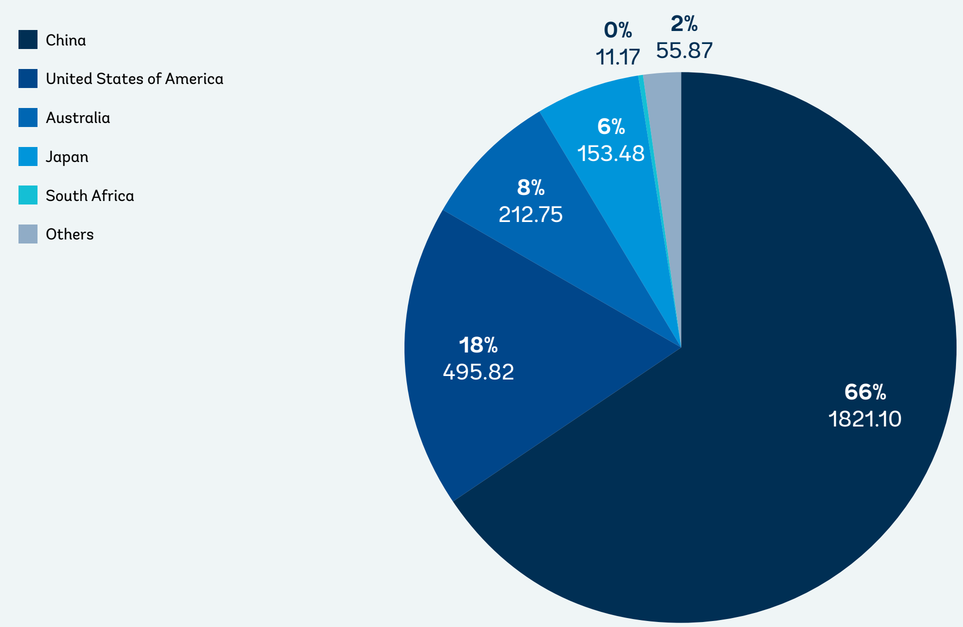
Source: Vanitec.org

Figure 3.7: Global Operational Installed Capacity of VRFB, 2022 (MWh)



Source: Vanitec.org

Figure 3.8: Global VRFB Capacity (MWh) (Operational + Announced/Under Construction), 2022



Source: Vanitec.org

The total capacity of VRFB is expected to reach around 2,700 MWh, assuming the VRFB projects in the pipeline are commissioned[28] Data shows that a seven-fold increase in VRFB capacity is expected, with the top five countries sharing more than 97% of the total VRFB installed capacity. A major increase in VRFB installation is planned in China, whose share is expected to reach around two thirds of the total global installed capacity, with 1,821 MWh of VRFB installation. China will be followed by the United States (18%), Australia (8%), Japan (6%), and South Africa (0.4%). Again, the top six manufacturers are expected to contribute around 96% of the total installed capacity. Rongke Power, a China -based company, is planning to increase its installed capacity to around 857.42 MWh of VRFB, which is about 31% of the total projected installed capacity. Rongke Power is followed by VRB Energy, Canada (20.2%), Shanghai Electric, China (15.54%), Concentric Power, the United States (8.18%), and CellCube, Austria (7.67%) in terms of market share of VRFB manufacturing.

Table 3.2: VRFB Capacity (Operational + Announced/Under Construction), 2022

Name of Manufacturer	VRFB Capacity (MWh) (Operational + Announced/Under Construction)
Rongke Power	857.42
VRB Energy	557.79
Shanghai Electric	428.99
Concentric Power	226.00
Others	691.02
Total	**2,761.23**

Source: Vanitec.org

3.11 VRFB End Use Application

With an increasing focus on RE-based power generation for achieving lower the temperature by 2 degrees in future, there is a growing demand for energy storage systems due to the inherently intermittent nature of solar- and wind-based electricity generation. Currently, most of the energy storage requirements are being fulfilled by pumped-Hydro storage. Pumped-Hydro storage systems are capital intensive, have a high incubation period, and are geographically constrained.

For wide adoption of RE-based power generation, a distributed, grid -level energy storage system will be required, with the storage capability of different power and energy requirementswith long duration electricity supplying capabilities. These unique requirements of RE-based power generation need unique solutions for grid-level energy storage systems. Battery Energy Storage Systems (BESS) represent one such solution that is commercially viable with availability of the same in the market. Lithium-ion (Li-ion) batteries are a leading BESS solution, but several fire incidents at grid-level storage [facilities] and constrained operational capacity (low discharge duration) are creating a huge challenge to the adoption of Li-ion batteries at a wider level. VRFBs are coming up as the option for the Li-ion batteries in this space as they offer the most sustainable battery solution for large-scale commercial deployment.

The major advantages of VRFBs are their long lifespan and the ability to charge/discharge over 30,000 times for over 20 to 25 years with minimal performance degradation. VRFBs have a high discharge capacity, up to 100% depth of discharge, which allows the entire battery to be used all the time. When fully used at least once daily, VRFBs currently prove to be cheaper than Li-ion batteries. There is also no fire risk from thermal runaway. One of the major advantages of VRFBs is also that nearly all the electrolyte in VRFBs is re-usable upon decommissioning. The CO_2 footprint over the VRFB lifecycle (from mining of vanadium to disposal of the battery) is smaller than for long -duration Li-Ion battery systems. Electrolyte can be recycled at the end of the life of the battery, but if electrolyte becomes non-recyclable, vanadium can be recovered from it and redeployed into another VRFB system or converted into FeV for use in steel. Theoretically, there is no cross-contamination of the electrolyte as only one element is used in its manufacturing, which is unique among flow batteries. The quality of vanadium electrolyte after 5, 10 or 20 years is the same as on day one. The same is true for the vanadium molecules within the electrolyte. VRFBs can thus be installed for large -scale capacity. There has been large-scale adoption of VRFBs in China and Japan, including multiple 400 MWh sites currently under construction in China.

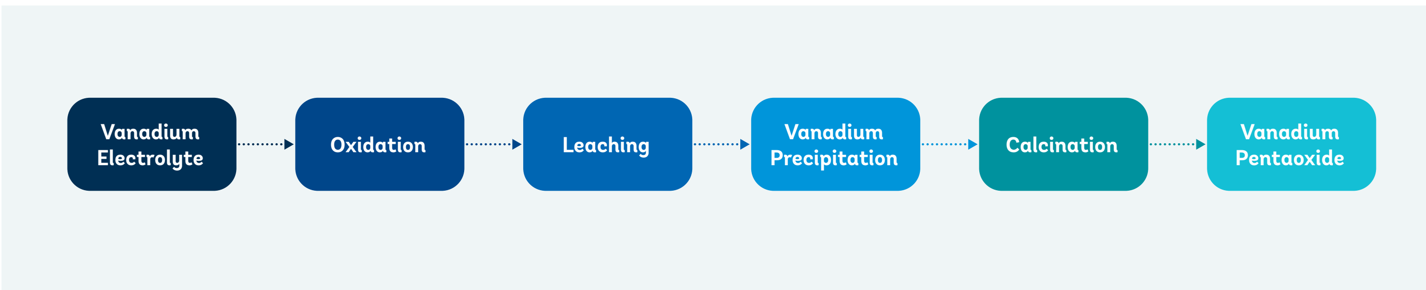
3.12 Recycling of Vanadium

When considering the use of the vanadium at the end of the life of the battery, there are two options available for recycling vanadium:

Option-1: Recycling of Vanadium Electrolyte (VE)

In this option, VE is recycled after usage in a battery to be used again in another battery. VE has a virtually infinite lifespan compared to VRFBs and can be reused in different batteries after recycling. VE recycling may become as a viable option when quality of VE gets detoriated due to solid precipitation during the operational life of the battery or due to cross contamination by anolyte and catholyte. These challenges can easily be solved by the ultrafiltration of the electrolyte, which removes the precipitated solids. If the balance of electronic valence is off between the anolyte and catholyte, some of the 5-valent solution could be replaced with new electrolyte (at a valence of 3.5) to return it to a balanced state.

This is the best option for recycling the vanadium contained in the electrolyte. As the vanadium does not deteriorate in the electrolyte, it can be used as a safe storage solution. Additionally, the cost of recycling VE is lower than the cost of reprocessing vanadium for VE.



Option-2: Reprocessing of Vanadium from the Vanadium Electrolyte

This option involves the extraction of vanadium from spent vanadium electrolyte, which can be used in traditional steel applications or other applications as required. Various companies globally have successfully demonstrated 92% to 99% recovery[29] of vanadium from the electrolyte.

There are multiple ways in which vanadium can be recovered from spent electrolytes. For reprocessing a vanadium electrolyte, the following general process will be required:[30]

For an existing vanadium processing facility, reprocessing spent electrolyte would be much less capital intensive compared to setting up a new processing facility altogether as there are multiple steps in the process that are similar to the beneficiation of vanadium from the vanadium ores. This provides an opportunity for an existing vanadium producer to reprocess spent electrolytes.

Some additional requirements for an existing vanadium beneficiation facility may include the following:

- A storage facility to store the spent electrolyte to be reprocessed either in tanks or totes
- Oxidation of the electrolyte from a typical 3.5 -valent solution to 5-valent solution. Oxidation of the electrolyte solution can also be done by modifying the circuit as needed for the electrolytes and other steps involved in the process

Vanadium thus lends itself to a circular economic model where the value of the metal is maintained for possibly unlimited use and not only for the initial value when use is established in a battery for the first time.

3.13 Circular Business Model

Vanadium is not consumed and does not degrade in the VE used in VRFBs.[31] After the battery's end of life, the VE can be recycled and redeployed in another VRFB or can be converted into vanadium for reuse in the open market. In addition, the conversion cost for vanadium from VE is significantly lower than the vanadium's market value.

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

With these environmental and economic advantages, and according to the hours required to recycle the metals, it is imperative to study the circular business model of vanadium in the VRFB space.

Three revenue generation options in the circular economy were studied to understand their applicability in the circular economy of vanadium in VRFBs.

1. **Sell and buy back model:** According to this model, users must finance upfront costs to purchase the product from producers with the assurance from the producers that it will buy back the product if the standard operating practices are followed. One major disadvantage of this model is that it does not provide any financial benefit to the users as the full cost of the product has to be paid by them. In this model, vanadium price volatility is still going to be a major challenge for VRFB producers (users in this case) and Vanadium Producers (producers in this case).

29 US Vanadium, Bushveld Vanadium, Electrochem
30 US Vanadium
31 IEEE, Rocky Mountain Institute, The University of New South Wales; Volterion; Technical University of Munich

2. **Renting model:** In this model, the producer bears the cost of production and receives the income as a regular payment from the user against the renting of the product. The producer is incurring the capital investment cost and holds the right to the product, while the user gets the benefit of not having to pay the capital cost of the product and only pays regular rent on the product.
3. **Leasing model:** In this model, a leasing company offers financing if the producer and user are unable or unwilling to finance the product. The leasing model is further divided into four categories to provide a product lease:
   - **a.** Operation Lease: In this case the leasing company buys the product from the producer and leases it to the user. The user has an option to buy the product at the end of the lease term. It is similar to the renting model, but instead of the product comes from the leasing company to the user rather than from the producer, and the leasing company holds the right to the product. Product rights are transferred to the user if the user buys the product at the end of the lease term. An operational lease purchase of the product by the user is optional.
   - **b.** Financial Lease Pledge: In this case, the user buys the product from the producer with financing from the leasing company. The user holds the economic and legal rights to the product, while the leasing company holds the pledge on the product in case the user ceases or is unable to pay the lease amount.
   - **c.** Financial Lease Hire-Purchase: Under this lease type, the user buys the product with financing from the leasing company and holds the economic rights to the product, while legal ownership of the product rests with the leasing company. Legal ownership is automatically transferred to the user upon payment of the last installment. Purchase of the product by the user is obligatory in both financial lease models.
   - **d.** Vendor Lease: In this case, the producer and the leasing companies together offer the user an overall proposition of purchase financing or leasing options. The producer and the leasing company may agree on topics such as distribution of the risks, reverse logistics, residual value of the product. A vendor lease is always an operation or financial lease. The only difference is that instead of the producer and leasing company working independently, they act together to provide leasing options to the user.

Of the three options above, the **renting or operation leasing model of VE** are suitable models for the circular economy of vanadium as there is very high upfront capital cost involved in producing vanadium and vanadium electrolyte for the VRBF manufacturers[32].

As already discussed above in value chain analysis, vertically integrating vanadium electrolyte manufacturing for an established vanadium producer is technically feasible and economically favorable due to the following reasons:

- They do not need to depend on the market for the supply of vanadium
- They are uninfluenced by vanadium price movement
- They have an opportunity to bifurcate the vanadium produced from a single end -use industry, the steel sector
- It offers a sustainable and recurring income source as a result of leasing or renting the VE

We also studied leasing models being followed in precious metals for comparative analysis and drew important parameters that we considered to build a feasible circular business model for vanadium.

32 Venitec.org

3.14 Comparative Analysis

In capital-intensive industries, such as manufacturing, pharmaceuticals, automotive, chemicals, and electronics, precious metals are widely being consumed as a catalyst in their production processes. In such processes, the metal itself is not consumed but is used because of its chemical properties. The availability of precious metals is limited and unevenly distributed across the globe, which makes their market pricing quite volatile. Considering these factors, the decision to purchase or lease these precious metals will have a material impact on the industrial firm's liquidity and balance sheet.

With purchasing precious metals by the industrial firms, the upfront cost is significant, and it exposes the company to commodity price risk and, potentially, currency risk, to limit cash consumption. Therefore, many firms choose to lease precious metals from a leasing company, reducing their capital outlay, while eliminating currency risk and the need for mark -to -market accounting on the price of the commodities owned. It is also evident that the transportation of precious metals is not only time-consuming, but expensive, whereas the leasing market offered the ability to swap metals from one location—or from one time period—with someone in another location or at another time. This cannot be done for free, thus, there is a premium charged to use this facility, which depends on the supply and demand in the specific location. This is possible if the two parties share the same interest in concurrent locations or collaborative leasing companies in a different location.

Precious metals are rare, naturally occurring metallic chemical elements of high economic value, such as gold, silver, and PGMs (which comprise six metals: platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), iridium (Ir), and osmium (Os)). These PGMs have very high melting points, high heat resistance, high corrosion resistance, and unique catalytic properties. Similarly, gold and silver also have unique physical and chemical properties and high economic value. There are several players working in the field of leasing precious metals (gold, silver and PGMs), including Mitsubishi Corporation International (Europe) Plc (MCIE), Kilo capital, Umicore, Monetary Metals, and Kitko Metals. In this report, platinum has been selected for comparative analysis considering its use in industrial contexts.

3.14.1 Platinum

Platinum is 30 times rarer than gold and, unlike most other metals, is difficult to find among the minerals in the Earth's outer crust. It can, however, be found in its pure form. It is an attractive silver-white metal that is malleable, ductile, very heavy, and has a high melting point. It is extremely resistant to tarnishing and corrosion. Along with platinum metals, small amounts of iridium are commonly added to produce a harder, stronger alloy that retains the advantages of pure platinum.

Table 3.3 illustrates that over 75% of total platinum production comes from primary sources, and approximately 25% of the supply is recycled platinum. Table 3.4 summarizes the major primary producers of platinum.

Table 3.3: Sources of Platinum, 2017-2021

Platinum (metric tons)	2017	2018	2019	2020	2021
Primary production	6,160	6,135	6,077	4,906	6,204
Recycled Platinum	1,915	1,955	2,137	1,929	1,936
Total supply	**8,075**	**8,090**	**8,214**	**6,834**	**8,140**

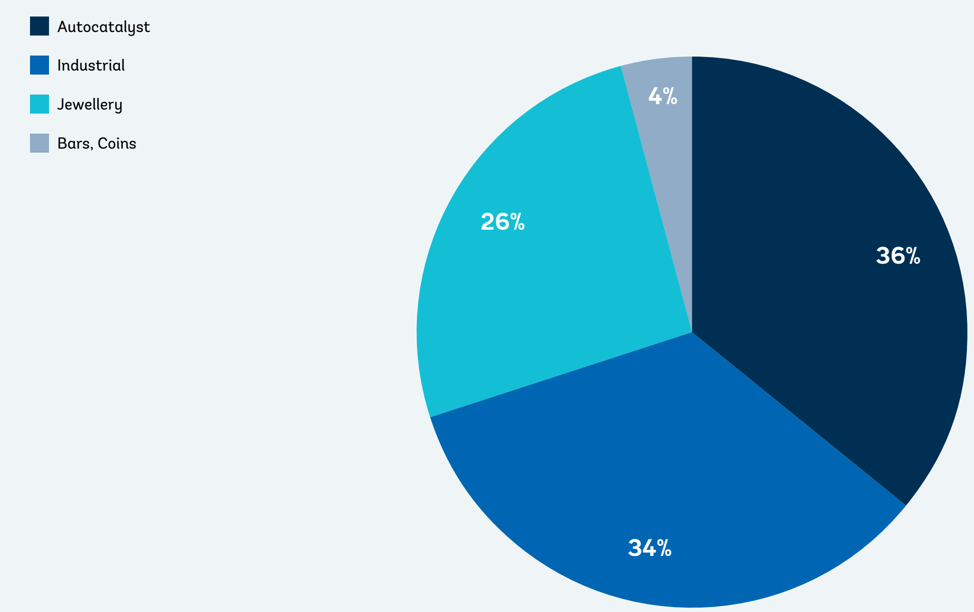
Source: Metals Focus 2019-2022, SFA (Oxford) 2017-2018.

The production and supply of platinum are highly concentrated in South Africa. South Africa is a major producer of platinum, contributing around three quarters of the total platinum produced globally. South Africa is followed by Russia (10%), Zimbabwe (8%), and North America (4%). The top three countries contribute over 92% of the total global supply of platinum.

Figure 3.9 indicates that almost 70% of the demand for platinum is for preparing autocatalysis and for industrial purposes. Demand for jewelry manufacturing stands at 26% and for investment, bar, and coins, only 4%.

The supply–demand analysis of gold and platinum reveals that most platinum consumption or demand (70%) arose from a combination of autocatalysis (36%) and industrial use (34%) in 2021, whereas consumption of gold in the industry sector (electronics, dentistry, and other industrial use) stands at approximately 7%. Most gold consumption (about 70%) came from the jewelry industry (48%) and the investment sector (21%) in 2021.

Figure 3.9: Demand for Platinum, by sector, 2021



Source: Metals Focus, 2019-2022

Table 3.4: Primary Producers of Platinum, 2017-2021

Platinum (metric tons)	2018	2019	2020	2021	2022
South Africa	137,053	132,989	111,993	141,625	124,401
Russia	22,000	24,000	23,000	21,000	20,000
Zimbabwe	14,703	13,857	15,005	14,732	17,104
Canada	7,600	8,600	4,600	5,000	5,400
United States	4,160	4,150	4,200	4,020	3,000
China	2,500	2,500	2,500	2,800	2,800
Finland	1,576	953	1,277	1,447	1,243
Colombia	270	178	414	672	400
Australia	120	110	110	100	90
Ethiopia	4	4	2	4	30
Serbia	5	10	20	20	15
Total	190,000	187,000	163,000	191,000	174,000

Source: Metals Focus 2019-2022, SFA (Oxford) 2017-2018.

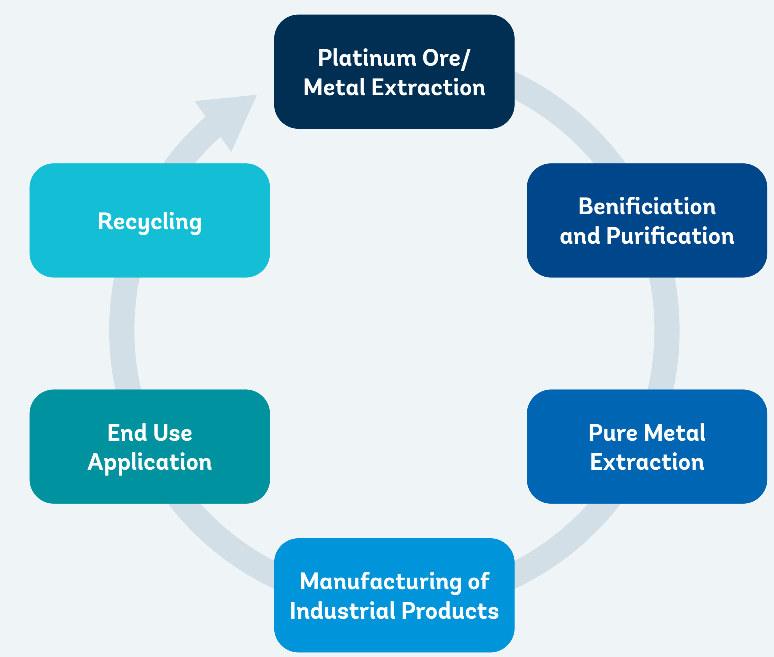
Therefore, it may be assumed that leasing models being adopted for platinum metal may be considered more relevant compared to leasing models adopted for gold when building business models for leasing vanadium for industrial use.

In the platinum market, the circular value chain is widely practiced globally because the recycling and extraction of platinum metal is cheaper than extraction from its ore[33] Click here to enter text.

This circular value chain can be achieved with the help of leasing agencies, as explained below.

33 https://technology.matthey.com/article/56/1/29-35/ Source: Platinum Metals Rev., 2012, 56, (1), 29 doi: 10.1595/147106712X611733

Figure 3.10: Circular Value Chain for Platinum



Source: PwC Analysis

3.15 Platinum Ore Extraction

PGMs are associated with base metal sulfides, such as chalcopyrite ($CuFeS_2$), millerite (NiS), pentlandite, pyrite and pyrrhotite. Gangue minerals associated with PGM-containing minerals are feldspar, biotite, plagioclase, and pyroxene. Currently, about three quarters of the total platinum produced globally is produced by primary sources, the rest is produced by recycling its end -use products. Mine production occurs mainly in South African mines, which account for about 74% of platinum mine production. Platinum mined in South Africa comes mainly from the Merensky reef, UG2 reef, and Platreef, which are all part of the Bushveld complex

3.16 Beneficiation and Purification of Platinum[34]

PGM ore extracted from the mine is first treated by the primary and secondary crushers, then beneficiated using gravity separation and floatation. Smelting is used to extract PGM -rich sulfides from the gangue minerals. After the smelting process, a hydrometallurgical process is used to purify the PGM. These hydrometallurgical processes can be dissolution-precipitation (pressure oxidation leach), solvent extraction and ion exchange, and molecular recognition technology. Pressure oxidation leach is a typical hydrometallurgical process used to separate base metals from the PGM residue. The base metals are leached, while the PGMs remain in the residue. The PGM residue is sent to a precious metal refinery where various solution extraction and precipitation methods are used to separate individual platinum group metals. Solvent extraction is another method by which PGMs can be separated from the base metals.

34 https://dx.doi.org/10.5772/intechopen.73214 Source: Extraction of Platinum Group Metals, Bongephiwe Mpilonhle Thethwayo, February 21st, 2018

3.17 Manufacturing of Industrial Products

Platinum metal extracted from the primary source or recycling sources are supplied to the manufacturing units of industrial products, such as autocatalysts, chemical productions, electronic products, medical fields, jewelry, and investment institutions.

3.18 End Use Application

Platinum is a highly valued and sought-after metal because of its properties and wide range of uses. The major applications of PGMs are as catalysts in the automotive industry, petroleum refining, environmental uses (gas remediation), industrial chemical production (ammonia production, fine chemical production) electronics, and medical fields. Catalytic converters are used to reduce pollutants by reducing exhaust gases. This accounts for about 37% of the platinum used as it is very effective at converting toxic gases into less harmful emissions.

It is expected that as the next generation of energy technologies for hydrogen production, such as electrolyzers and fuel cells for stationery and transport applications, become mature, the demand for PGMs will further increase.

The metal is also used extensively in jewelry and dental alloys, which accounts for about one quarter of its consumption. Platinum is also used for investment, to make coins and other currency. It is also employed in the pharmaceutical industry as a selective hydrogenation agent. Platinum is used in pacemakers and other equipment inserted in the human body because of its resistance to corrosion from bodily fluids and lack of reactivity to bodily functions. Platinum compounds are important chemotherapy drugs used to treat cancers. Platinum is also used to power computers as it is found in thermocouples and hard discs.

3.19 Recycling

According to the study report published by Johnson Matthey plc,[35] mass-produced consumer components, for example, consumer components such as computer motherboards, contain around 200–250 grams per metric ton (g t–1) of gold and around 80 g t–1 of palladium; mobile phone handsets contain up to 350 g t–1 of gold and 130 g t–1 of palladium; and automotive catalytic converters may contain up to 2000 g t–1 of PGM in the ceramic catalyst brick, the active part of the converter. This is significantly higher than the gold or PGM content in primary ores (on average < 10 g t–1). Additionally, based on our analysis, the value for extracting vanadium from VE is only about one quarter of the cost of the production of vanadium from primary sources, which explains the economic viability of recycling these metals (vanadium, platinum, gold). As these metals have high intrinsic metal value and low recycling costs, recyclability is attractive from an economic point of view, and because of the much higher concentration of metals in the used products, compared to mining of ores, recyclability also helps significantly reduce the environmental burden of metal supply, especially in terms of the impact on the climate.

Because of its high value, platinum can readily be recycled. Currently, most recycling comes from spent automotive catalysts, used chemicals, old jewelry, and electronic devices. In addition to end-of-life recycling, significant volumes of platinum are used in closed-loop production processes, for example, in glass manufacturing, where old platinum equipment is recycled and turned into new equipment, or in the chemical and pharmaceutical world. It is important to note that in all applications, technical recyclability does not present a challenge as yields of well over 95% can be achieved if the product or the PGM-containing component is sent to a state-of-the-art precious metals refinery.

35 https://technology.matthey.com/article/56/1/29-35/

3.20 Technical and Market Challenges

There are various technical and market challenges that can influence the efficiency of recycling at different stages of the recycling process:

- Well-tuned recycling chain
- Diverse specialized stakeholder mix
- Mechanism adopted for the collection of old products, followed by sorting/dismantling and pre-processing relevant fractions
- Recovery of metals

To effectively recycle precious metals, including platinum metal, the following conditions must be met:

1. **Technical recyclability** of the material or metal combination. All precious metals and many other metals can be recovered from, for example, a printed circuit board if state-of-the-art processes are used.
2. **Accessibility** of the relevant components. An underfloor automotive catalyst or personal computer (PC) motherboard is easily accessible for dismantling, whereas a circuit board used in car electronics (for example, in the engine management system) usually is not. As long circuit boards are isolated or dismantled before the car is put through the shredder, the precious metals they contain are easily recyclable.
3. **Economic viability,** whether intrinsically or externally created. A dismantled PC motherboard has a positive net value; therefore, recycling alone is viable. By contrast, a dismantled ultra-thin PGM-coated PC hard disk usually has a negative net value due to the cost of processing it. Recovering the platinum and/or ruthenium from it would currently not be economically viable unless paid for externally or subsidized.
4. **Collection mechanisms** to ensure the product is available for recycling. If collection mechanisms are not in place, items such as old PCs or mobile phones may end up being stored in households or discarded for landfill or municipal incineration. The precious metal they contain would effectively be lost to the recycling chain.
5. **Entry into the recycling chain** and remaining up to the final step. Items such as PC motherboards, mobile phones, or cars containing catalysts are often sent (legally or illegally) to countries lacking the proper infrastructure for recycling at their end of life. This can also result in precious metals being lost to the recycling chain.
6. **Optimal technical and organizational** setup of this recycling chain. Comprehensive recycling chains, for example, items such as PCs or mobile phones, should not be mixed with other low -grade electronic waste and channeled into a shredder process without prior removal of the precious metal-containing circuit boards. The same applies to the PGM-containing catalyst in a car or fuel cell.
7. **Sufficient capacity** along the entire value chain to make comprehensive recycling feasible. Once conditions 1 to 6 are met, the only requirement is to ensure that there is sufficient capacity to process the quantity of material available for recycling. Precious metal refiners will invest in enhancing their recycling capacities if there is sufficient security of feed later. Conditions 5 and 6 are thus crucial to triggering timely investments in a principally growing market for (precious) metals recycling.

Efficient recycling of end-of-life products today serves as insurance for the future. Effective recycling systems would thus contribute significantly to conserving the natural resources of metals and securing a sufficient supply of PGMs and other scarce metals for future generations. They would further mitigate metal price volatility and limit the climatic impacts of metal production, which is energy intensive, especially with (precious) metals mined from ores containing low concentrations of the desired metals.

3.21 Reuse of Platinum

At the end of the life of the products, after they are processed through the recycling facility, they move on to the metal purification process, and pure metal is obtained. This pure metal is again available for reuse in manufacturing industrial end -use products. If the metal is procured under the leasing model, the recycled platinum can be reused by the metal leaseholder if the lease term has not expired, otherwise the lessee must return the pure metal to the lessor.

3.22 Circular Business Model for Platinum

There are five major steps involved in a standard circular business model for platinum using the leasing mechanism:

- The lessor supplies the pure metal to the lessee
- The metal is consumed by the lessee for product manufacturing
- The product is used by the end user
- The product is transported to the recycling facility at the end of the life of the product
- The metal is recycled and/ or extracted by the lessee
- The platinum is reused

At the end of the lease term, the counterparties return either:

- The original metal provided (after applying chemical processes to separate it from the other chemicals with which it has been mixed); or
- The same type of metal (i.e., platinum) in the same quantity and grade as the metal originally provided by the lessor.

In return, the lessor receives a lease fee in accordance with the lease agreement signed between the lessee and lessor.

Under a typical precious metal lease, the leasing company (a precious metal trading company, bank, metal producer, or other lender) bears the risk of the industrial firm failing to return metal at the end of the lease term. The lessor may seek monetary reimbursement for any unreturned metals in the event the manufacturer fails to perform under the lease agreement.

The technical recyclability of the PGMs, combined with the structures in place within the PGM industry, means that it has reached a leading position in terms of sustainable metals management and recycling. In some areas, further scope for improvement exists and can be achieved by involving all stakeholders, with the appropriate political support for the relevant legislation. Similarly, the recycling and reuse of vanadium and VE can be promoted to achieve sustainable metal management.

This analysis indicates that vanadium can be leased, and a circular vanadium value chain can be implemented globally. According to our proposed models for vanadium circularity, long -term models with a duration of 20 to 25 years can be implemented easily considering the financial, economic, social, and environmental aspects associated with the models. The details of each model are explained in section 3.24.

Table 3.5: Comparison of Vanadium Leasing and Platinum Leasing

Particulars	Platinum	Vanadium
Source of raw metal	Primary sources: about 74%	Primary Sources: about 18%
	Recycling: about 26%	Secondary and Co-production Sources: about 82%
Source (region)	South Africa (74%)	China (67%)
	Russia (10%)	Russia (17%)
	Zimbabwe (8%)	South Africa (8%)
Cost of recycling	Autocatalysts may contain up to 2000 g/t of platinum compared to less than 10g/t in platinum ores. With a high metal content, the cost of manufacturing platinum from autocatalysts is much lower compared to platinum manufacturing from platinum ore.	The cost of recycling VE is one sixth of the cost of extracting vanadium
Recyclability	Over 95% of platinum can be recovered	VE can be recycled almost completely, and 97% to 99% of the vanadium in the VE can be recovered
Application	Autocatalysts, industrial products, jewelry, and investment	VE manufacturing Steel manufacturing
Leasing Period	Short term (1/3/6 month)	Short -term leasing (5–10 years)
	Long term (1 year+)	Long -term leasing (20–25 years)

Source: PwC Analysis

3.23 Proposed Business Model for Circular Vanadium Ownership

Two business models with three scenarios each have been identified based on the following:

- A complete vanadium–VRFB value chain analysis,
- The options available for circularity in the vanadium–VRFB value chain, and
- The end user of the VRFB

Both models work in similar ways with one key difference: in Model 1, VE is leased to VRFB manufacturers, who use this leased electrolyte in a single VRFB or multiple VRFBs manufactured by them. In this model, a VRFB manufacturer may sell all the battery components except the VE. VRFB manufacturers are also liable for safekeeping of the VE leased by them, wherever it is being used. In the second model, VE is leased directly to the end user who has the complete VRFB setup done by a VRFB manufacturer without any provision of VE. The advantages and disadvantages of the two models are discussed in Table 3.7.

Table 3.6: Model 1 and Model 2 Scenarios and their Applicability

Model		Scenario		Applicability
Model 1	Leasing Vanadium Electrolyte to the VRFB Battery Manufacturer	Scenario A	Single long-term leasing	Utility -scale storage solution where battery storage requirement will be there for whole life of VRFB
		Scenario B	Multiple short-term leasing	Industrial or domestic storage solution where battery requirement will be less than the life of VRFB
		Scenario C	Multiple short-term leasing in a focused geographical region	Industrial or domestic storage solution where battery requirement will be less than the life of VRFB within a certain geographical location
Model 2	Leasing Vanadium Electrolyte directly to the End User	Scenario A	Single long-term leasing	Utility -scale storage solution where battery storage requirement will be there for whole life of VRFB
		Scenario B	Multiple short-term leasing	Industrial or domestic storage solution where battery requirement will be less than the life of VE
		Scenario C	Multiple short-term leasing in a focused geographical region	Industrial or domestic storage solution where battery requirement will be less than the life of VRFB within a certain geographical location

Source: PwC Analysis

Table 3.7: Advantages and Disadvantages of Model 1 and Model 2

Model	Advantages	Disadvantages
Model 1	The VRFB manufacturer is better placed to reach the local customer base.	Legal ownership during the lease period and end -use location of VE is different, which may lower the standards with which the VE is utilized.
Model 2	Legal ownership during the lease period and the end -use location of the VE are the same, which helps maintain the standards with which the VE is utilized.	The manufacturer must create its own customer base to compete with the local VRFB manufacturer.
	Additional benefits of removing the intermediary from the leasing process are an increase in profitability for the VE manufacturer and a lower cost for end users.	

Source: PwC Analysis

With both models, the following three scenarios emerge:

3.23.1 Scenario A: Single long-term leasing

Leasing duration: In this scenario VE, will be leased for the lifespan of the VRFB or longer, i.e., more than or equal to 20 to 25 years.

Movement of VE: After manufacturing, VE is transported to the end-use location where it is integrated into the VRFB system. Once used, the VE is transported back to the VE manufacturing facility where the VE manufacturer, according to its requirements, either recycles the VE or processes the vanadium from the VE.

If the VE requirement exceeds the life of the VRFB and the VE must be recycled before it can be used in another VRFB. It should be evaluated that transporting VE back to the VE manufacturer to be recycled or prepare a makeshift recycling facility at the end -use location only to avoid multiple transportation of the VE.

Illustrative Example: To further examine and identify the challenges associated with this scenario an illustration is shown below.

Vanadium Electrolyte Producer: ABC Vanadium Inc. produces vanadium from its mining and beneficiation facilities in South Africa. Most of the produced vanadium is, historically, supplied to steel manufacturers worldwide. ABC Vanadium Inc. also supplies vanadium to XYZ Electrolyte Limited, its subsidiary in Austria, to produce vanadium electrolyte.

VRFB Manufacturing company: VB Limited is a VRFB manufacturing company based in Germany.

End User: EU Renewable Power Limited, an RE -based electricity generation company, plans to set up a battery energy storage system in Sweden to supply uninterrupted electricity.

EU Renewable Power Limited ordered a VRFB system at its facilities in Sweden for an uninterrupted power supply.

As discussed previously, the largest share of the cost in a VRFB is attributed to the vanadium electrolyte. Additionally, the electrolyte is stored in separate tanks from the core battery stack and circulated into the battery system through pumps; electrolyte can be integrated into the battery at a later stage before starting the operation of the VRFB. In case of unavailability of the required capital, a VRFB manufacturer may opt to lease the electrolyte.

EU Renewable Power Limited leases the electrolyte from XYZ Electrolyte Limited for 25 years based on the life of the battery. The electrolyte is transported directly to the end-use site in Sweden from electrolyte manufacturing plants to avoid multiple transportation costs. It should be noted that the electrolyte contains vanadium, a critical metal, hence transporting it from one country to another will require regulatory and legal approval.

VB Limited supplies the complete VRFB system to EU Renewable Power Limited. EU Renewable Power Limited owns all the components of the battery except the electrolyte, which will be used by EU Renewable Power Limited for a lease term of 25 years.

At the end of the lease term, the electrolyte is transported back to the electrolyte manufacturing facility. XYZ Electrolyte Limited may either recycle the electrolyte for further leasing or process the vanadium out of the electrolyte to be used according to the company's requirements.

Applicability: This scenario will apply when the end use of the VE is for a long period, such as a power distribution company requiring energy storage solutions or an electricity generation facility that generates RE -based electricity and needs a storage solution for a continuous and reliable power supply.

3.23.2 Scenario B: Multiple short-term Leasing

Leasing duration: In this scenario, VE will be leased to the end user or VRFB manufacturer for shorter durations than the lifespan of the VRFB battery system. The lease term will be between 5 to 10 years, depending on the end use.

Movement of VE: Post manufacturing, VE transported to the first end-use location to be used for the short-term lease. During the first lease term, the VE manufacturer may identify another client for leasing the VE for another term of 5 to 10 years. At the end of the first lease term, VE will be recycled at the VE manufacturing location and transported to the second end -use location. In this way, VE manufacturers can lease the VE until it can no longer be used, at which time VE will be transported back to the manufacturing location to be processed into vanadium and can be further re-used.

Illustrative Example: To further examine and identify the challenges associated with this scenario an illustration is shown below.

Vanadium Electrolyte Producer: ABC Vanadium Inc. produces vanadium from its mining and beneficiation facilities in South Africa. Most of the vanadium produced is, historically, supplied to steel manufacturers worldwide. ABC Vanadium Inc. also supplies vanadium to XYZ Electrolyte Limited, its subsidiary in Austria, to produce vanadium electrolyte.

VRFB Manufacturing company: VB Limited, a VRFB manufacturing company, based in Germany.

End User:

1. PQR Manufacturing Limited is a small-scale manufacturing company based in Nigeria. PQR Manufacturing Limited has an unreliable power supply. It is expected that a reliable, continuous power supply will be available after five years. Hence, PQR Manufacturing Limited ordered the VRFB battery from VB Limited for that period (2023 to 2028).
2. STU Industries is planning to set up a factory in Zambia by the year 2029. It faces the challenge of an unreliable electricity supply for the first seven years of operation and requires the VRFB battery for that period (2029 to 2036).

PQR Manufacturing Limited procures the complete VRFB system from VB Limited, except for the electrolyte, which it procures on a five-year lease directly from XYZ Electrolyte Limited. PQR Limited minimizes its cost by leasing the electrolyte in the VRFB system instead of buying it.

During this five-year period, XYZ Electrolyte found another client, STU Industries, for its electrolyte. STU Industries had the entire VRBF installed from a VRFB manufacturer at its facility, except the electrolyte it leases for seven years from XYZ Electrolyte Ltd.

XYZ Electrolyte brings the VE from Nigeria to South Africa for recycling at its manufacturing plant and then sends it to STU industries in Zambia for the next duration of leasing. .

In this way, XYZ leases its electrolyte to multiple end users until the electrolyte becomes unusable in a VRFB. XYZ Limited then transports the electrolyte back to its electrolyte manufacturing facility to process the vanadium out of the electrolyte for use according the company's requirements.

Applicability: This scenario will apply when the end use of the VE is for a short duration, for example, a factory owner that needs an electricity storage solution for load shedding or to reduce the cost of power consumption by offsetting peak hour consumption. A small VRFB solution would be required for such applications.

3.23.3 Scenario C: Multiple short-term leasing in focused geographical region

In this scenario, VE will be leased to multiple players for short durations, similar to scenario B, within a focused geographical location to minimize the logistic costs and other logistic challenges.

In this scenario, all the lessees are from a focused geographical area, for example, a country, making the transportation of VE from one lessee to another much easier and ore cost effective. However, in this scenario, the identification of multiple lessees in a certain geographical area would present a challenge.

To reduce the transportation cost in this scenario, the recycling facility will need to be established at the end-use location. The financial analysis below compares the costs of transporting VE and establishing the VE recycling facility to assess the viability of this scenario.

3.23.4 Financial analysis for setting up the VE recycling facility in the focused end-use geography

The following assumptions formed the basis of the financial analysis:

1. South Africa is considered the VE manufacturing country and Europe as an end -use location, since transportation data for these locations was obtained from the financial model provided by the client. However, the transportation cost is influenced by the distance between the VE manufacturing facility and the end-use location.
2. The fee for reprocessing the electrolyte is US$5.5/kgV.[36]
3. Obtaining 1 MWh of VRFB36 will require 4.8748 metric tons of vanadium.

[36] Bushveld financial model

4. If theCAPEX:3376
5. The CAPEX required to set up the reprocessing facility (80% of the total cost) totals US$21449.26/MWh.[37]
6. It was assumed that the cost of setting up the recycling facility is the same as the reprocessing cost.
7. The cost of transporting VE from South Africa to Europe is US$0.31/L.

Table 3.8: Assumptions used for the Financial Analysis

Particulars	Value	Unit
CAPEX for Recycling VE per MWh	21,449.26	US$/MWh
Per MWh VE Requirement	52,630	L/MWh
CAPEX Required per Liter of VE Recycled	0.41	US$/Liter
Per Liter VE Transportation Cost (one side)	0.31	US$/L
Per Liter VE Transportation Cost (both sides)	0.62	US$/L
Per MWh Transportation Cost (one side)	16,315	US$/MWh
Per MWh Transportation cost (both sides)	32,630	US$/MWh

Table 3.8 demonstrates that the capital cost for setting up the recycling facility is 1.31 times the one-way transportation cost of the VE between the end -use location (Europe) and the VE recycling location (South Africa). Since the VE will be transported to and from the VE recycling location (South Africa) to the end -use location (Europe) after completion of each lease period for recycling, the transportation cost will be higher compared to the cost of setting up the recycling facility. The analysis revealed that setting up a recycling facility in a focused geography is economical compared to the frequent transportation of VE from the end-use location to the manufacturing facility.

3.23.5 Comparative analysis of different model scenarios

To further understand which business model scenario is best suited for implementation, various parameters, such as financial, economic, regulatory, environment and social aspects, are analyzed. The proposed business model scenarios are compared based on various factors associated with these parameters.

In the current market scenario, the major consumers of VRFBs in the next decade will involve utilities (generation, transmission, and distribution) and commercial and industrial consumers, including telecom towers that will require long-term deployment of the battery. Key application include the following:

- **Grid Congestion Relief:** In congested areas where new transmission and distribution lines may be needed, VRFBs can alleviate stress without the same capital investment and environmental disruption required to build out new lines.
- **Distributed Generation:** VRFBs can be installed in rural or remote microgrids to act as a potential replacement for diesel generators providing backup power.
- **Arbitrage:** In large industrial applications such as manufacturing processes, VRFBs can shift energy-intensive processes to off-peak hours to relieve strain on the grid.
- **Ancillary Services:** VRFBs are also being used to provide ancillary services, such as balancing and frequency response.
- **RE Integration:** VRFBs will become increasingly important as the decade progresses with more renewable generation sources coming online and longer -duration energy storage (i.e., longer than four hours) required to balance the grid.
- **Standalone Charging Systems:** VRFBs can be paired with solar PV systems to form standalone charging systems. They can also be added to existing charging infrastructure in urban areas because of their ability to be cycled frequently without experiencing capacity degradation.

[37] Bushveld Financial model and PwC estimates

Table 3.9: Detailed Comparison of the Feasibility of Various Business Models

Parameters	Factors	Scenario A: Long -Term Leasing	Scenario B: Short -Term Leasing	Scenario C: Short-term Leasing—Focused Market	Scenario Ranking
Financial					
	1. Cost of transportation	Transportation frequency of the VE being used in the battery will be lower with long-term leasing, resulting in a lower cost for transportation.	Transportation frequency of the VE being used in the battery will be higher with the short-term leasing, resulting in a higher cost for transportation.	Although the VE transportation frequency will be higher compared to the long-term scenario, transportation will occur in a focused geography, resulting in significantly lower travel distances between each lease period. Hence, the transportation cost in this scenario will be the lowest.	C>A>B
	2. Cost of recycling	The frequency of VE recycling is lower compared to other scenarios, making the recycling frequency the lowest among the proposed scenarios Because of the low frequency of transportation and shifting, there is a lower risk of contamination to the VE, resulting in a lower cost for recycling.	With increased recycling frequency, the recycling cost per unit of VE will be higher with short -term leasing. With multiple movements of the electrolyte, the risk of contamination increases, resulting in a shorter life of the electrolyte before it is recycled.	The impact will be the same as in scenario B.	A>B=C
	3. Per unit upfront cost of setting up the battery system at the end -use location. (Upfront cost)	Since the battery setup will be for a long duration, the cost incurred for setup will be lower per unit of energy stored.	Since the battery setup will be for a short duration, the cost incurred for setup will be higher per unit of energy stored.	The impact will be the same as in scenario B.	A>B=C
	4. Total cost of battery maintenance	The maintenance cost increases with time, resulting in a higher maintenance cost with long -term leasing.	The short life of the battery will require lower maintenance, resulting in a lower overall cost of maintenance.	The impact will be the same as in scenario B.	B=C>A
	5. Damages and spills during shifting and transportation	With a lower frequency of movement of the VE, there will be less shifting of the electrolyte from the battery to the transportation vehicle, decreasing the risk of spillage and other damages to the VE.	There will be a higher frequency of VE shifting from the battery to the transportation vehicle, increasing the risk of damage and spillage of the VE.	The impact will be the same as in scenario B.	A>B=C
	6. Lease rate	The lease rate is expected to be lower due to a longer PPA tenor and greater of cash flow predictability.	The lease rate is expected to be higher due to a shorter PPA tenor and the need to secure multiple clients for leasing.	The impact will be the same as in scenario B.	A>B=C

Parameters	Factors	Scenario A: Long -Term Leasing	Scenario B: Short -Term Leasing	Scenario C: Short-term Leasing—Focused Market	Scenario Ranking
Financial					
	7. Leveliged Cost of Storage (LCOS)	LCOS is expected to be lower due to low lease rates and lower transportation and reprocessing costs because of long lease terms.	LCOS is expected to be higher because of high lease rates and more frequent transportation and reprocessing costs.	As the distance of travel between lease periods will be significantly lower compared to the other two scenarios, transportation costs will be lower. However, because of shorter lease terms, the cost of recycling would be higher than in scenario A. LCOS is expected to be higher than in scenario A but lower than in scenario C due to: • Higher lease rate • Higher recycling cost • Lowest transportation cost among the scenarios.	A>C>B
	8. Profitability	Profitability is expected to be higher because of a longer more predictable PPA tenor and one-off transportation and reprocessing costs.	Profitability is expected to be lower because of a shorter PPA tenor and the need to secure multiple clients for leasing and multiple transportation and reprocessing costs.	The impact will be the same as in scenario B.	A>B=C
Environmental					
	1. Environmental impact due to transportation	The frequency of VE transportation is low and will result in: • Lower carbon emissions, • Lower natural resource utilization (fuel /other packaging material for transportation), and • Fewer direct and indirect environmental impacts (air, noise, water, and marine pollution).	The frequency of VE transportation is high and will result in: • Higher carbon emissions, • Higher natural resource utilization (fuel/other packaging material for transportation), and • More direct and indirect environmental impacts (air, noise, water, and marine pollution).	As the traveling distance between lease periods will be significantly lower compared to the other two scenarios, the environmental impact from transportation will be the lowest.	C>A>B
	2. Waste generation	It is expected that long-term leasing will be directly linked to the life expectancy of the battery and battery parts (other than the electrolyte), thus onetime generation of battery waste will be involved, which can be recycled as electrical/plastic/metal waste by mechanical separation. Thus, the long-term leasing model will have minimal waste generation potential due to VRFB operations.	With short-term leasing, the battery parts will be used for a shorter duration. In this scenario, battery waste will be generated at the completion of each leasing period, i.e., at frequent intervals, which will result in a higher quantum of battery waste generation.	The impact will be the same as in scenario B.	A>B=C

Table 3.9: Detailed Comparison of the Feasibility of Various Business Models (continued)

Parameters	Factors	Scenario A: Long -Term Leasing	Scenario B: Short -Term Leasing	Scenario C: Short-term Leasing—Focused Market	Scenario Ranking
Environmental					
	3. Toxic discharge to soil	There is a lower risk of soil contamination due to toxic discharge as the frequency of VE shifting is lower.	There is a higher risk of soil contamination due to toxic discharge during shifting of the VE from the battery to the transportation vehicle and vice versa.	The impact will be the same as in scenario B.	A>B=C
	4. Environmental impact due to the production of other battery components	In the VRFBs, there are other components like reactors (ion exchange membrane, current collector, flow plates), balance of plant (pumps, tanks, pipes, heat exchangers, etc.) In long -term leasing, these components will be used for a longer duration Hence, the environmental impact to produce other components will be lower.	In short-term leasing, the other battery components will be used for a shorter duration, which will result in a higher environmental impact due to the production of these components.	The impact will be the same as in scenario B.	A>B=C
Social	**1. Employment**				
	Three sections of employment are compared: **a) Job creation** **b) Employment duration, and** **c) Immigration**	VE recycling will generate additional jobs in the VRFB space as, after every lease period, the VE will need to be recycled before being deployed for another lease. The direct jobs will be generated in two forms: 1. VE recycling: Jobs generated to recycle the VE. 2.VE transportation: Jobs generated to transport VE from the end -use location to the recycling facility at the end of the first lease and then to the new lease location at the start of the new lease term. In addition to the abovementioned jobs related to recycling and movement of VE, there will be an additional need for: VRFB installation and dismantling: Jobs generated to install and dismantle the VRFB at the start and end of the lease period. VRFB maintenance: Jobs generated for maintenance of the various VRFB components, such as the pumps, pipes, battery stacks.			
	a) Job creation	In this scenario, VE recycling will happen every 20–25 years compared to every 5–10 years in other scenarios, i.e., low frequency of VE recycling, VE transportation, and VRFB installation and dismantling. This scenario will require a lower quantum of work, resulting in less job creation for VE recycling, VE transportation, and VRFB installation and dismantling. However, due to long -term installation in this scenario, the requirement for maintenance will be higher, resulting in more maintenance job creation.	This scenario will have a higher frequency of VE recycling, VE transportation, and installation and dismantling of VRFB, which will result in a higher quantum of work and more job creation. However, short-term installation will require less frequent maintenance, resulting in fewer maintenance -related jobs.	The impact will be the same as in scenario B.	C>B>A

Parameters	Factors	Scenario A: Long -Term Leasing	Scenario B: Short -Term Leasing	Scenario C: Short-term Leasing—Focused Market	Scenario Ranking
Social	**1. Employment**				
	b) Employment duration	1. VE recycling: The duration of jobs will not be impacted in different scenarios as it is the recycling that will occur continuously at the recycling plant in all the scenarios. 2. VE transportation: The duration of jobs will not be impacted in different scenarios, as the transportation of VE will occur continuously for all the scenarios. 3. VRFB installation and dismantling: VRFB installation is a one-off job, hence it will have no duration of job, but will have an impact on immigration (discussed below). 4. VRFB maintenance: The battery will be installed for a longer duration in this scenario, which will result in a longer employment duration for maintenance of the VRFB.	No influence on job duration for jobs related to VE recycling, VE transportation, and VRFB installation and dismantling. However, for VRFB maintenance, the battery will be installed for a shorter duration in this scenario, which will result in a shorter employment duration for maintenance of the VRFB.	No influence on job duration for jobs related to VE recycling, VE transportation, and VRFB installation and dismantling. However, for VRFB maintenance, as the battery installation is done in a specific geographical location, the same maintenance personnel can be deployed for the maintenance of various battery systems installed in that region/geography. This will result in a longer duration of maintenance -related jobs in this scenario.	C>A>B
	c) Immigration	VRFB is a relatively new, commercially deployed battery system. To install and operationalize it, specialized skills will be required. Hence, we assume that there will be immigration involved until the technology becomes more prevalent and such skills are developed with increased deployment. As the frequency of installation and dismantling will be lower in this scenario, international movement of the personnel setting up the battery system will be lower compared to the other scenarios.	With the increased frequency of VRFB installation and dismantling, immigration is expected to be the highest in this scenario.	The frequency of setting up will increase but will occur in a specific location. Hence, the immigration requirement will be the lowest in this scenario.	B>A>C

Table 3.9: Detailed Comparison of the Feasibility of Various Business Models (continued)

Parameters	Factors	Scenario A: Long -Term Leasing	Scenario B: Short -Term Leasing	Scenario C: Short-term Leasing—Focused Market	Scenario Ranking
Social	1. Employment				
	2. Skills Development	1. VE Recycling: • New skills will be required • Skills development will be lower compared to other scenarios due to the lower frequency of recycling. 2. VE Transportation: • No new skills will be required. 3. Installation and dismantling of VRFB: • New skills will be required • In this scenario, the frequency of installation and dismantling is low, resulting in lower demand for these skills compared to other scenarios and lower skill development opportunities for the wider population. 4. Maintenance of VRFB: • New skills will be required In this scenario, maintenance requirements will be higher, resulting in higher potential skill development for the wider population.	1. VE Recycling: • New skills will be required • Skills development will be higher compared to other scenarios due to the higher frequency of recycling. 2. VE Transportation: • No new skills will be required. 3. Installation and dismantling of VRFB: • New skills will be required • In this scenario, the frequency of installation and dismantling is high. However, the installation will occur in various locations (not in a focused location as done in scenario C), resulting in more immigration (discussed above) compared to wider skill development. 4. Maintenance of VRFB: • New skills will be required In this scenario, maintenance requirements will be lower as well as the duration of job will lower, resulting in lower potential for skill development.	1. VE Recycling: • New skills will be required • Skills development will be higher compared to other scenarios due to the higher frequency of recycling. 2. VE Transportation: • No new skills will be required. 3. Installation & dismantling of VRFB: • New skills will be required • In this scenario, the frequency of installation and dismantling is high. Moreover, the installation and dismantling will be happening in a specific location, resulting in higher skill development opportunities for the wider population. 4. Maintenance of VRFB: • New skill will be required Although VRFB deployment will take place over a shorter period, resulting in lower maintenance requirements, it will occur in a specific location, resulting in the highest degree of development of localized maintenance skills in this scenario.	C>A>B
	3. Micro entrepreneurship	With long-term leasing, the size of the battery deployed will be greater. Because of the longer life of the battery, maintenance and service requirements will be higher compared to short -term leasing, increasing the potential for the development of a service-oriented value chain and creating more opportunities for micro entrepreneurship.	In this scenario, the duration for which the battery will be installed is lower, requiring less maintenance and services for the mechanical parts, such as pumps and pipes, resulting in fewer opportunities for the development of a service-oriented value chain and low potential for micro entrepreneurship.	As the battery installation will occur in a specific location, the maintenance and service requirements will be the highest of all scenarios, creating a greater opportunity for the development of a service-oriented value chain and resulting in more micro entrepreneurship opportunities.	C>A>B

Parameters	Factors	Scenario A: Long -Term Leasing	Scenario B: Short -Term Leasing	Scenario C: Short-term Leasing—Focused Market	Scenario Ranking
Social	1. Employment				
	4. Energy access in low-income areas	At present, long- term leasing is a cheaper option as compared to other scenarios. It has better potential to be implemented in economically weaker areas of society with poor grid connectivity, resulting in better energy availability.	At present, short-term leasing is a more expensive option than long -term leasing. There will be lower potential for implementation in economically weaker areas of society.	The impact will be the same as in scenario B.	A>B=C
	5. Health and safety of the workforce	The lower exposure of the workforce to the VE due to the lower frequency of movement of the VE will decrease the risks to the health and safety of the workforce.	With the increased exposure of the workforce to the toxic vanadium electrolyte, increased safeguards will be required for shifting the VE from electrolyte tanks to the transportation vehicle.	The impact will be the same as in scenario B.	A>B=C
Regulatory					
	1. Licensing and permitting requirements	Because of international movements, regulatory approvals will be required, and regulations/ guidelines must be followed. This includes customs and excise licensing requirements associated with the export and import of vanadium and its associated derivatives. However, the frequency of transportation and compliance with related licensing requirements will be less and would present reduced compliance risks.	Due to increased international movements resulting from multiple and more frequent leasing agreements, compliance commitments related to licensing and permitting will increase and pose a more significant risk when compared to the long-term leasing option. This can decrease the ease of doing business.	Since the leasing is done in a focused geographical area, the regulatory approval requirement will be for onetime transportation of VE from the manufacturing location to the end-use location. After onetime transportation, the movement of VE will occur in a specific location, hence compliance risks will be lower than with short -term leasing.	C>A>B
	2. Environmental impact regulations	While the impact of mining regulations would stay constant across the three options, regulations pertaining to the recycling of VE and other environmental impacts will be less cumbersome in a long-term leasing scenario, due to less frequent and less environmentally intensive processes occurring as part of the long-term leasing model.	More frequent recycling and end-of-life occurrences linked to short -term leasing will trigger more significant compliance risks from an environmental perspective.	The environmental impact of transportation of the VE will be the lowest as the movement of VE is happening in a particular geography (distance is significantly reduced because of focused geographical movement), there would be fewer environmental regulatory hurdles in this scenario. Additionally, understanding the environmental regulations of a specific geographical area will be less onerous compared to the need to comply with environmental requirements in multiple jurisdictions in the other two models.	C>A>B

Conclusion

- Long -term leasing (scenario A) is the most suitable option for leasing VE as it provides the most economical storage solution to the end user due to low transportation costs and associated logistical costs. Moreover, in the current market conditions, VRFBs are limited to long -term deployment, making this scenario the best option for deployment in the near future.
- It is expected that, as VRFB technology evolves, short -term deployment opportunities may arise, such as battery back-up for UPS systems. In such conditions, focused market leasing (scenario C) will be a better option for leasing, as it provides better social benefits to the end -use location due to the increased frequency of recycling and movement of the VE, which leads to increased employment opportunities.
- Because of the high frequency of transportation and longer distances, resulting in more significant financial and environmental impacts, short-term leasing (scenario B) is infeasible.

4 Analysis of Supply and Demand in the Vanadium Market

4.1 Global Supply

Vanadium is one of the most abundant elements on earth, with known reserves sufficient to meet current market demand for over 150 years. Vanadium occurs as a major constituent in four types of mineral deposits:

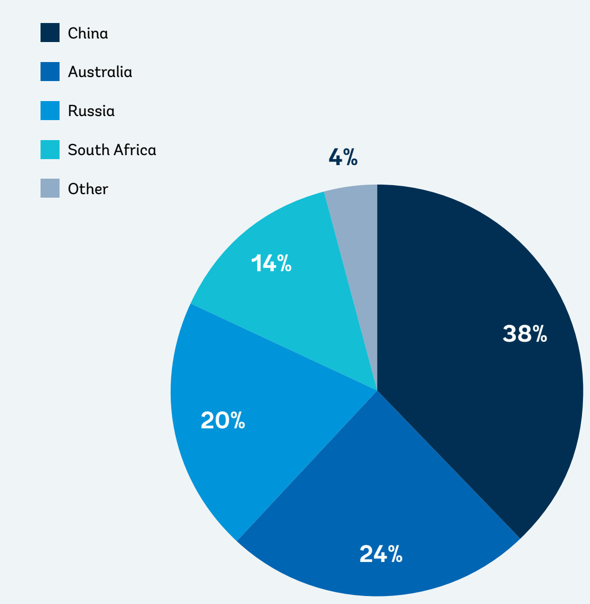
- Vanadiferous titanomagnetite deposits (VTM)
- Sandstone-hosted vanadium deposits (SSV)
- Shale-hosted vanadium deposits
- Vanadate deposits

The United States Geological Survey (USGS) estimates global vanadium reserves at 24 million metric tons. China (the world's largest producer and consumer of the mineral, as well as the world's third-largest country by land area) holds the largest share of these reserves. Australia (which does not currently produce vanadium commercially) holds the second-largest reserves, followed by Russia and South Africa. Brazil and the United States, which are among the other" category of countries in Figure 4.1, have much smaller vanadium reserves.

Vanadium production is concentrated in only a few countries, with several countries having ceased production over the past 25 years. According to the USGS, between 1998 and 2005, vanadium production occurred in the following countries: Australia, China, Hungary, Kazakhstan, Russia, South Africa, and the United States. However, by 2009, three countries (Australia, Hungary, Kazakhstan) ceased production, with one new country (Brazil) starting vanadium production in subsequent years.

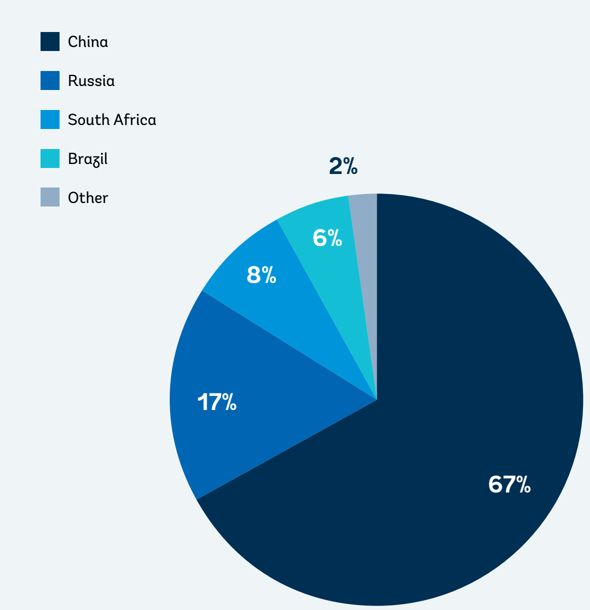
In 2021, the USGS reported global production of 110,000 mtV, primarily by four countries: China, Russia, South Africa, and Brazil. China alone accounted for two thirds of global output in 2021, having almost doubled its proportion of global production from 1998, from only 36% of the global total in 1998 to over 60% in 2021. In terms of volume, China's output increased from 15,500 mtV in 1998 to 73,000 mtV in 2021. Given the country's dominance in global steel production and its vast reserves of vanadium, this increase in production is not surprising.

Figure 4.1: Distribution of Global Vanadium Reserves, 2021



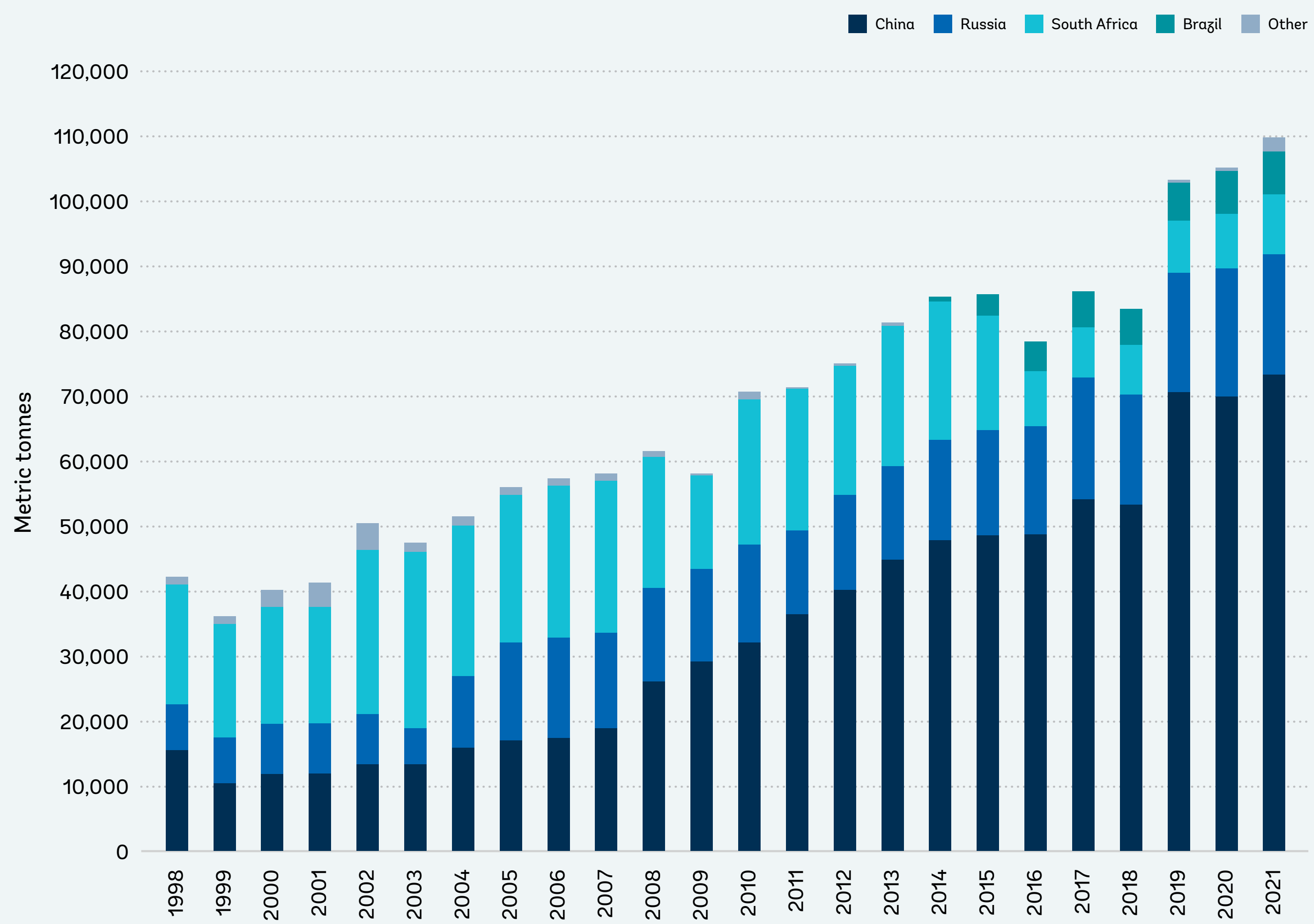
Source: Merchant Research & Consulting

Figure 4.2: Global Vanadium Production, 2021



Source: USGS

Figure 4.3: Historical Global Vanadium Production, 1998-2021



Source: USGS

Vanadium production data is published annually in preliminary form with subsequent updates to the data as more information becomes available. The data here are the latest available estimates from the USGS for each year and may not necessarily align with the first round of data published for each year.

South Africa's global market share has fallen from 50% in the early 2000s to less than 10% in recent years. Production peaked at 27,172 mtV in 2003 and moderated thereafter to an average of 20,500 mtV per annum during 2011-15. Production then fell from 17,788 mtV in 2015 to 8,163 mtV in 2016 because of a mine closure by Evraz Highveld Steel and Vanadium. South Africa's production increased to 9,100 mtV in 2021.

Table 4.1 lists companies located in the primary vanadium producing countries, with a short introduction to each of these companies' operations.

Despite holding nearly one quarter of global vanadium reserves, Australia is not currently one of the top vanadium -producing countries. In addition, the country does not have any flow battery or electrolyte production plants, even though it is the birthplace of the vanadium flow battery. Early in 2022, the Australian Prime Minister, Scott Morrison, announced that Australian Vanadium Limited would receive $A 49 million to help fund their vanadium processing plant, as support for technology sector projects in the manufacturing industry, with the company planning to process high-purity vanadium.

Table 4.1: Examples of Companies in the Primary Vanadium-Producing Countries

Country	Company	Detail
China	Pangang Group Vanadium Titanium & Resources Co., Ltd	Pangang Group is headquartered in Panzhihua, a prefecture-level city in Sichuan province, considered the vanadium and titanium capital of China. Its principal operations include the manufacture and sale of vanadium and titanium products, with the company having won the National Technological Invention Award through its vanadium-nitride production technology. With a production capacity of 40,000 mtV products, it is the world's leading supplier of vanadium products like vanadium pentoxide, ferro-vanadium, vanadium nitride, and vanadium aluminum.
Russia	Evraz Lgok	Evraz Lgok, part of the multinational steel manufacturing and mining company EVRAZ, is a major mining company in Russia. Evraz Lgok is one of Russia's largest iron ore mines and extracts vanadium content at the Gusevogorskoe deposit. This is part of the Mt Kachkanar deposit, which is the only source of vanadium ore in Russia. The company recently invested in new mining equipment, with plans to purchase more over the 2022–24 period as production expands. In addition, railway tracks and cable power lines were built to accommodate expansion.
South Africa	Bushveld Minerals	Bushveld Minerals, which owns two of the four operating vanadium processing facilities in the world, is a vertically integrated, low-cost, primary producer of vanadium. It is also one of only three such producers globally. Bushveld Minerals produced 3% of the world's vanadium in 2021, approximately 3,600 mtV. Its two main operational pillars are Bushveld Vanadium and Bushveld Energy, which allows the company to participate in the entire vanadium value chain. These two operations mine and process vanadium, as well as provide energy storage solutions, respectively.
Canada / Brazil	Largo Resources	Largo Resources is headquartered in Canada and supplies vanadium products sourced from its Maracás Menchen Mine in Brazil. Largo's two vanadium supply brands are its VPURE™ and VPURE+™ products. There was also a recent 2020 acquisition of vanadium redox flow battery (VRFB) technology, with integration into its VCHARGE vanadium battery technology. Currently, Largo Resources is combining its vanadium operations with its manufacturing capabilities, which will provide energy storage solutions focused on vanadium.
United States	Energy Fuels Inc.	Energy Fuels Inc. mainly produces uranium, but it is also the United States' only primary vanadium producer, with the element found in many of its uranium mines. The company mines and produces vanadium and operates the countries' sole conventional vanadium mill (the White Mesa Mill) in southern Utah.

Source: PwC research

4.2 Global Demand

Vanadium is a medium-hard, steel-blue metal. It is valuable in the manufacturing industry because of its malleable, ductile, and corrosion-resistant qualities. The mineral is primarily used in the production of steel alloys which are used in the production of diverse products. These include the construction of buildings, nuclear reactors, ships, engines, and hand tools, among other uses. Vanadium is also increasingly being used as part of battery storage applications, in particular the storage of renewable energy created from solar and wind installations.

Approximately 90% of global vanadium consumption is in the making of steel for end-products in the industrial and automobile sectors. Low-alloy, high-strength steel, for example, is used in construction rebar. Steel accounts for most vanadium use, with steel production and consumption having grown significantly over the past two decades. In 2010, average steel production and consumption was around 1.4 billion metric tons. By 2021, this increased to 1.9 billion metric tons, and by 2031 steel production and consumption is forecast at 2.2 billion metric tons.

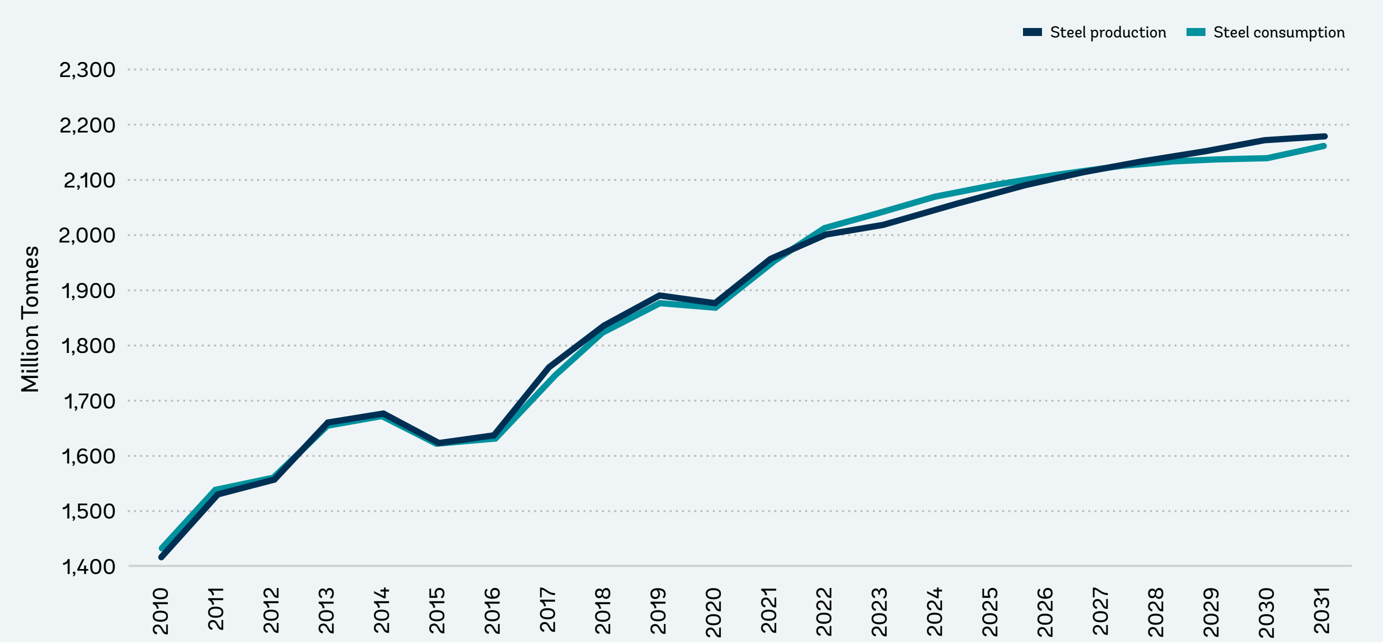
Vanadium is used in the production of alloys, such as titanium and aluminum. For example, the strength-to-weight ratio of vanadium-titanium alloys makes it ideal for aerospace applications. In addition, vanadium is used in tubes and pipes that carry chemicals because of its corrosion-resistant properties.

Using vanadium alloy in automobiles helps increase fuel efficiency by reducing the overall weight, and includes armor plating, vehicle axles, and engine parts. This use of vanadium has rapidly expanded, as vanadium was not being incorporated into cars two decades ago, versus its use in 45% of cars in 2017. It is estimated that by 2025, the alloy will be incorporated into the production of almost 85% of automobiles.

Unsurprisingly, given its diverse applications, global demand for vanadium continues to grow.

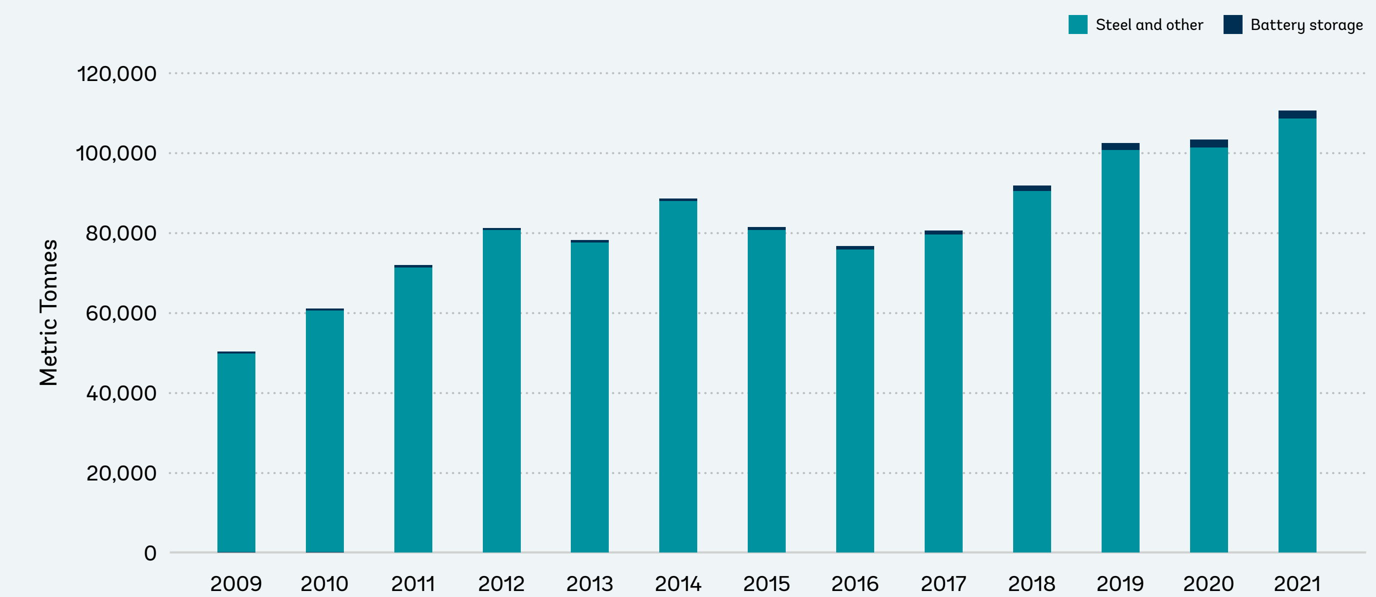
China is the world's largest steel producer and accounted for 65% of global demand for vanadium in 2021. Industrialization in China, with increased demand for steel in construction, infrastructure, and rebar applications, is a significant driver of the demand for vanadium.

Figure 4.4: Global Steel Production and Consumption, 2010-2031



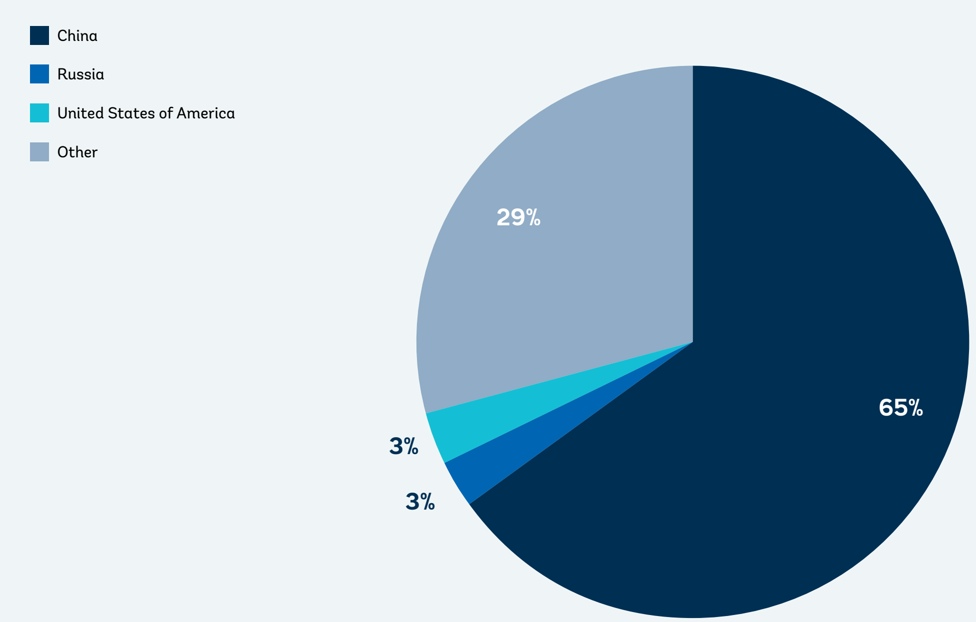
Source: Fitch Solutions

Figure 4.5: Global Vanadium Consumption, by end use



Source: Merchant Research & Consulting; PwC research

Figure 4.6: Global Demand for Vanadium, 2021

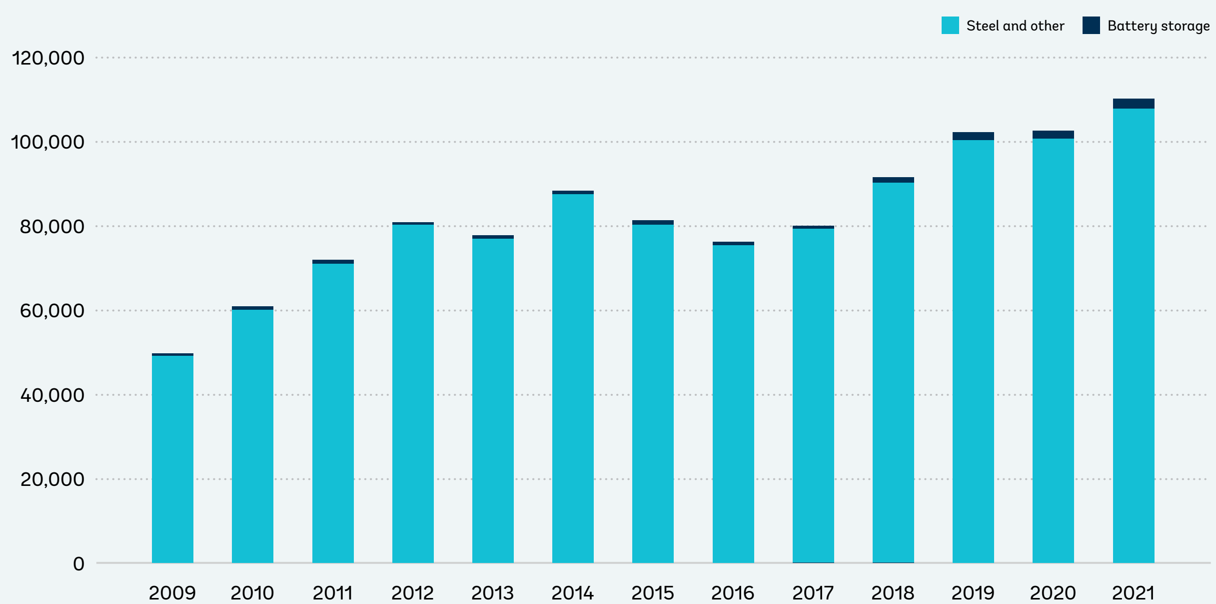


Source: Vanitec.org

Country example: China's exports and imports of vanadium-related commodities

China, as the dominant vanadium producer, is the worlds' largest exporter of the metal in various forms. However, the country's own demand for vanadium, which has been steadily increasing over the years, exceeds its supply capacity. Due to this, China also imports vanadium in different forms. The following table lists China's vanadium-related trade data for 2021 highlighting the share of its top sources and destinations.

Niobium, tantalum, vanadium ores and concentrates		Ferrovanadium	
Exports (98% of total)	**Imports (90% of total)**	**Exports (97% of total)**	**Imports (98% of total)**
Hong Kong	Nigeria	South Korea	Czech Republic
Other Asia (not elsewhere specified)	Democratic Republic of the Congo	Netherlands	Austria
United States	Rwanda	Japan	Russia
Belgium	Brazil	Taiwan	Germany
Nigeria	Sierra Leone	Canada	South Korea



Country example: United States applications of imported vanadium-related products

Demand growth is attributed to vanadium's many uses. The United States, for example, imports vanadium in the following forms for domestic consumption:

- Aluminum-vanadium master alloy
- Ash and residues
- Ferrovanadium
- Hydrides and nitrides of vanadium
- Oxides and hydroxides
- Sulfates
- Vanadates
- Vanadium chlorides
- Vanadium metal
- Vanadium ores and concentrates
- Vanadium pentoxide (anhydride)

Vanadium pentoxide (anhydride) accounted for the largest portion of the country's imports at 48.0% of the total and is the main component of the VRFB, the most recent application of vanadium in batteries. Ferrovanadium, the second largest contributor at 39.0% of imports, is used in steel metallurgy processes, with vanadium's primary use being to strengthen steel.

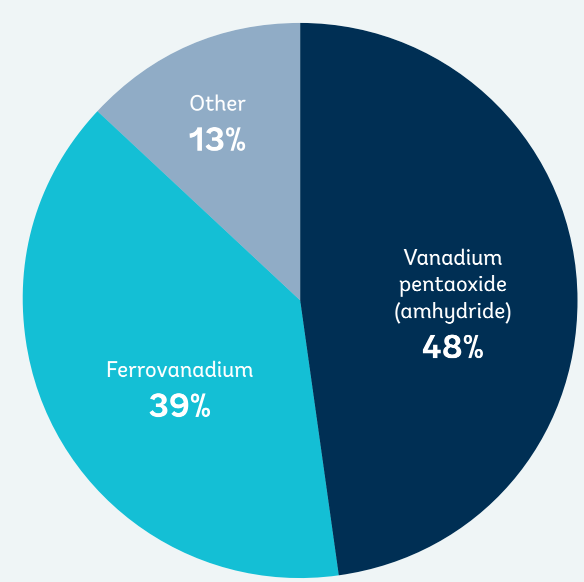
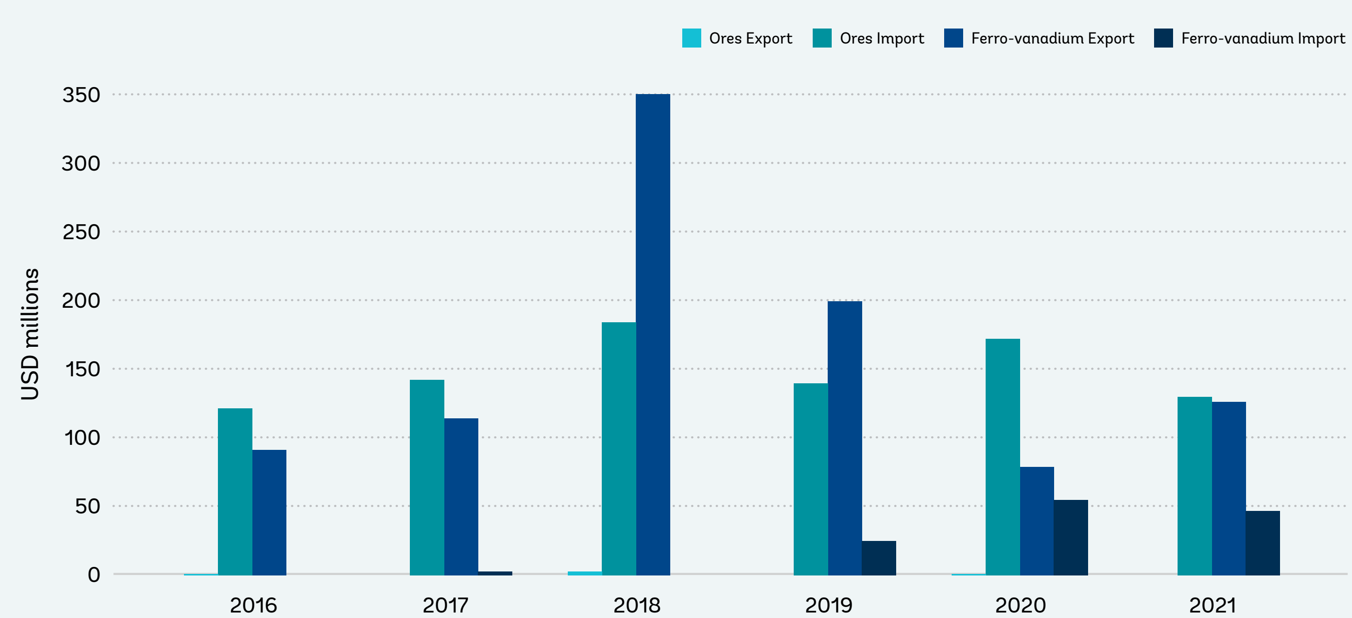
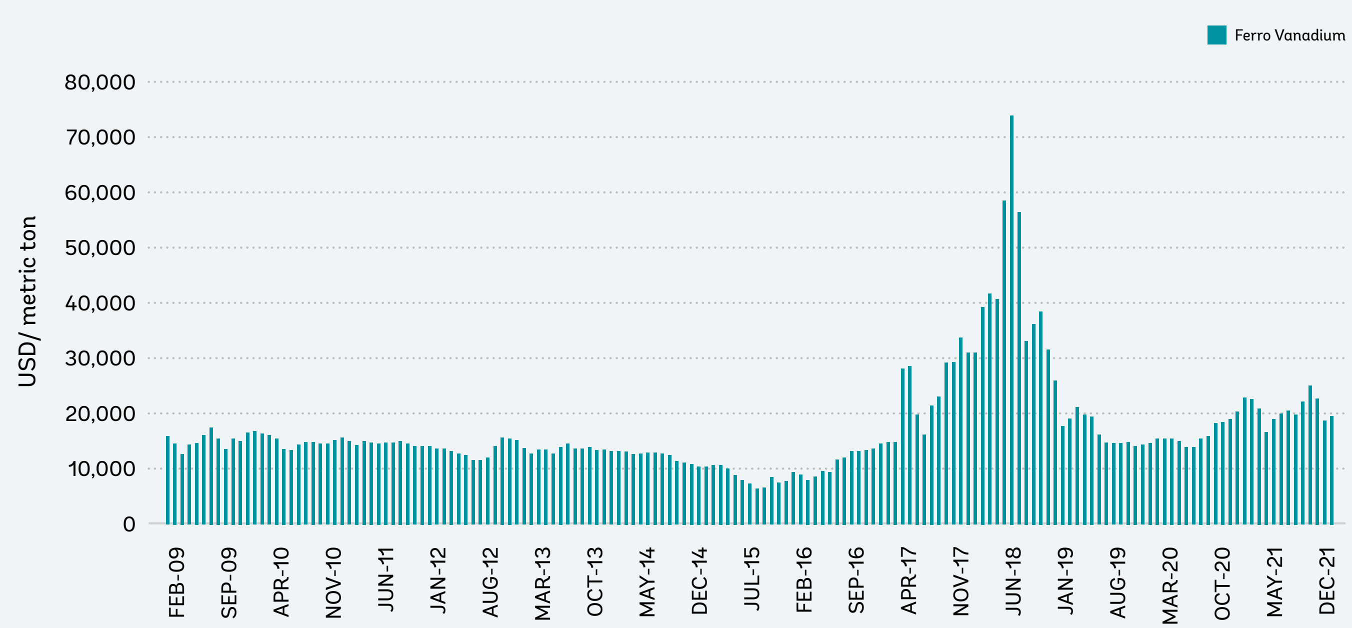


Figure 4.7: Exports and Imports of Vanadium, 2016-21 (USD millions)



Source: Merchant Research & Consulting

Figure 4.8: Ferro Vanadium 50% China spot price (US$ per metric ton)



Source: Investing.com

A push for green stimulus plans, along with increasing support and demand for energy storage geared toward renewable energy, is also increasing the demand for VRFBs and vanadium. Increased demand for fuel efficiency to decrease the carbon footprint is another driver of demand for vanadium, which is used to lighten the weight of automobiles and reduce fuel consumption.

4.3 Global Market Prices

Vanadium prices have fluctuated over the past few decades due to supply and demand factors. For example, market prices declined during 2013–15 after feedstock production increased and peaked in 2013. Periods of lower demand also impacted market pricing: global consumption declined from 88,500 metric tons in 2014 to 81,500 metric tons in 2015, alongside a decline in global steel production. As a result, vanadium declined from US$15,395 per metric ton in December 2012 to a low of US$6,354 per metric ton in December 2015.

Market prices increased during 2016 following the closure of the Evraz Highveld's Mapochs mine in South Africa, as well as the suspension of operations at the vanadium-processing facility, Venchem. South Africa was the second -largest vanadium producer in 2013, but production fell over 60% by 2016. These factors resulted in an increase in the price of vanadium to US$13,000 per metric ton by the close of 2016.

Vanadium prices spiked during 2017/18, partly due to China's shift toward more environmentally friendly mining and production practices. Multiple mines that were causing pollution were closed, with many vanadium producers forced to shut down operations. With this decrease in supply, the demand for steel continued to grow, pushing steel prices upward. In 2018, China also implemented the Chinese Rebar Standard GB/T 1499.2.2018, which saw stricter rules enforced on rebar producers to produce high-strength rebar. Vanadium micro-alloying increases the strength of rebar and improves its properties, making it the perfect solution for producers. As a result, vanadium consumption in China increased significantly during 2018, compared to the previous year. This change in regulation impacted the production and exports of steel rebar, resulting in a further increase in global steel prices. The vanadium price peaked above US$73,000 per metric ton in October 2018, before correcting to less than US$15,000 per metric ton by the close of 2019.

The COVID-19 pandemic adversely affected global steel production and consumption in 2020 as countries implemented various restrictions and lockdowns. Most sectors saw contractions in growth, including the industrial sector, which had both direct and indirect effects on the steel industry, disrupting steel demand. The pandemic also saw excess inventory at mills, with the steel supply chain impacted, resulting in a decline in steel prices. As a result, the vanadium price declined to a low of US$13,632 per metric ton in November 2020.

Prices have once again started rising in 2021/22 as economies around the demonstrate a recovery in growth. Increasing demand for vanadium even saw the USGS adding the commodity to their list of critical minerals in 2022. This list contains those minerals that play a critical role in the United States' renewable energy development, national security, infrastructure, and overall economy. The vanadium price averaged US$21,055 per metric ton during the first half of 2022.

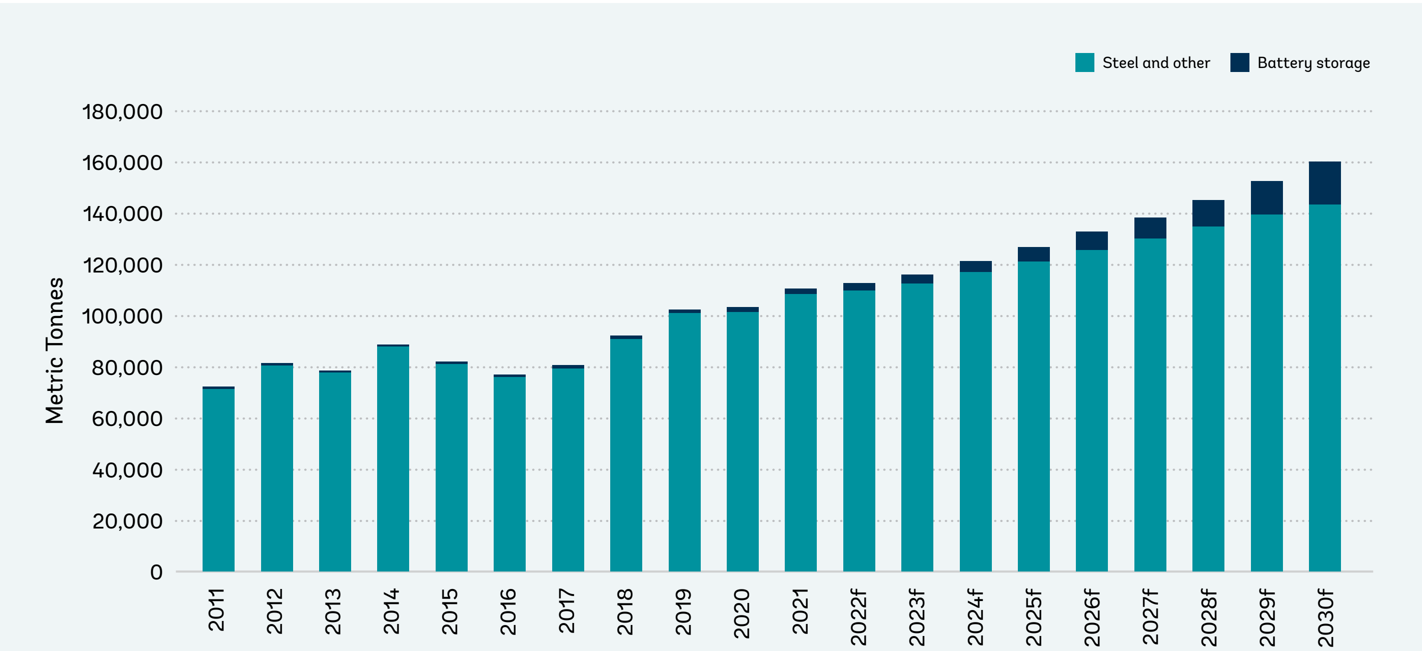
Outlook for future demand and supply

The steel and alloy industries currently account for 95% of vanadium consumption, with a further 3% used by the ceramic and chemical industries. Global steel production increased by a CAGR of 2.4% per annum during the decade ending in 2021 and will remain the dominant consumption market for vanadium over the coming decade.

However, vanadium demand from steel manufacturers will face pressure over the next several years. A previously expected recovery in steel production after the COVID-19 pandemic has been undone by the fallout from the Russian invasion of Ukraine. This has had several adverse impacts that result in a weaker demand for steel, including (but not limited to) the following:

- Weaker economic growth: A slowdown in global economic growth—and in particular in Europe—is adversely impacting the world's construction and manufacturing industries. The European economy is being negatively affected by the economic fallout from the Russian invasion of Ukraine and slower economic growth in China. The impact is expected to last several years which will reduce the speed of construction activity and fixed capital formation.

Figure 4.8: Global Vanadium Consumption



Source: PwC

- Sanctions against the Putin administration: Russia is among the world's five largest steel producers. Economic sanctions in the wake of the invasion of Ukraine have disrupted normal trade patterns in and out of the country, which has adversely affected the country's steel production and demand for associated imported inputs.
- China's zero-COVID policy: Beijing's approach to eradicating the pandemic has resulted in a considerably negative impact on the world's second-largest economy. The Chinese economy grew by only 0.4% year-on-year in the second quarter of 2022 when dozens of cities (including the country's commercial center, Shanghai) imposed strict weeks-long lockdowns. China (the world's largest producer and consumer of steel) will see its economy grow by less than 4% this year.

As a result of these factors, global steel production is expected to grow by a CAGR of only 1.8% per annum during 2022–25, compared to 2.4% per annum during the decade ending in 2021.

Battery storage currently accounts for only 2% of vanadium demand, equal to 2,200 of 110,400 mtV in 2021. Under the baseline scenario, this share is forecast to increase to just over 10% of the market by 2030. PwC forecasts that battery storage demand will grow by an average of 25% per annum over the long term, reaching 16,391 metric tons by 2030. This outlook is premised on the importance of vanadium as a clean energy input and the growth of renewable and sustainable energy solutions (e.g., wind and solar) requiring storage capacity.

Over the past four years in particular, vanadium production has kept pace with the growth in vanadium consumption. The supply side of the market is very responsive to changes in demand. For example, China increased its production from around 48,500 mtV per annum during 2014-2016 to 54,100 mtV in 2017 to fill the gap left by the closure of Evraz Highveld's Mapochs mine in South Africa. Chinese production—reinforced by the world's largest reserves of vanadium—increased by almost one third in 2019, to 70,600 mtV, reflecting the country's agility in adapting to changing market conditions. Most of the production in China is from slag generated in the production of steel from vanadium titanium magnetite (VTM).

4.4 Price Forecast Scenarios

PwC used the widely accepted econometric modeling software package Eviews to compile historical and forecast data series, conduct correlation analysis, and subsequently produce various regression models with the vanadium price (US$ per metric ton) as the dependent (forecast) variable. The data considered in our correlation analysis, which is an initial step to understanding the relationship between the vanadium price and other relevant factors, include the following:

- Global vanadium consumption
- Global vanadium production (excluding China)
- Chinese vanadium production
- Market balance for vanadium (consumption/production)
- Global steel price (US$ per metric ton)
- Global steel production
- Global steel consumption
- Market balance for steel (consumption/production)
- Global vanadium demand for battery storage
- Global vanadium demand for steel

PwC produced three standard ordinary least squares (OLS) regression models forecasting the vanadium price from 2023 to 2030. All data series are presented and applied on an annual basis. All three models feature a dummy variable to nullify the 2018 vanadium price spike. In addition, all three models are normally distributed, are homoscedastic, do not have serial correlation up to tw0 lags, and passed all necessary residual tests.

Future **scenario 1 f**orecasts the vanadium price based on a simple regression using only global steel consumption as an explanatory (predictor) variable. This model indicates a situation where there is no significant demand for vanadium from a battery storage perspective. The model assumes that global steel consumption increases by 1.2% per annum up to 2030. Based on this projection, the vanadium price increases steadily from around US$21,000 per metric ton in 2022 to approximately US$24,500 per metric ton by 2030.

Future **scenario 2** includes global vanadium production and vanadium demand from battery storage as explanatory variables. The model also includes a one-year lag vanadium price to further improve model fit. With the introduction of these real-work demand factors, the projected vanadium price rises significantly, increasing up to six times by 2030 because of the additional demand for vanadium from outside the steel industry.

Table 4.2: Scenario 1—Price Forecasts up to 2030

Year	Vanadium V2O5 price (US$ per metric ton)	Global steel consumption (million metric tons)
2020	14,468	1,878
2021	19,268	1,954
2022	21,055	1,987
2023	20,900	2,007
2024	21,506	2,035
2025	22,150	2,065
2026	22,726	2,092
2027	23,175	2,113
2028	23,613	2,134
2029	24,031	2,153
2030	24,443	2,173

Source: PwC (Forecast based on scarce demand for vanadium for battery storage)

The second model suggests that, given the expected rapid increase in vanadium demand for battery applications, the current projected increase in global supply up to 2030 will be insufficient to keep market prices affordable. This is easy to understand: with increasing demand from a relatively new user of vanadium (battery storage) competing with the traditional uses of steel and other metal production, competition for the resource will intensify. This will inherently include some speculative investment in vanadium, which will add to upside pressure on market prices.

Table 4.3: Scenario 2—Price Forecasts to 2030 following rapid growth in vanadium demand underscored by little change in vanadium production

Year	Vanadium V2O5 price (US$ per metric ton)	Global steel consumption (million metric tons)	Vanadium production mtV	Vanadium battery demand mtV
2020	14,468	1,878	102,400	1,760
2021	19,268	1,954	110,000	2,200
2022	21,055	1,987	112,400	2,750
2023	25,690	2,007	116,300	3,438
2024	31,849	2,035	122,000	4,297
2025	38,929	2,065	127,500	5,371
2026	48,457	2,092	133,000	6,714
2027	61,110	2,113	138,000	8,392
2028	78,207	2,134	144,900	10,490
2029	99,257	2,153	153,000	13,113
2030	125,718	2,173	161,000	16,391

Source: PwC

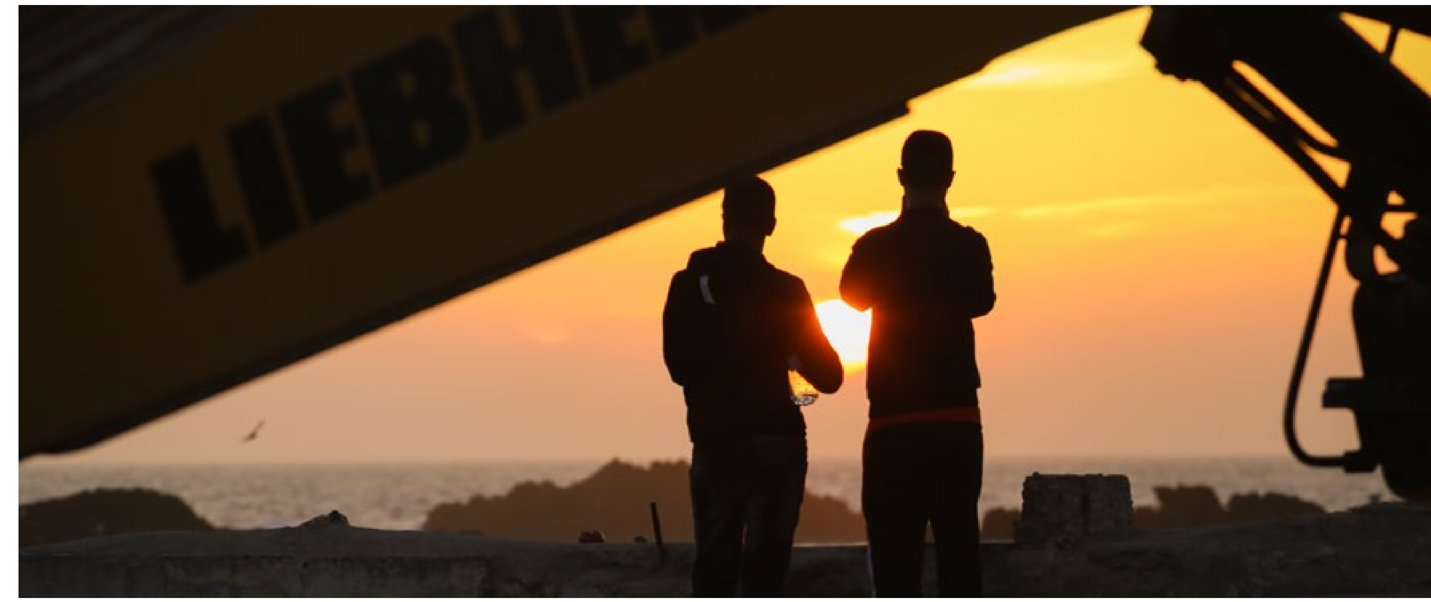
Note: Forecast based on rapid growth in vanadium demand accompaniedby little change in vanadium production

Table 4.4: Scenario 3—Price Forecasts to 2030 following growth in both vanadium demand and supply

Year	Vanadium price (USD/tonne)	Global steel consumption (million tonnes)	Vanadium production mtV	Vanadium battery demand mtV
2020	14,468	1,878	102,400	1,760
2021	19,268	1,954	110,000	2,200
2022	21,055	1,987	123,640	2,750
2023	25,690	2,007	139,560	3,438
2024	31,849	2,035	146,400	4,297
2025	38,929	2,065	153,000	5,371
2026	48,457	2,092	159,600	6,714
2027	61,110	2,113	172,500	8,392
2028	78,207	2,134	181,125	10,490
2029	99,257	2,153	191,250	13,113
2030	125,718	2,173	201,250	16,391

Source: PwC

Note: Forecast based on rapid growth in vanadium demand accompaniedby little change in vanadium production



Future scenario 3 attempts to remedy this price escalation by assuming accelerated growth in global vanadium production. Under scenario 2, global supply is forecast to grow by a CAGR of 4.3% during 2022–30, while under scenario 3, this growth rate is lifted to a CAGR of 6.9%. This increase in supply (resulting in a market surplus) would keep price growth capped to just below US$30,000 per metric ton by 2030.

A vanadium supply CAGR of 6.9% up to 2030 is certainly not unrealistic: similar growth rates were recorded during 2009–14 and 2016–19. The key to these growth rates is market reactiveness to demand due to the diversity of source material for producing vanadium. Vanadium is often mined with one of the 65 other minerals with which it is chemically combined.

Secondary vanadium production (vanadium produced from, for example, fly ash, petroleum residues, alumina slag, and from the recycling of spent catalysts used in crude oil refining) accounts for 10% of global supply and is diverse in origin. Secondary production sources have grown significantly over the past two years, with a strong focus globally on recycling industrial wastes. Further significant growth in secondary production is expected over the next decade as changes in bunker fuel specifications impact (increase) the amount of spent catalyst generated by oil refineries. The general focus on recycling industrial wastes will add to this upward trend.

Apart from increasing output at existing primary, secondary, and co-production operations, several new vanadium projects are expected to come online over the coming decade, including (but not limited to) the following:

- The Gibellini open pit mine in the US state of Nevada's Battle Mountain region: The partnership between Hitachi Energy and Nevada Vanadium is expected to start operations in 2024.
- The Richmond Vanadium Project with prospects in the Richmond and Julia Creek districts of Australia's North Queensland: The resource is one of the largest undeveloped vanadium assets in the world. According to Horizon Minerals (HRZ), which is working in a joint venture with Richmond Vanadium Technology (RVT), a Definitive Feasibility Study (DFS) was completed in the second half of 2021 to determine power supply needs for the project. Progress is being made on environmental studies, and HRZ is preparing documents for government permitting and approvals.
- Jangada Mines Plc's Pitombeiras project in Brazil's northeastern region of Ceará: The exact timing of construction of the plant is currently unknown.

5 Financial and Economic analysis

5.1 Financial Analysis

As part of the financial analysis, we used the financial model38 provided by the company developing this new Circular Vanadium Business Model (CVBM) (the 1 MWh facility referred to in the Scope) to understand the proposed financing structure and to assess the key sensitivities related to the proposed CVBM. This analysis was primarily performed on scenario 1 ("vanadium sale") in the financial model.

The financial model assumed that the full cost of vanadium would be funded by an investor seeking to gain exposure to the underlying commodity price, and a meaningful equity internal rate of return (IRR) could not be calculated in the financial model (100% debt, representing the cash realized from the vanadium commodity investor, 0% equity). Our analysis therefore assessed the Project IRR, which represents the internal rate of return prior to any financing considerations. This Project IRR can be used as a reference when assessing a proposed cost of financing or the return levels required by a potential investor.

The commercial structure presented in the financial model did not allow for the assessment of debt carrying capacity as typical debt covenants were not considered relevant or were not calculated in the financial model. The Project IRR acts as a proxy for assessing the ability to finance or fund the proposed CVBM.

To understand the impact of the various assumptions used for the proposed CVBM, a sensitivity analysis was performed on select revenue and cost drivers in the financial model provided. Key financial sensitivities were run by calculating the cost of storage (US$c/kwh) and the Project IRR by adjusting the following key model assumptions to understand the degree of sensitivity to the proposed CVBM:

- Lease rate (%)
- Price of vanadium
- Client upfront payment (includes customs duty and shipping costs)
- Cost of debt funding
- Capital expenditure—vanadium cost
- Conversion cost (only assessed for the Project IRR—The impact on the levelized cost of storage is captured under the aforementioned "Client upfront payment" sensitivity)
- Reprocessing costs
- Lease term / Power Purchase Agreement ("PPA") tenor
- US dollar inflation forecast per annum

Data tables for each variable were run in the financial model to determine the impact of adjusting each variable on the levelized cost of storage and Project IRR (Project IRR is calculated pre-financing and is a key performance indicator included in the financial model). Each key variable was sensitized up and down between 10% to 40%. The results yielded are presented in the sensitivity analysis in section 5.1.2.

Note: The financial model provided contained a circular reference, which is typically avoided by PwC when developing financial models. This concern was raised with the company that shared the financial model for our analysis, and it was concluded that the analysis should proceed without further adjustment to the financial model to remove the circularity.

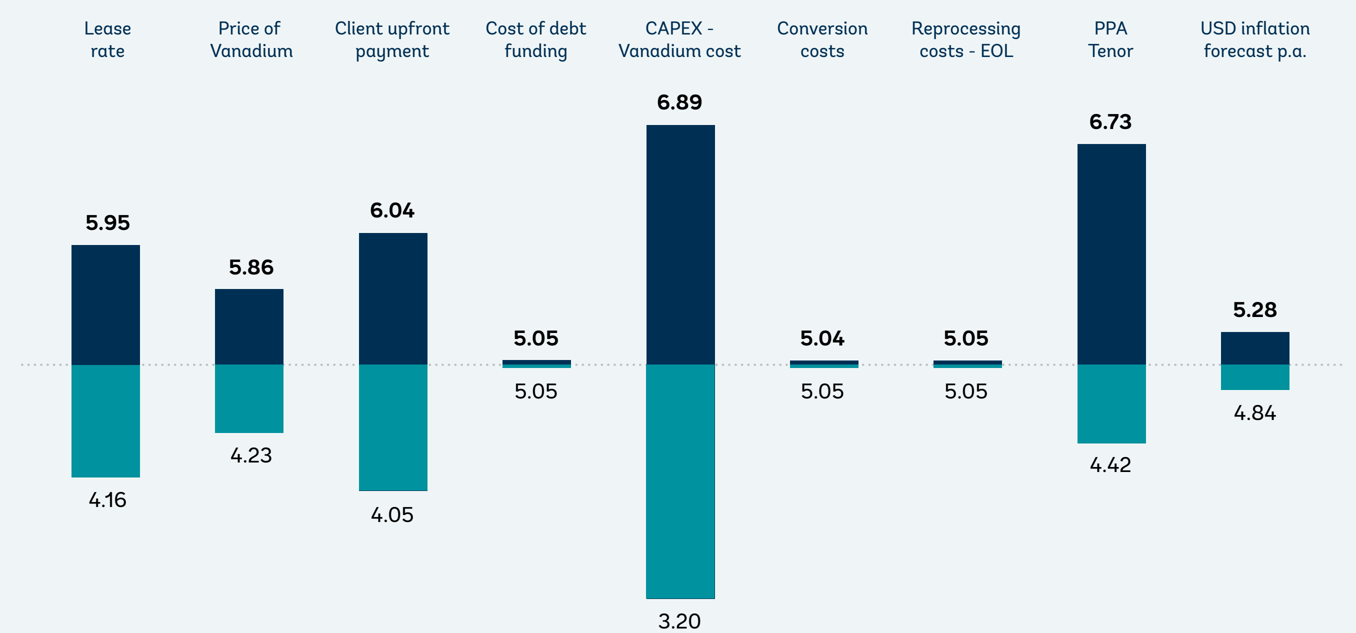
5.1.1 Key findings

The financial model provided to us assumes the following financing assumptions:

- Mined vanadium is sold to an investor with an interest in gaining exposure to the movement in the price of vanadium, who carries the full cost of acquiring the vanadium commodity (100% financing—the financing obtained by / return required by the speculative investor is, however, not considered further).
  - The capital cost of vanadium assumed for the 1 kWh facility (the amount purchased by the investor / lessor) is US$192,000, calculated using circa 4.87 metric tons of vanadium at a spot price of US$39.39 per kilogram.
- The commodity is then leased to an off taker (e.g., a VRFB manufacturer or end user).
- The off taker pays an upfront fee equal to the direct costs associated with the logistics of transporting the vanadium to its destination (c. 54% of the cost of vanadium and c. 35% of the total cost—aggregate of vanadium cost and conversion and transport cost—based on the current assumptions for the financial model).

38 The financial model was developed by the third party company developing a CVBM and was provided to the World Bank for the purposes of this Report. The financial model was used as-is to perform the financial and sensitivity analysis presented in this section and was not verified / audited by PwC in any way.

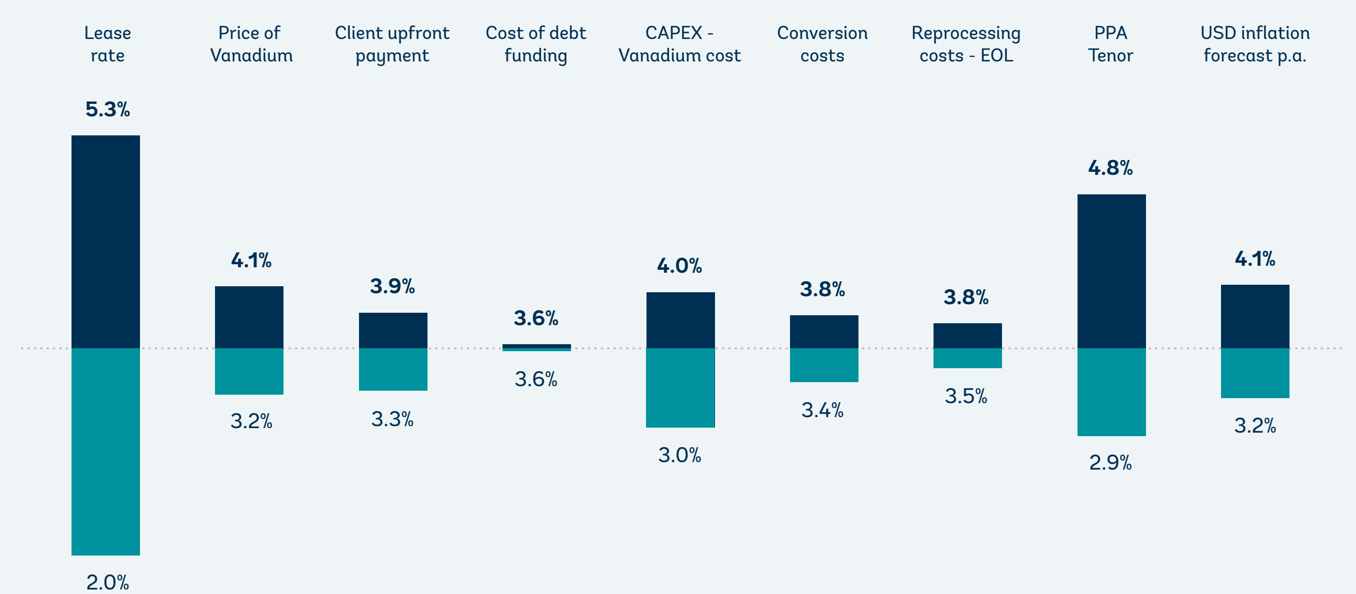
Figure 5.1: Levelized Cost of Storage Sensitivities (US$c/ kWh)



Source: PwC analysis

Note: The financial model base case is US$5.05c / kWh.

Figure 5.2: Project IRR Sensitivities (%)



Source: PwC analysis

Note: The financial model base case is 3.6%.

- In addition to the upfront fee, the off taker pays a fixed annual lease consideration, calculated with reference to the cost of the vanadium, the assumed future value of the vanadium at the end of the lease period (assumed to be 20 years in the financial model), and the lease rate (assumed to be 3.5% per annum in the financial model). The annual lease consideration is then indexed by an inflationary factor annually (US inflation assumed to be 2.3% per annum in the financial model).
- An intermediary acts as a collection agent for the lease payments and collects a management fee.
- The vanadium is returned to the commodity owner at the end of the lease period.

Note: Costs associated with transporting the vanadium back to the owner are not currently included in the financial model. This may be justified if the vanadium will be re-processed at a location close to the site used by the end user but should otherwise be considered since logistical costs are viewed as significant under the current model (c. 35% of initial cost when entering the lease).

Given that the financial model considers the proposed CVBM, the operating costs (OPEX) in the model are limited to reprocessing costs and management fees (assumed to be the net income in the model after servicing the payments to the lessor).

The after-tax IRR (Project IRR) calculated in the model is 3.6%. The financial model assumes a cost of financing (in US dollars) of c. 2.88% per annum. The proposed return and financing levels were not assessed as part of our scope of services.

5.1.2 Sensitivity analysis

The sensitivity analysis ranges shown below indicate the impact on (i) the levelized cost of storage and (ii) the Project IRR respectively, for a 40% increase or decrease in the stated input metric.

5.2 Lease Rate (%)

The annual lease fee charged to the end user (the lessee) by the vanadium lessor over the duration of the PPA tenor is calculated on the basis of an annual repayment with a starting balance equal to the cost of vanadium on commencement of the lease, an assumed lease rate (effectively the annual interest rate on the financing instrument), and the assumed future value of the vanadium at the end of the lease period.

A 10% increase in the lease rate resulted in a c.4.5% increase in levelized cost of storage and c.11.6% increase in IRR. A 10% decrease in the lease rate resulted in a c.4.4% decrease in levelized cost of storage and a c.11.5% decrease in IRR.

5.3 Price of Vanadium

The assumed spot price of the vanadium commodity at the end of the lease term is used to determine the value of the vanadium recovered at the end of the lease.

A 10% increase in the price of vanadium resulted in a c.4.0% decrease in levelized cost of storage and c.2.8% decrease in IRR. A 10% decrease in the price of vanadium resulted in a c.4.0% increase in levelized cost of storage and a c.2.9% increase in IRR.

5.4 Client Upfront Payment

The upfront payment by the lessee is used to cover the conversion and transport costs incurred by the vanadium producer (c.35% of the total cost). These costs include the initial conversion costs from vanadium into vanadium electrolyte (but exclude the cost of conversion at the end of the lease term), customs duties, and shipping costs.

A 10% increase in the client upfront payment resulted in a c.4.9% increase in levelized cost of storage and a c.2.0% increase in IRR. A 10% decrease in the client upfront payment resulted in a c.4.9% decrease in levelized cost of storage and a c.2.1% decrease in IRR.

5.5 Cost of Debt Funding

This is the assumed interest or return rate charged to acquire the vanadium commodity by the investor (excluding the costs of conversion and transport which are covered by the upfront payment).

As the cost of debt is not directly passed through to the lease rate, and the IRR presented is a project-level IRR (i.e., pre-financing), the levelized cost of storage and Project IRR were not affected by changes in the cost of debt funding. The cost of debt funding and required equity returns should, however, be compared to the Project IRR to assess the likely return profile for the investors.

5.6 Capital Expenditure—Vanadium Cost

The assumed cost of mining and preparing the vanadium by the vanadium producer prior to leasing or sale.

A 10% increase in CAPEX resulted in a c.9.2% increase in levelized cost of storage and a c. 6.9% increase in IRR. A 10% decrease in CAPEX resulted in a c.9.2% decrease in levelized cost of storage and a c. 4.1% decrease in IRR.

5.7 Conversion Cost

This is the cost of converting the vanadium into vanadium electrolyte and vice versa. The initial conversion costs are addressed in the client upfront payment sensitivity assessment above, but the conversion cost at the end of the lease term impacts the Project IRR separately.

A 10% increase in the conversion cost resulted in a c. 1.6% decrease in IRR. A 10% decrease in the conversion cost resulted in a c.1.5% increase in IRR.

5.8 Reprocessing Costs

This is the cost of recycling or reprocessing vanadium from electrolyte so that it can again be used in VRFB.

A 10% increase in the reprocessing costs did not impact the levelized cost of storage but resulted in a c.1.1% decrease in IRR. A 10% decrease in the reprocessing costs did not impact the levelized cost of storage but resulted in a c.1.1% increase in IRR.

5.9 Lease Term/ PPA Tenor

This is the period over which the end user leases the vanadium from the vanadium producer (assumed to be 20 years).

A 10% increase in PPA tenor resulted in a c.2.6% increase in levelized cost of storage and a c.3.8% increase in IRR. A 10% decrease in PPA tenor resulted in a c.2.8% decrease in levelized cost of storage and a c.4.2% decrease in IRR.

5.10 Annual US dollar Inflation Forecast

The lease rate is increased annually based on the US dollar inflation rate.

A 10% increase in the US dollar inflation forecast resulted in a c.1.1% increase in the levelized cost of storage and a c.3% increase in IRR. A 10% decrease in the US dollar inflation forecast resulted in a c.1.1% decrease in levelized cost of storage and a c.2.9% decrease in IRR.

5.10.1 Risk matrix

We have prepared a high-level risk matrix based on our understanding of the proposed CVBM, which has been supplemented through a discussion with Largo Resources.

The risk matrix aims to provide a high-level overview of potential risks that may be considered from an investor's perspective. This should not be considered an exhaustive list of all risks relevant to the proposed CVBM. There may be additional risks (which may have a significant impact on the CVBM) that can only be identified, assessed, and addressed once the CVBM, or a specific proposed project, is at a more advanced stage of development and after detailed interrogation and due diligence has been performed.

Table 5.1: Summary of financial assumptions

Financial Assumption	Value
Lease rate	3.5% per annum
Price of vanadium	USD 39.39 per kg
Client upfront payment	Direct costs associated with logistics of transporting vanadium (54% of vanadium cost, 35% of total cost)
Cost of debt funding	c. 2.88% per annum
Capital expenditure - vanadium cost	USD 192,000
Conversion cost	The conversion cost is the cost of converting vanadium into vanadium electrolyte and vice versa. The initial conversion costs are addressed in the "Client upfront payment" sensitivity, but the conversion cost at the end of the lease term impacts the Project IRR separately
Reprocessing cost	The reprocessing cost is mentioned as one of the key model assumptions and is part of the operating costs (OPEX) in the financial model.
Lease term / PPA tenor	20 years
USD inflation forecast per annum	2.3%

Source: PwC

Table 5.2: High-Level Risk Matrix

No.	Risk category	Description	Mitigation
Financing Risk			
1	Financing structure	Determining which party will raise the financing for the CVBM. The vanadium producer could consider selling the vanadium to a Special Purpose Vehicle (SPV) that can raise bespoke financing aligned to the commercial nuances of the CVBM. The SPV's investors would likely need to take a speculative view and be comfortable with the potential market movements in the vanadium price.	The vanadium producer will likely require continuous cash flow to support its mining operations. Therefore, if the vanadium producer also becomes the lessor, and the leasing revenue is deferred over the contract period with a material terminal value, this will require that external funding is raised to finance the vanadium used in the batteries.
2	Availability of funding (liquidity)	Financing or investment may not be available or may be difficult to secure because of the relatively novel nature of the CVBM or the perceived risk of investing in vanadium as a long-term commodity. The CVBM risk and reward profile will be benchmarked against alternative investments into other long-term assets or commodity classes.	The market needs to be educated about the proposed benefits of the CVBM and the expected trajectory of vanadium commodity prices. A market sounding with prospective investors and financiers would be beneficial to obtain input into key considerations for providing funding for the proposed CVBM.
3	Interest rate risk	In the context of financing obtained by the lessor, there is a risk that interest rates may increase over time, the increased cost of which the lessor cannot pass through to the end user of the vanadium battery	Consider a lease rate or income stream indexed to the underlying interest rates of lessor financing or using fixed or hedged interest rates for lessor financing.
4	Debt repayment structure	One of the primary objectives of the CVBM is that a substantial portion of the value of the CVBM is realized at the end of the battery's life, with only limited lease payments being received over the PPA tenor. In the financial model considered, interest is serviced over the PPA tenor, and principal is returned at the end of the term to match this profile. If more traditional debt that will require ongoing principal repayments is raised, there may be a mismatch in the timing of cash flows as the lease payments of the CVBM are structured to earn a steady yield, while the principal will only be returned to the investor or financier at the end of the lease period.	The repayment structure envisaged may not be achieved if more traditional debt financing is used. A fully amortizing instrument, where interest and principal are paid over the course of the PPA, should be considered to understand the impact of the mismatch in cash flow profiles between lease income and debt service. Lessors may need to consider accepting an element of refinancing risk if shorter dated, bullet-repayment instruments are being considered.
Operating Phase			
5	Counterparty risk	End users may offer weak credit ratings or weak capacity to meet their obligations under the lease.	The SPV may need to assess the credit risk and require counterparty guarantees (parent-company guarantees) and termination obligations from the end user or VRFB manufacturer regarding offtake obligations, including payment and return of the vanadium or electrolyte.
6	Foreign exchange	The lessor faces exposure to fluctuations in foreign currencies	Financing costs, revenues, and capital expenditure should be denominated in a single currency, where possible, providing a natural hedge against foreign exchange movements. Alternatively, hedging arrangements should be considered, but these may impact the overall cost.

Table 5.2: High-Level Risk Matrix (continued)

No.	Risk category	Description	Mitigation
Operating Phase			
7	**Insurance**	An adequate insurance program should be maintained (to cover, for example, the risk of theft, damage, or expropriation and loss of commodity)	The VRFB manufacturer or end user should maintain the appropriate insurance.
8	**Electrolyte recycling risk**	The considers the ability to effectively recycle or reprocess vanadium electrolyte at the end of the lease term	The vanadium producer should ensure that recycling or reprocessing technologies are acceptable and expected to be readily available at the end of the lease term. End users should be required to return vanadium in a predefined condition. A defined hand-back regime with the VRFB manufacturer or end user should be required to ensure the electrolyte or vanadium is returned in the appropriate condition, with defined penalties or compensation for non-compliance.
9	**Shipping cost to end user**	There is a risk that transport costs (including freight, customs duties, etc.) incurred to transport vanadium from the producer to the end user increase, impacting the overall economic feasibility of the CVBM. The financial model provided assumes that the end user will fund the upfront payment to cover conversion transportation costs. There is a risk that the end -user may need to fund the upfront contribution from internal cash resources if the cost cannot be incorporated as part of a project finance solution. Shorter-dated leases may also require more frequent logistical costs to be incurred to move the vanadium electrolyte from one geographic location to another.	The cost of transportation or logistics should be passed on to the VRFB manufacturer or end user where possible. A market sounding exercise with prospective lessees would provide useful guidance on how these upfront costs are expected to be funded (cash funding, included in a project finance package, etc.), as the nature of the funding will dictate the risks. Electrolyte or vanadium reprocessing facilities should be in proximity to the end users where possible to reduce the logistical costs when moving the commodity at the end of the lease term.
10	**Loss of vanadium on conversion**	This considers the loss of vanadium when converted to vanadium electrolyte	The VRFB manufacturer must be carefully selected, with high -quality controls and a sound reputation in the market. The appropriate VRFB battery storage technology should be used to ensure the integrity of the vanadium electrolyte over the lease term.
11	**Vanadium terminal value**	This considers the value of vanadium recovered at the end of the PPA tenor	The ownership of vanadium should be transferred to an investor who is willing to take a speculative view of the future value of vanadium.
12	**Lease rate or rate of return of leasing commodity**	This considers the attractiveness of the rate of return to investors or lessors	A market sounding exercise with prospective lessees would provide useful guidance on expected rates of return. This would need to be taken into consideration when assessing the affordability of the CVBM.

5.11 Economic Analysis

The aim of the cost-benefit analysis (CBA) is to assign a monetary value to the benefits expected from the proposed circular vanadium business model and compare them to the expected costs. If the benefits exceed the costs, there is economic justification for proceeding with the leasing model.

An economic CBA was conducted to quantify the economic viability of the leasing model, based on the financial feasibility model that was provided by the company developing this new business model (the 1 MWh facility). The economic CBA tool was developed using economic (shadow) prices and real (inflation -adjusted) prices. The economic prices reflect the true scarcity of resources. Economic prices are also a better reflection of actual demand or supply conditions in the market that should determine the real commercial viability of the project. Market prices do not capture the scarcity of resources because of interference in market price setting, such as electricity tariffs and wage levels. Furthermore, the CBA considers other economic variables that the financial modeling does not include, such as external social costs and benefits and environmental costs.

The economic CBA was conducted over a 20-year period with an economic discount rate of 2.41%.[39] .The shadow factors used in the analysis are described in Appendix A. Three standard CBA evaluation criteria were used to determine the economic viability of the 1 MWh facility vanadium business model.

Table 5.3: Economic CBA criteria and definitions

Criteria	Definition
Net Economic Present Value (NEPV)	NEPV is the difference between the benefits and the costs, discounted to the present using a discount rate. For the project to be accepted, the NPV has to be positive as this indicates that the overall benefits outweigh the overall costs of the project.
Benefit -Cost Ratio (BCR)	BCR is the ratio between the present value of the benefits and the present value of the costs. A project is considered viable if the BCR is greater than one. The BCR indicates the return expected from the proposed circular vanadium business model for every US dollar invested.
Internal Rate of Return (IRR)	IRR is the discount rate at which the present value of both the costs and benefits are equal. For a project to be considered viable, the IRR has to be greater than the discount rate.

Figure 5.3 summarizes the steps taken through the economic CBA to determine the economic viability of the 1 MWh facility vanadium business model.

An explanation of these steps is provided in Appendix A.

39 South African 10-year bond: 10.5%; Inflation: 7.9% y-o-y, Discount Rate =((10 year bond yield)/Inflation-1)X 100, Discount Rate =(1.105/1.079-1)X 100, Discount Rate= 2.4%

Figure 5.3: Steps to Determine the Economic Viability of the 1 MWh Facility Vanadium Business Model

Source: PwC analysis

Table 5.4: Costs associated with the Proposed Circular Vanadium Business Model

Risk category	Mitigation
Leasing company	**Commodity prices:** The spot price of vanadium is vulnerable to commodity price fluctuations. In September 2022, the price of vanadium pentoxide 98% was USD3.31/kg, marginally up from the average price of USD3.13/kg for September 2017[40,41] However, during this five-year period the price of vanadium has fluctuated between USD2.31/kg and USD13.04/kg. Such fluctuations in the price of vanadium will likely cause disparities on the price of electrolytes particularly for a 20-year leasing agreement.
End -user	**Transport costs:** The costs of transporting a VRFB to the end consumer will depend on the size of the battery that will be leased as this will determine the truck size required to deliver the battery. A VRF battery comes in both a 20ft container and a 40ft container, which will require a truck and a shipping container. The estimated costs are as follow: • **Truck hire**: 20 Tin Flatbed Trailer – US$100.76 rate per day, US$1.14 per kilometer and US$40.93 driver per day.[42] (Costs will vary depending on a company's rates.)[43] • **Shipping containers**[44]: 20-ft Shipping Container: US$850.13 per unit 40-ft Shipping Container: US$1,196.47 per unit The loading of a VRFB on and off a truck for transportation can incur handling damage. This could have a negative impact on the pipes and the electrolyte reservoir. Although these are likely to be one-off costs, incurred at the point of transportation, damages or maintenance work that may require the VRFB to be replaced or moved would imply that additional costs pertaining to the above will be incurred. **Storage capacity:** The electrolytes used in VRFBs are usually stored in liquid form, in large tanks. The leasing company may seek to rent existing premises as opposed to building new facilities to store the electrolytes. Because of a lack of adequate data to quantify the average rental costs for commercial property per square meter in South Africa, we will use the average building cost per square meter for shopping centers and commercial and industrial property as a proxy for rental fees. According to data from EstimationQS, the building costs per square meter for commercial property, shopping centers, and industrial property are US$499.63, US$483.38, and US$419.86 per month, respectively.[45] • Industrial property: 13.86m^2 X US$419.86/m^2 = US$5,819.26 per month. • Commercial property: 13.86m^2 X US$499.63/m^2 = US$6,924.87 per month. • Shopping Centers: 13.86m^2 X US$483.38/m^2 = US$6,699.65 per month.
Leasing company	**Global warming:** To quantify the cost of vanadium on the environment, we looked at the carbon dioxide impact of the extraction and life cycle of vanadium compared to lithium-ion. From extraction and during its life cycle, vanadium has a more costly impact on global warming per carbon dioxide equivalent (kg CO_2 eq.), relative to lithium-ion.[46] To quantify this cost for this report, we have used South Africa's carbon tax rate. For 2022, South Africa's carbon tax rate is US$9 per metric ton of carbon dioxide equivalent and is expected to increase by US$1 per annum until 2030.[47] This is below the global standard for carbon taxes of between US$40 and US$80 per metric ton carbon dioxide equivalent.[48] South Africa is expected to increase carbon tax emission rates gradually to meet global standards. The environmental cost of global warming associated with the supply and life cycle of VRFB will have a growing impact on operational costs. The carbon emissions cost of vanadium is approximately 4% higher than lithium-ion. Calculations of the global warming impact from the supply and life cycle of lithium-ion and VRFB can be found in the appendix We note that the cost calculations pertain solely to the supply phase and life cycle of a lithium-ion battery and vanadium battery. With limited studies and data available pertaining to the end -of -life (recycling) cost of global warming, we note that costs will likely vary from the costs above.

40 Vanadium Pentoxide 98%Min Europe Spot Historical Prices, Investing.com, https://www.investing.com/commodities/vanadium-pentoxide-98-min-europe-futures-historical-data
41 Vandium Pentoxide 98%Min Europe Spot Historical Prices Conversion. 1lbs = 0.453592kg
42 Please note that the exchange rate conversion used for these figures was an average exchange rate of R15.88/US$ for 2022 according to data from IHS Markit.
43 "Johannesburg Truck Hire." Johannesburg Truck Hire, https://www.jhbtruckhire.co.za/Truck-Hire-Rates.jma. Accessed 29 August 2022.
44 "How Much Does A Container Cost In South Africa? – Greater Good SA." Greater Good SA, https://www.myggsa.co.za/how-much-does-a-container-cost-in-south-africa/. Accessed 29 August 2022.
45 "Building Costs Per Square Meter in South Africa - For New Residential, Commercial and Industrial Properties." Estimation QS, 22 March 2022, https://estimationqs.com/building-costs-per-square-metre-in-south-africa/. Accessed 29 August 2022
46 da Silva Lima, Lígia, et al. "Life cycle assessment of lithium-ion batteries and vanadium redox flow batteries-based renewable energy storage systems." Sustainable Energy Technologies and Assessments, vol. Volume 46, no. 101286, August 2021, p. 6, https://www.sciencedirect.com/science/article/pii/S2213138821002964.
47 South Africa's carbon tax rate goes up but emitters get more time to clean up, The Conversation, https://theconversation.com/south-africas-carbon-tax-rate-goes-up-but-emitters-get-more-time-to-clean-up-177834,February 25, 2022, Lee Steenkamp
48 Report of the High-Level Commission on Carbon Prices, Columbia Academic Commons, https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f2409f8dce5316811916/1505227332748/CarbonPricing_FullReport.pdf

Costs associated with leasing a circular flow model that could not be included in the CBA

The following costs are associated with leasing a circular flow model and could be included in the CBA. In obtaining an objective picture of the costs associated with the proposed circular vanadium business model, we then identified the following costs and who they impact. We note that some of these costs were not quantifiable; nonetheless, they will have a cost impact on the proposed circular vanadium business model.

The proposed circular vanadium business model has additional costs that are non-quantifiable. The leasing company will have to contend with fluctuations in commodity prices, which can result in inconsistent costs in obtaining the vanadium. The end -user faces transportation and storage costs. The substantial size of the batteries will require trucks for transportation, while their size may induce elevated rental costs. Last, the extraction of vanadium has a larger impact on the environment for its kg CO_2 equivalent, which could induce higher carbon taxes compared to options such as lithium-ion.

In obtaining an objective picture of the benefits associated with the proposed circular vanadium business model, we then identified the following benefits and who they impact. We note that some of these benefits were not quantifiable; nonetheless, they will have a cost impact on the economic model.

Table 5.5: Benefits associated with the Proposed Circular Vanadium Business Model

Risk category	Mitigation
Leasing company	**No extraction costs:** The leasing company will not incur any costs associated with the extraction (mining) of the vanadium. The leasing company will therefore not have to pay carbon emission taxes, which will fall to the mining company. This will minimize the overhead costs of the leasing company.
End -user	**Increased lifespan and durability:** With an ability to cycle more than 20,000 times over a 20-year to 25-year period, VRFB are a more attractive option than current options, such as lithium-ion batteries, which have a life cycle of between 500 to 5,000 cycles. This ability of VRFB to last longer generates additional benefits, such as mitigating the need to frequently replace/recycle the VRFB compared to a lithium-ion battery. Over time, VRFB provides a constant flow of electricity relative to lithium-ion batteries, which tend to demonstrate a reduction in power as capacity declines. **Safety:** Unlike VRFB, lithium-ion batteries experience thermal runaway, which can cause fires and significant financial losses. For example, in 2021, a fire broke out in South Korea's Hongseong-gun, Chungcheongnam-do ESS. Despite there being no casualties, the ESS building and 140 internal batteries were burned down, resulting in property damage of approximately US$385,800. The outage of an ESS can impact the supply of electricity and end users' production, especially given the length of time the ESS remains inactive. **Power density:** VRFBs offer a consistent supply of energy for up to 10 hours compared to lithium-ion batteries, which only offer up to two hours of large amounts of energy. This boosts the attractiveness of VRFBs as an alternative energy source relative to lithium-ion batteries, particularly for energy -intensive industries such as mining and manufacturing.
Economy	**Mitigant to load shedding:** It has been 15 years since businesses and households in South Africa started experiencing rolling blackouts (load shedding). Below are various calculations of the impact of load shedding on the South African economy using the cost of unserved energy (CoUE) method. The CoUE is a descriptor of electricity interruption cost and is used to determine the value placed on a unit of energy not supplied because of an unplanned electricity outage. This has also often been a reference point for calculating the cost of load shedding (CoLS). Our analysis shows that load shedding has a significant impact on South Africa's economy. In 2021, planned load shedding cost the economy between US$810 million and US$8.6 billion,[49] while unplanned load shedding cost between US$1.56 billion and US$17.23 billion. The use of a VRFB will function as a mitigant to load shedding, which can help reduce production losses for firms that are heavily reliant on electricity, such as those in the mining and manufacturing sectors. VRFB offers an extended life span relative to alternatives such as lithium-ion batteries. This will allow the end -user to have extended hours of production during load shedding, despite the stage of load shedding.

49 Please note that the exchange rate conversion used for these figures was an average exchange rate of R15.88/US$ for 2022 according to data from IHS Markit.

The non-quantifiable benefits offered by the proposed circular vanadium business model further strengthen its investment case. The proposed circular vanadium business model mitigates against extraction costs for the leasing company. The end user derives many benefits such as, safety, power density and the increased life span of the battery. Last, the proposed circular vanadium business model offers a benefit to the economy by offering a mitigant to load shedding.

Results of the Cost -Benefit Analysis

In this section, the results of the CBA are presented for the 1 MWh facility vanadium business model. We carried out the CBA in nominal Rand values at a discount rate of 2.41% over a 20-year period. In analyzing the viability of the model, we considered the results of the NPV, IRR and BCR.

Table 5.6: Results of the Cost -Benefit Analysis

The NPV, BCR, and IRR all suggest that the investment in the 1 MWh facility leasing model over the next 20 years is economically viable as its expected to yield positive returns.	
Net Present Value (NPV), US$	6,751
Internal Rate of Return (IRR)	3%
Benefit -Cost Ratio (BCR)	1.02
Payback Period Years	20

Source: PwC analysis

All three measures yielded positive results, which suggests that the model would be viable for investment. For the project to be accepted, the NPV must be positive. For this project, the criteria are met, with an NPV of US$6,751 stemming from total benefits of US$386,172 less the total costs of US$379,421. With a BCR of 1.02, the project meets the criteria for a viable investment. The IRR of 3% for the circular vanadium business model, is higher than the 2.41% economic discount rate and meets the criteria for the project to be a viable investment. All three measurement tools used suggest that the project presents an economically viable investment opportunity.

Table 5.7: Summary of CBA Results for the Circular Vanadium Business Model (US$)

Description	Present Value	Total
COSTS (US$)		
1. Capital expenditure[50]		
Vanadium Electrolyte Cost	192,956	197,606
Conversion Cost	79,325	81,237
Customs Duty	74,424	76,217
Shipping Cost to EU – Vanadium	1,720	1,761
Shipping Cost – Electrolyte	18,069	18,504
Other CAPEX	0	0
Total capital cost (US$)	366,493	375,325
2. Operational cost		
Other Cost	0	0
Holding Cost	0	0
Shipping Costs	0	0
Reprocessing Costs – EOL	12,928	21,317
Management Fee	0	0
Total operating cost (US$)	12,928	21,317
TOTAL COST (US$)	379,421	396,642
BENEFITS (US$)		
1. Revenue[51]		
Scrap Vanadium Value	0	0
Write-Back of Pre-Payment	109,523	139,320
Gain on Vanadium Revaluation	76,047	94,474
Vanadium Recovery	133,550	215,027
Annual Lease Fee Premium	0	0
Annual Lease Fee	67,051	86,840
Total revenue (US$)	386,172	535,661
TOTAL BENEFITS (US$)	386,172	535,661
SURPLUS/DEFICIT	6,751	139,019

Source: PwC analysis

50 The cost -benefit analysis was modelled in South African rand based on an average forecasted exchange rate of R15.88/US$1 for 2022 according to data from IHS Markit.
51 The cost -benefit analysis was modelled in South African rand. An average forecasted exchange rate of R20.10/US$1 (average between 2022–42) was used to convert revenue to US dollars according to data from IHS Markit .

The summarized CBA results are presented in Table 5.8.

Table 5.8: Summarized CBA results

NPV (US$)	BCR (Ratio)	IRR (%)
Indicators	6,751	1.02 3

Source: PwC calculations

The CBA results are interpreted as follows:

- The NPV of the 1 MWh facility leasing model compares the present value of the quantifiable benefits associated with the vanadium business model with the present value of the quantifiable costs attributable to the vanadium business model. These costs and benefits have been calculated over a 20-year period, discounted at 2.41%. The present value of benefits should be greater than the present value of the costs for the 1 MWh facility leasing model to be considered viable (the NPV should be greater than zero).
- Based on the calculations, the 1 MWh facility leasing model NPV is positive, so the total quantifiable benefits of the leasing model outweigh the quantifiable costs over the period of analysis. This results in a gain of about US$6,751. This amount is not a surplus per annum but the overall gains over the 20-year period. This would mean that, on average, there is a gain of approximately US$338 per annum (US$6,751 over 20 years) due to the proposed circular vanadium business model.
- The BCR calculates the ratio of the present value of the quantifiable benefits attributable to the 1 MWh facility leasing model relative to the present value of the costs. Simply stated, it is the present value of these benefits divided by the present value of the costs. This ratio measures the efficiency of the proposed leasing model by calculating the US dollar value received for every US$1 invested in the 1 MWh facility leasing model. For the leasing model to be considered efficient, it should yield a return that is greater than US$1, which means that the BCR ratio should be greater than one.
- The BCR for the 1 MWh facility leasing model is 1.02, indicating that for each US dollar spent on the leasing model, there is an expected return of US$1.02. This means that the 1 MWh facility leasing model is efficient.

In this case, both the NPV and the BCR confirm that the 1 MWh facility leasing model is economically viable, as the benefits outweigh the costs. Nonetheless, one should be careful when interpreting these results, given that there are several benefits and costs that have been derived through the proposed circular vanadium business model that the team could not quantify in the analysis.

6 Regulatory and Legal Analysis (specific to South Africa)

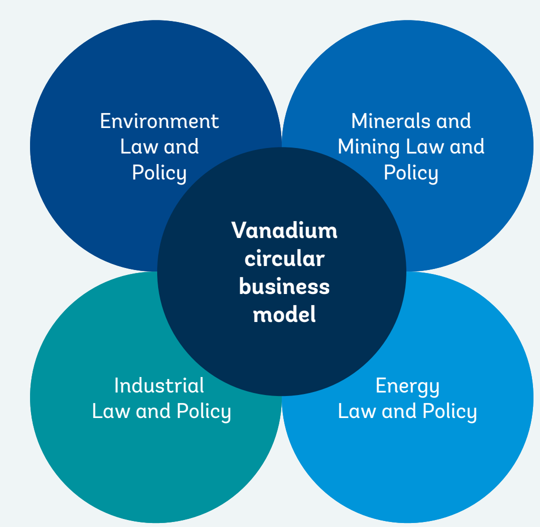
The commercial viability of a circular vanadium battery model depends on the regulatory provisions of the relevant jurisdiction and the extent to which such a model is supported by domestic legislation. An enabling environment created by existing energy, mining, industrial, and environmental laws and policies must be created to ensure that the business model is feasible from a regulatory perspective. South Africa's energy sector is currently experiencing a dynamic shift when considering the laws and policies that are being published. From a policy perspective, it is clear that there is a deliberate move towards creating a regulatory framework that would facilitate the country's decarbonization journey. Although a circular vanadium business model would contribute to the realization of the county's decarbonization efforts, the enabling regulatory environment facilitates the increased deployment of VRFBs and the circular vanadium model is underdeveloped.

While South Africa is well endowed with renewable energy resources that can be sustainable alternatives to fossil fuels, so far, these have remained largely untapped and BESS applications remain underdeveloped within the South African context. Moreover, the application of BESS technologies has suffered because of regulations that are primarily focused on increasing fossil fuel deployment. Direct legal regulatory intervention has become urgent in view of South Africa's electricity supply deficit. Although current regulations do not prevent BESS uptake, little to no guidance is provided as to how BESS and, more specifically, VRFB applications will be supported. However, the existing laws and policies also create regulatory barriers that would need to be overcome for BESS to truly become a commercially viable option for South Africa.

The Department of Mineral Resources and Energy has acknowledged in its Strategic Plan (2020-2025) that the demand for vanadium is an opportunity that needs to be managed in a way that ensures the sustainability of the mining industry and to move from a raw export economy to a beneficiation processing economy. However, to achieve this, law and policy must create an enabling environment to support a circular vanadium business model. Mining, energy, environmental and industrial legal frameworks must be integrated and aligned to minimize regulatory barriers that the vanadium sector will face, whilst also being robust enough to ensure compliance with the principle of climate smart mining. The harmonization of laws and policies related to the vanadium value chain will ultimately contribute to a commercially feasible vanadium circular business model, as illustrated in Figure 6.1.

Every component of the value chain has certain regulatory hurdles and requirements that need to be understood and navigated to ensure that the business model complies with the following relevant laws and policies.

Figure 6.1: Key Components of a Circular Vanadium Business Model



Source: PwC South Africa

6.1 Constitution of the Republic of South Africa

The Constitution operates as a framework within which South Africa's mining, environmental, and industrial legislation must operate. Any law or conduct inconsistent with the Constitution is invalid, and as the supreme law of South Africa, the obligations imposed by it must be fulfilled. A common denominator of most mining, energy, environmental, and industrial laws and policies is that their provisions are embedded in the concept of sustainable development, as enshrined in section 24 of the Constitution.

Section 24 of the Constitution is arguably the cornerstone for the promotion of sustainable mining in South Africa. It proclaims the right of everyone:

a) To an environment that is not harmful to their health or wellbeing; and
b) To have the environment protected, for the benefit of present and future generations, through legislative and other measures that:
   i. prevent pollution and ecological degradation
   ii. promote conservation; and
   iii. secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

Section 24(b) affirms that the State is obligated to protect the environment through legislative and other measures that, inter alia, "secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development." The circular model proposed by this study will ensure that vanadium mining in South Africa is aligned with the principle of sustainable development while promoting economic and social development within an emerging sector in South Africa. The sustainable application of vanadium in utility -scale VRFBs will also contribute to the decarbonization of the South African electricity grid as envisaged in the country's Nationally Determined Contribution. It is within this context that a circular vanadium business model and the increased deployment of VRFBs in South Africa can realize the sustainable development objectives set out in the Constitution.

6.2 Energy laws and policies

The following energy laws and policies are relevant for the successful deployment of VRFBs in South Africa. Table 6.1 highlights the purpose of each Act, as well as supportive provisions and barriers to VRFB deployment.

6.3 Environmental Laws and policies

Environmental requirements for utility-scale VRFB deployment may concern the identification of suitable locations for the project deployment, safety requirements for hazard avoidance (e.g., fire, thermal runway, explosive, chemical and toxic leaks etc.) and asset end-of-life (e.g., circularity, reuse, repurpose and storage of used batteries). South Africa still lacks environmental laws and regulations specifically focused on the environmental management associated with utility -scale BESS operations. South Africa's existing environmental framework for the deployment of VRFBs is discussed in Table 6.2.

6.4 Industrial laws and policies

Considering South Africa's ample vanadium reserves, the country has an immense opportunity for further development of a local battery value chain. However, increased localization for the deployment of utility -scale VRFBs will require the introduction of incentives and enabling industrial laws and policies. South Africa's overarching policies aimed at facilitating the industrial development of the country are the Industrial Policy Action Plan (IPAP) and the Medium-Term Strategic Framework (MTSF). However, to date, South Africa has developed no policies or regulatory measures that are specifically targeted to incentivize the increased uptake of VRFBs. There has, however, been a range of incentives aimed at increasing the uptake of renewables. The introduction of clean energy tax incentives has historically been provided for in Section 12 of the Income Tax Act and has resulted in increased renewable energy uptake and energy efficiency measures. Some measures set out in Section 12 can be interpreted as also covering BESS/VRFB applications. Table 6.3 outlines some incentives that could support the uptake of BESS in South Africa and the key policies related to the industrial development of VRFBs.

Table 6.1: Energy Laws and Policies

Integrated energy plan	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
The Integrated Energy Plan (IEP) aims to guide future energy infrastructure investments and identify and recommend policy development to shape the future energy landscape of the country. It is an overarching plan that informs the development of future energy sector roadmaps, i.e., for the security of supply (liquid fuels and electricity) and a diversity of supply (coal, gas, and renewable energy). **Applicability in value chain:** End user application	South Africa's Integrated Energy Plan specifically promotes opportunities related to BESS applications. The IEP states that: "Solar PV and CSP with storage present excellent opportunities to diversify the electricity mix, to produce distributed generation and to provide off-grid electricity. Solar technologies also present the greatest potential for job creation and localization. Incentive programs and special focused programs to promote further development in the technology, as well as solar roll-out programs, should be pursued."
Integrated resources plan of 2019	
Purpose of the Act and relevance to CVBM	**Supportive provisions**
The Integrated Resources Plan (IRP) is South Africa's overarching electricity infrastructure development plan based on least-cost electricity supply and demand balance, taking into account the security of supply and the environment (minimize negative emissions and water usage). The IRP 2019 explains that it is developed within a context characterized by rapid changes in energy technologies and uncertainty regarding the impact of technological changes on the future energy provision system. The pace of technological development of BESS/ VRFBs technologies will be one of the key advancements that will impact South Africa's energy planning going forward.	The IRP promotes the increased uptake of energy storage applications and provides that: "taking into account the longer gas infrastructure lead time, the power system selects more energy storage. This can be expected, given the extent of the wind and solar PV option in the IRP." The IRP has allocated a total of 2088 MW of storage up to 2030 as part of South Africa's energy mix, with 513 MW being allocated to 2022 and the remaining 1575 MW to be procured in 2029. A significant change introduced by the Electricity Regulation Amendment Bill 2022 allows the Minister of Energy to publish a section 34 determination that deviates from the Integrated Resource Plan or Transmission Development Plan in an emergency or if it is necessary to do so in the national interest. This means that the capacity provisions outlined in the IRP can be ignored in the event of an emergency or if it is in the national interest and therefore allows BESS applications to be procured at far greater capacities to address the peak capacity constraints faced by the country. Furthermore, the IRP provides that: "Storage technologies including battery systems, compressed air energy storage, flywheel energy storage, hydrogen fuel cells etc. are developments which can address this issue (variability and intermittency), especially in the South African context where over 6 GW of renewable energy has been introduced, yet the power system does not have the requisite storage capacity or flexibility." It is clear from the provisions in the IRP that the government considered BESS applications to be an integral part of the energy transition; however, the capacity limitations set out in the IRP restrict the ability of the BESS industry to grow and compete at the levels necessary to become a commercially viable option for South Africa.

Table 6.1: Energy Laws and Policies (continued)

Electricity Regulation Act	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
The Act aims to "promote the use of diverse energy sources and energy efficiency." A 2011 Amendment Bill proposed to amend this Act to add expressly that the objective would be to promote the use of "diverse sources of energy, renewable energy sources, and energy efficiency", but the Bill was never passed. **Applicability in value chain:** End user application	Section 34 of the Act gives effect to the energy diversification objective of the Act and empowers the Minister of Mineral Resources and Energy to issue determinations, in line with the capacity provisions set out in the IRP, to procure energy from different generation sources. This includes the procurement of renewable energy and BESS capacity provided for the IRP. Section 46(1)(b) is one of the key enabling provisions underpinning the drafting and revisions of the IRP and provides that the minister may determine which types of energy sources may be procured and the percentages of electricity that must be generated from such sources. This enables the minister to **make determinations specifically aimed at procurement of renewable energy** and could be leveraged to also **require renewable energy capacity to be paired with BESS capacity** as part of the renewable procurement requirements. In October 2020, the Minister of Mineral Resources and Energy published an amendment to the Electricity Regulations on New Generation Capacity published under the Electricity Regulation Act. **The amendment allows municipalities to apply to the minister to procure or buy new generation capacity in accordance with the Integrated Resource Plan,** subject to certain conditions.[52] This provision is a fundamental change in the existing municipal electricity procurement model and provides a regulatory platform for municipalities to not only procure renewable energy directly from IPPs, but to build BESS capacity requirements into energy procurement processes. However, a serious flaw in this legal regime is that it makes energy procurement entirely dependent on ministerial discretion. This implies that private sector investors, other spheres of government (such as metropolitan municipalities), and large corporates wanting to generate electricity cannot do so unless there is a determination. Another barrier plaguing the uptake of VRFBs is section 34 of ERA that limits the energy regulator's (NERSA) power to issue a generation license by making it subject to ministerial consent. The minister, rather than the regulator, has de facto control over who can enter the electricity market and the sources used.

52 See regulation 5(3) that provides that: "A municipality, as an organ of state, may apply to the Minister to procure or buy new generation capacity in accordance with the Integrated Resource Plan, and such municipality must:

(a) conduct and submit a feasibility study as contemplated in sub-regulation (2), where it intends to deliver the new generation capacity project through an internal mechanism as contemplated in section 76(a) of the Municipal Systems Act;

(b) submit proof that it has complied with the provisions of section 120 of the Municipal Finance Management Act and the Municipal Public-Private Partnership Regulations published by Government Notice No R. 309 in Government Gagette No. 27431 of 1 April 2005, where it intends to deliver the new generation capacity project through an external mechanism as contemplated in section 76 (b) of the Municipal Systems Act, and

(c) submit proof that the application is aligned with its Integrated Development Plan."

Table 6.1: Energy Laws and Policies (continued)

Electricity Regulation Ammendment Nill of 2022	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
On February 10, 2022, the South African government published the proposed Electricity Regulation Amendment Bill. The proposed amendments broaden the national regulatory framework for the electricity supply industry. They aim to establish a wholesale electricity market in line with international best practice and provide for the establishment and functions of a Transmission System Operator. The proposed amendments form part of several steps the country is taking to reform the electricity sector to achieve a stable and secure supply of energy. The Bill is yet to be finalized and promulgated, but its provisions will result in a significant paradigm shift for the country's energy sector. **Applicability in value chain:** End user application	The following key amendments are relevant to the development of the BESS/VRFB industry. The Bill specifically provides for the procurement of ancillary services, that is, "services necessary to support the continuous and secure operation of electric power system and necessary to maintain reliable operations of the interconnected power system, including, but not limited to, those services necessary for voltage and reactive power control, automatic generation control, frequency control and black start capabilities." **This implicitly promotes the deployment of BESS applications such as VRFBs to provide ancillary services.** However, it must be noted that Eskom's Ancillary Services Technical Requirements for 2022/23—2026/27 explicitly excludes BESS and renewable energy technologies as viable options to provide ancillary services. For the proposed ancillary services provision in the Bill to be effective in relation to BESS and renewables, Eskom would have to amend their Ancillary Services Technical Requirements to allow BESS and renewable energy technologies to be considered as options for ancillary services. The Minister of Public Enterprises will establish a juristic person known as the Transmission System Operator SOC Ltd. to provide for an open market that will allow for a non-discriminatory competitive electricity trading platform. **Market participants will trade energy based on regulated and bilateral agreements in the day ahead market.** Furthermore, the Bill provides that "Market participants will supply reserves in the day ahead reserve market and Balance Responsible Parties will trade physicals with one another after the day's market closing to account for changing circumstances." This provides an opportunity for BESS capacity to enter the market and for BESS owners to purchase surplus energy after market closure at the end of each day. **In such a case, energy arbitrage would be possible whereby BESS owners could purchase surplus electricity at lower rates at closure of the market and sell the electricity back into the market at a later stage, for a higher tariff.** Schedule 2 of the Bill exempts generation facilities with energy storage to be registered or licensed with NERSA only if such facilities are used to provide standby or back-up electricity in the event of, or for a duration no longer than, an electricity supply interruption. This provision specifically aims to reduce the administrative burden if BESS applications are adopted to provide electricity during planned and unplanned electricity outages. Schedule 2 of the Bill exempts generation facilities with energy storage to be licensed with NERSA where the facility has a capacity of no more than 100 MW with a Point of Connection on the transmission or distribution power system. This provision minimizes the administrative burden for renewable energy project developers and enables them to build renewable energy plants paired with BESS without the risk of electricity curtailment.

Table 6.1: Energy Laws and Policies (continued)

National Energy Act	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
The National Energy Act is South Africa's overarching legislation regulating the energy sector. Section 5 of the National Energy Act imposes a duty on the Minister of Energy to promote access to affordable, sustainable, and environmentally suitable energy and energy services to all people. **Applicability in value chain:** End user application	The Act requires the Minister of Energy, in consultation with the Minister of Trade and Industry, the Minister of Labor, and the Minister of Environmental Affairs, to "adopt measures not contemplated in any other legislation, to minimize the negative safety, health and environmental impacts of energy carriers."
Mineral and Mining Laws and Policies Mineral and Petroleum Resources Development Act	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
Mineral resource exploitation in South Africa is regulated by both statute and common law. The Mineral and Petroleum Resources Development Act 28 of 2002 (the MPRDA) is the primary regulatory framework legislation governing ore extraction. The Act aims to provide for equitable access to and the sustainable development of the nation's mineral and petroleum resources and related matters. **Applicability in value chain:** Vanadium Ore Extraction and Processing	Under Section 3(1), all mineral and petroleum resources, which includes vanadium, are the common heritage of the people of South Africa, and the State is the custodian thereof for the benefit of all South Africans. The government has the discretion to grant, issue, refuse, control, administer, and manage any mining and petroleum rights. As the custodian of mineral rights, only the State can authorize exploitation of mineral resources and grant these rights through the minister. In terms of section 26 of the Act, the minister can also promote the beneficiation of a specific mineral, such as vanadium, subject to such terms and conditions as the minister may determine. Given the potential of vanadium beneficiation to contribute to the alleviation of South Africa's electricity crisis in VRFBs, there is a need for the Minister of Mineral Resources and Energy to introduce measures specifically aimed at supporting the beneficiation of vanadium.
Minerals and Petroleum Resources Royalty Act	
Purpose of the Act and relevance to CVBM	**Supportive provisions /Barriers**
In terms of section 3(4) of the MPRDA, the Minister of Finance must determine and levy a State royalty by means of an Act of Parliament. The minister did this by promulgating the Mineral and Petroleum Resources Royalty Act, 2008 as well as the Mineral and Petroleum Resources Royalty (Administration) Act, 2008, both of which are administered bySARS. The royalty is triggered on transferring a mineral extracted from within the Republic. As for all other taxes, duties, levies, fees, or money collected by SARS, the royalty collected is paid to the National Revenue Fund.	The following persons/entity must register for the payment of the royalty to SARS: • Any persons/entity who holds a prospecting right, retention permit, exploration right, mining right, mining permit, or production right or a lease or sublease regarding such a right; or • Any person/entity who wins or recovers a mineral resource extracted within the Republic. Royalties are payable for the duration of the mining right, according to Section 25 (2) (g) of the MPRDA. The Mineral and Petroleum Resources Royalty Act (2008) ("Royalty Act") requires that a royalty fee be paid to the National Revenue Fund regarding the transfer of mineral resources extracted within the Republic. According to Schedule 2 of the Royalty Act, vanadium >1 % V_2O_5 equivalent and <2% calcium (CaO) and silica (SIO2) bearing gangue minerals is classified as an unrefined mineral resource. The royalty payable for an unrefined mineral resource is calculated as follows: 0.5 + [earnings before interest and taxes / (gross sales in respect of unrefined mineral resource x 9)] x 100. The royalty is required bi-annually, with the deficit between forecast sales and actual sales payable in a third payment.

Table 6.1: Energy Laws and Policies (continued)

The Exploration Strategy for the Mining Industry in South Africa (April 2022)	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
The purpose of the Exploration Strategy is to attract mineral exploration investment, reignite mineral development, accelerate new mineral discoveries, and encourage optimal utilization of the South African mineral resources in line with the environmental, social, and corporate governance principles for sustainable growth, and to propel South Africa to a competitive position against other jurisdictions of comparable mineral endowment. **Applicability in value chain:** Vanadium Ore Extraction	The Strategy identifies the "Rising Demand for Clean Energy" as an opportunity for the South African mining industry. More specifically, battery storage is considered a key opportunity for South Africa to leverage, given the global demand in BESS technologies. Additionally, energy instability is considered a key weakness for the mining sector because of the inability of the mining sector to access a stable and reliable electricity grid. This presents VRFB producers with an opportunity to not only contribute to the global demand for clean energy, but to contribute to solving one of the most pressing challenges currently faced by the mining sector. The strategy identified vanadium as a "critical mineral" essential for the shift toward a green economy. To support exploration of the vanadium resources, the Department of Mineral Resources and Energy will outline an investment promotion plan focusing on promoting the country's minerals industry, cognizant of the global trends within the mining and metals sector, and the economic realities of the country, such as unemployment and slow economic growth. This will include providing junior exploration companies and other projects with technical and financial support until the feasibility stage. The Strategy provides the basis for VRFB producers and vanadium ore extraction companies to participate in a new generation of the mining industry that is responsive to current and future market demands
Draft Mine Closure Strategy (2021)	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
The draft National Mine Closure strategy was published for comment in 2021. The draft strategy highlighted the adverse impacts of mining and the irreversible environmental degradation and economic hardship when a mine closes. Therefore, the strategy seeks concurrent economic diversification, looking beyond non-renewable resources and seeking long-term solutions.	The strategy does not explicitly support the deployment of BESS or VRFBs. However, the draft Strategy recognizes the energy supply crisis in South Africa and the fact that self-generation of energy by mining companies is a critically important aspect of promoting sustainable post-mining economies. The Strategy recognizes that the recent developments whereby operating mines generate their own power will create a generation base that can provide energy post -mining developments, as well as provide sustainable energy where long-term pumping and treatment of water is required. This presents an opportunity for BESS operators to participate in post-mine closure strategies and play a key role in relation of the Strategy's objectives.

Table 6.2: Environmental Laws and Policies

National Environmental Management Act (NEMA)	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
The Act helps provide for co-operative environmental governance by establishing principles for decision making on matters affecting the environment, institutions that will promote cooperative governance, and procedures for coordinating environmental functions exercised by organs of the State. The Act also provides for certain aspects of the administration and enforcement of other relevant environmental management laws and matters.	MPRDA stipulates that the principles of the NEMA apply to all mining and serve as guidelines for the interpretation, administration, and implementation of the environmental requirements of the MPRDA. Consequently, a holder of a mining permission, right, or permit: • Must consider, investigate, assess, and communicate the impact of their activities on the environment comprehensively. • Must, as far as is reasonably practicable, rehabilitate the environment to its natural or predetermined state, or to a land use that conforms to the generally accepted principle of sustainable development • Is responsible for environmental damage, pollution, or ecological degradation as a result of reconnaissance, prospecting, or mining operations that may occur inside and outside the boundaries of the areas to which such right, permission, or permit relates. • Must ensure that it will take place within the framework of national environmental management policies, norms, and standards However, most of the measures applicable to the vanadium sector are outlined in subsets of regulations published under NEMA, which is the overarching environmental legislation for South Africa. The most relevant regulatory measures are outlined below.
Environmental Impact Assessment Regulations	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
The Act aids in providing for co-operative environmental governance by establishing principles for decision making on matters affecting the environment, institutions that will promote cooperative governance, and procedures for coordinating environmental functions exercised by organs of the State. The Act also provides for certain aspects of the administration and enforcement of other relevant environmental management laws and matters.	South Africa has yet to develop the necessary regulatory provisions to ensure that the environmental impact of BESS applications is managed appropriately. However, sections 24 and 44 of National Environmental Management Act make provisions for the promulgation of regulations that identify activities that may not commence without an environmental authorization (EA) issued by the competent authority. In this context, the Environmental Impact Assessment Regulations that came into effect on December 8, 2014, and were amended in April 2017, promulgated in terms of NEMA, govern the process, methodologies, and requirements for undertaking environmental impact assessments to support EA applications. Listing Notice 1 of the Regulations lists activities that require a Basic Assessment process, while Listing Notice 2 lists activities that require a Scoping & Environmental Impact Report (S&EIR). Listing Notice 3 lists activities in certain sensitive geographic areas that require a Basic Assessment.

Table 6.2: Environmental Laws and Policies (continued)

The National Environmental Management Air Quality Act (NEM:AQA) Act No. 39 of 2004	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
Section 21 of the NEM: AQA refers to activities that result in atmospheric emissions with significant impacts. A list detailing related activities shall be published, including minimum emission standards regarding polluting substances. These will outline permissible emissions volumes, rates, or concentrations and measurement procedures. For such activities, an atmospheric emission license is required before commencement of operations. The Act establishes the procedure for the application for and issuance of atmospheric emission licenses. The license will specify the maximum allowed volume, emission rate, or concentration of pollutants that may be discharged into the atmosphere.	"Vanadium Ore Processing" is listed as an emissions activity and must therefore comply with various requirements. No company or person may, without a provisional atmospheric emission license or an atmospheric emission license, conduct an activity (vanadium ore processing) (a) listed on the national list anywhere in the Republic; or (b) listed on the list applicable in a province anywhere in that province. With Vanadium Ore Processing, the requirement to obtain an atmospheric emission license applies on a national level, and any company conducting vanadium ore extraction would have to obtain an atmospheric emission license, no matter where in the country such an activity occurs.
South Africa's revised Nationally Determined Contribution (2021)	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
On September 14, 2021, the Cabinet approved South Africa's updated climate change mitigation target range for 2030 in its Nationally Determined Contribution (NDC) for submission to the United Nations Framework Convention on Climate Change (UNFCCC). Therefore, this year's update conveys a significantly more ambitious mitigation target, whereby the country's emissions will peak in 2025 at 510 MtCO_2-eq, which is lower than anticipated, and whereby the entire target range has been lowered for 2030.	The NDC does not outline any provisions explicitly linked to the increased deployment of BESS or VRFBs. However, the updated NDC contains certain provisions that implicitly support the uptake of BESS technologies in South Africa. First, the updated NDC acknowledges that South Africa's electricity sector is the country's largest source of emissions and that it will be one of the most challenging sectors to decarbonize. The NDC explicitly states that the achievement of the mitigation goals set out in the NDC will depend on massive investment in renewable energy over the next decade. However, such an investment would not be a logical investment without a commensurate investment in BESS technologies such as VRFBs.
South Africa's revised Nationally Determined Contribution (2021)	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
Published by the Department of Forestry, Fisheries and the Environment (DFFE) in November 2020 (in line with the National Environmental Management: Waste Act No. 59 of 2008), the regulations require the establishment of Producer Responsibility Organizations (PRO), through which producers of batteries, in this case, need to provide a framework for ensuring the effective and efficient management of end-of-life products and to encourage and enable the implementation of circular economy initiatives. Extended Producer Responsibility is a means through which the manufacturers and importers of products are required to bear a significant responsibility for the impact their products have on the environment, from manufacture to the day they are discarded. The Regulations ensure that products that can be recycled or upcycled are and that waste products diverted to landfill are kept at a minimum, fulfilling the Waste Management Strategy 2020 goal of creating a circular economy.	In March 2022, the Minster for the Department of Forestry Fisheries and the Environment initiated a consultation process linked to the requirement of specified sectors, including battery manufacturers, to implement Extended Producer Responsibility (EPR) measures. However, the ambit of the regulations currently only covers the manufacturing of "portable" batteries. According to the definition in the regulations, a "portable" battery is a sealed battery that can be "carried without difficulty" and is neither an automotive nor an industrial battery. Given the nature of VRFBs, manufacturers of such batteries would not be subject to the provisions set out in the regulations.

Table 6.3: Industrial Laws and Policies

Industrial Policy Action Plan (IPAP)	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
The principal objective of IPAP is to achieve structural change by encouraging the development, growth, and increased competitiveness of the South African manufacturing sector. Its provisions stimulate demand for a vast range of upstream inputs and services, while also stimulating additional downstream activity. It is a critical driver of innovation and productivity growth on a domestic level and is also central to the development of a strong export strategy. **Applicability in value chain:** Vanadium electrolyte manufacturing, VRFB manufacturing, VRFB end use	The IPAP identifies vanadium (among other metals such as manganese and nickel) as sought-after metals in the battery materials market and highlights vanadium electrolyte manufacturing projects as a key mineral beneficiation project. The IPAP acknowledges the important role of BESS in distributed energy generation models, which are increasingly becoming the business-as-usual approach in developed economies. Furthermore, the IPAP recognizes the opportunities for BESS in South Africa in relation to capital deferrals and arbitrage (storing production surplus during low demand periods and meeting higher demand during peak periods). To realize the potential of VRFBs, the IPAP introduced a key action program specifically focused on the demonstration of energy storage technologies in South Africa. This will include the development of a vanadium electrolyte production facility, followed by a vanadium redox flow battery assembly/manufacturing plant in South Africa. This will facilitate new industrial development opportunities with a global market perspective. This project will support: • Increased beneficiation of South African vanadium resources. • Localization of vanadium redox flow battery technology to support market development in South Africa and regionally.
Medium-Term Strategic Framework (MTSF)	
Purpose of the Act and relevance to CVBM	**Supportive provisions / Barriers**
The Medium-Term Strategic Framework (MTSF) 2019-2024 is the country's second five-year implementation plan to achieve the goals set out in the county's National Development Plan. The MTSF 2019-2024 also sets out the package of interventions and programs that will advance the seven priorities adopted by the government. South Africa's energy transition forms part of Priority 2: Economic Transformation and Job Creation.	Although the MTSF does not outline any specific provisions relating to BESS technologies, securing the supply of energy is a key outcome to realize economic transformation. As part of securing energy supply, the following outcomes are highlighted in the framework that could support the increased deployment of BESS/VRFB technologies: • Explore embedded generation options to augment Eskom capacity—the increased deployment of BESS/VRFBs is a key aspect to consider as part of the increasing number of large-scale embedded generation options. • Diversify energy sources by implementing the approved Integrated Resource Plan—if the IRP is amended to increase the capacity of renewables in the South African electricity grid, BESS applications will play a fundamental role in decreasing the variability associated with the increased uptake of renewable energy technologies.

6.5 Income Tax Act

In South Africa, the government has introduced a range of incentives aimed at increasing the uptake of renewables. The introduction of clean energy tax incentives has historically been provided for in Section 12 of the Income Tax Act and has resulted in increased renewable energy uptake and energy efficiency measures. Some measures set out in Section 12 can, however, be interpreted to also cover BESS applications. Table 6.4 outlines some incentives that could support the uptake of BESS/VRFBs in South Africa.

Key barriers preventing the uptake of storage in South Africa

The preceding analysis of the South African laws and policies identified the following key barriers as the most limiting factors prohibiting the increased uptake of VRFBs as a utility -scale BESS solution:

- Currently, the market is purely driven by behind-the-meter (BTM) battery installations in Uninterrupted Power Supply (UPS), telecom, rooftop solar, solar home lighting systems, and microgrids. The lack of an enabling regulatory framework contributes to the slow uptake of VRFBs as a utility-scale solution.
- Inadequate standards for storage batteries in South Africa enables the import of substandard and uncertified products to the detriment of the development of the local market and local manufacturers.
- A lack of incentives specifically aimed at promoting the competitiveness and commercial feasibility of BESS technologies is hampering the uptake of BESS technologies.
- The IRP2019 foresees the addition of 0.5 GW of energy storage in 2022 and the addition of a further 1.5 GW only seven years later. This staggered timing of energy storage additions is not conducive to stimulating a battery storage industry.

Table 6.4: Tax Incentive Measures

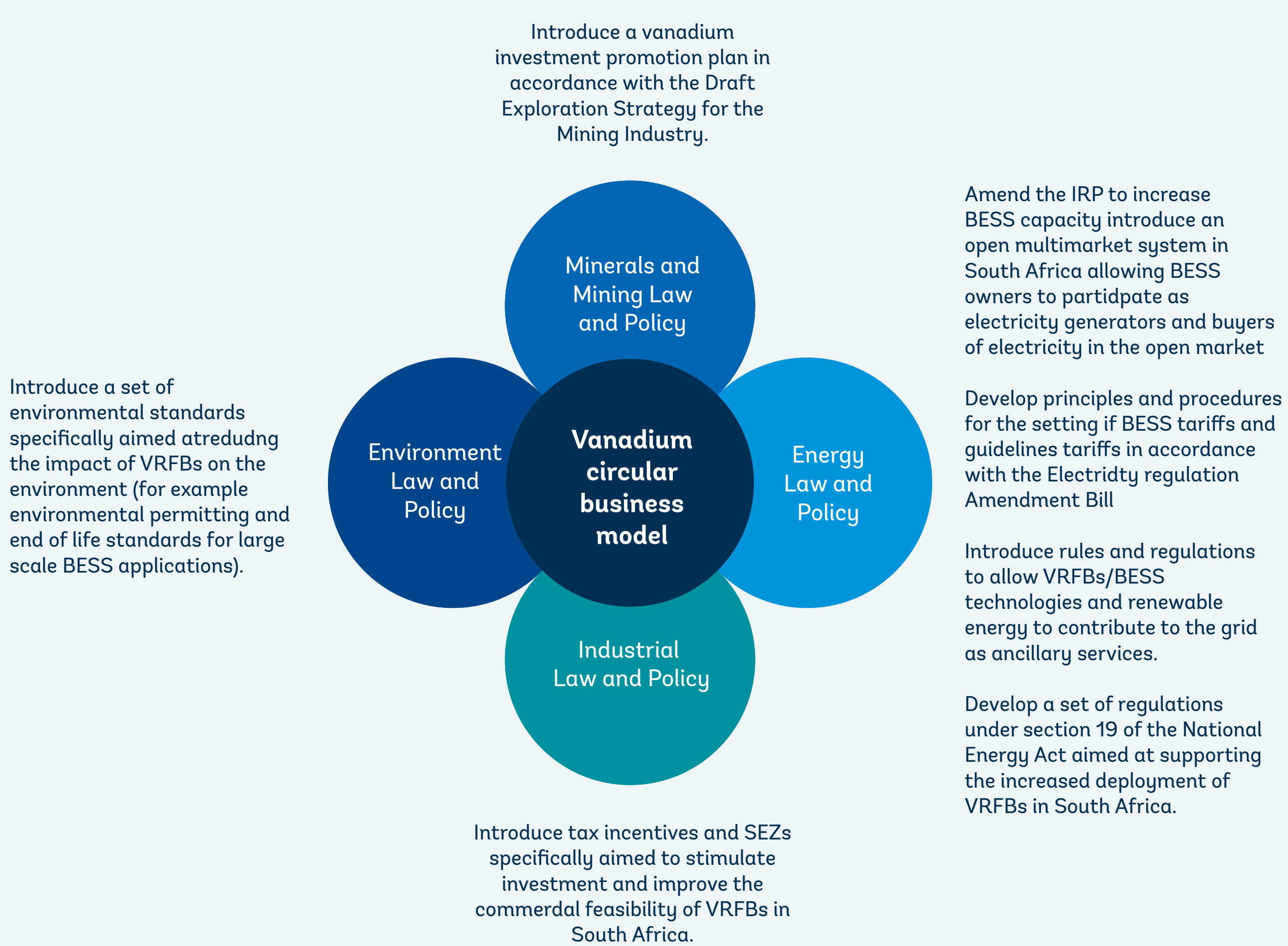
Description	Details	Section	Application to BESS
Accelerated depreciation allowance (RE)	Regarding assets brought into use for the first time and solely to produce renewable electricity. The allowance is based on the cost of the assets, and 50%, 30%, and 20% is granted in each of the first three years of use, respectively.	**12B(1)(h)**	The application of Section 12B should be extended to include BESS applications as generation assets.
Industrial policy project (IPP) allowance (Energy Efficiency)	Industrial policy projects that use improved energy efficiency and cleaner production technology, inter alia, are entitled to an allowance of 35% – 100% of the cost of new and unused manufacturing assets used in the project.	**12I**	BESS projects could be classified as industrial policy projects to receive the additional investment and training allowance set out in Section 12
Research and Development allowance (Renewable Energy and Energy efficiency)	A 150% allowance for expenditure incurred directly and solely on approved R&D activities undertaken in South Africa. The expenditure must be incurred in the production of income in any trade. The allowance also extends to pre-trade expenditure incurred for approved R&D activities.	**11D; 11A**	To encourage pilot projects, Sections 11D and 11A could be extended to include BESS research and development projects.

Source: PwC calculations

Key recommendations

The projected decline in VRFB prices, the continuing innovation in new battery technologies, as well as their benefits at times of peak demand and load shedding are continuously strengthening the commercial case for increased BESS deployments. However, as BESS applications represent a new form of energy technology in South Africa, the country has yet to develop the regulatory regime that would promote the uptake of BESS, and more specifically, VRFBs. Urgent action is required by the Department of Industry and Competition (DTC) and entities such as the National Regulator for Compulsory Specifications (NRCS) and the South African Bureau of Standards (SABS) to put relevant standards and testing capabilities in place.

Figure 6.2: Key Components of a Circular Vanadium Business Model



Source: PwC South Africa

Leveraging the provisions of existing legislation, such as section 19(1) of the National Energy Act that allows the Minister of Mineral Resources and Energy to publish BESS -specific regulations, can bring about tremendous development opportunities for BESS. Such regulations would support BESS provisions currently set out in existing developmental policies such as the IRP and IEP.

Additionally, emerging energy regulation, such as the Electricity Regulation Amendment Bill, will make it possible for VRFBs owners to participate in a liberalized electricity market, incentivizing the increased deployment of VRFBs when compared to the current single -buyer electricity market. From the assessment, it is clear that the greatest regulatory reform required to support a circular vanadium business model would be in the energy policy space. The key regulatory changes set out below would contribute to the successful implementation of a circular vanadium business model in South Africa.

6.5.1 Mining regulatory recommendations

- Introduce an investment promotion plan in accordance with the Draft Exploration Strategy for the Mining Industry in South Africa that focuses on supporting the vanadium extraction industry.
- Introduce vanadium beneficiation support mechanisms under section 26 of the Minerals and Petroleum Resources Development Act.

6.5.2 Environmental regulatory recommendations

- Develop a specific recycling/reuse regulatory regime aimed at reducing the impact of the vanadium value chain on the environment. This should include the following:
  - Guidelines on the identification of appropriate locations for BESS solutions considering various factors such as weather conditions, natural resources, access to infrastructure, and the natural environment, among others.
  - Guidelines for the dismantling of BESS equipment and the end of its service life, including specific BESS end-of-life provisions regarding qualifications for entities engaged in recycling used battery equipment and the reconditioning and testing of such materials, equipment, and devices.

6.5.3 Energy regulatory recommendations

- Amend South Africa's IRP:
  - For BESS to be commercially feasible, the IRP must be updated to at least triple the renewable energy capacity provisions for wind and solar to address South Africa's international climate change commitments, set out its IDC and the country's energy crisis.
  - Balancing a large quantity of renewable power, especially solar PV and wind (both variable sources), requires the support of energy storage systems, such as VRFBs.
- Introduce a set of regulations under section 19 of the National Energy Act, specifically aimed at promoting the increased deployment of BESS and VRFBs.

6.5.4 Industrial regulatory recommendations

- Introduce tax incentives associated with the manufacturing, piloting, and deployment of VRFBs similar to the tax incentives introduced for the increased uptake of renewable energy in section 12 of the Income Tax Act.
- Introduce free trade zones: Special Economic Zones (SEZs) are duty-free areas offering storage and distribution facilities for value-adding activities within the Special Economic Zone for subsequent export. Vanadium electrolyte manufacturers will benefit from the development of a free trade zone to increase the commercial feasibility of exporting vanadium electrolytes to end users.

SEZs could play an important part in the development of local battery value chains. For example, the vanadium electrolyte plant of Bushveld Energy is being established in the Coega SEZ in the Eastern Cape, at the port of Coega. It could be advantageous to locate additional battery value chain activities, such as VRFB battery manufacturers, in the same SEZ.

6.6 Using a Vanadium Leasing SPV to Benefit the Public Entity

A Special Purpose Vehicle (SPV) is a legal entity created by the sponsor or originator (private sector or public sector), to fulfill a temporary or permanent objective of the sponsoring entity. Its powers are very limited, and it will end when the purpose is attained. Public sector SPVs generally have a much longer life span. However, to structure a vanadium leasing model that would also benefit the public sector, it would be necessary to establish a private sector SPV that includes a public entity.

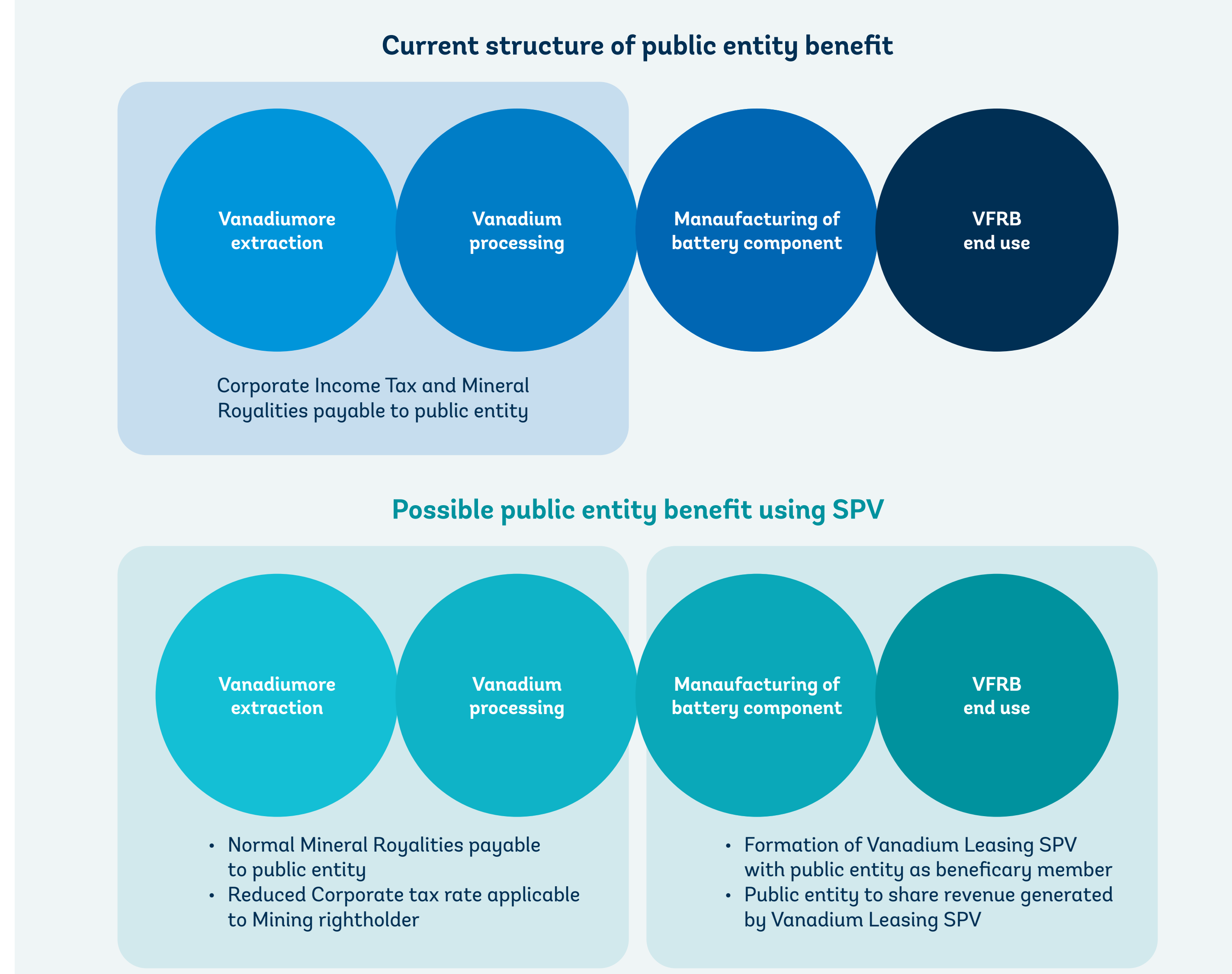
While such mechanisms were a rarity in the 1990s, they have become increasingly popular, and we now see many types of SPVs with various legal, ownership, governance, and management structures—some of which would appear to have worked better than others. Some are legislated (e.g., the Saldanha Bay Industrial Development Zone), some are not (e.g., the Mandela Bay Development Agency). When considering vanadium leasing models, there have already been developments in this space. In September 2020, Invinity Energy Systems, a manufacturer of vanadium flow batteries for the large-scale energy storage requirements of businesses, industry, and electricity networks, formed a special purpose company, Vanadium Electrolyte Rental Limited (VERL), in partnership with Bushveld Minerals to provide an electrolyte rental option for the company's customers. The formation of VERL provides Invinity customers with the additional option of renting the electrolyte used in the Vanadium Flow Battery (VFB) system over a set term. This approach allows customers to reduce the upfront capital outlay of a flow battery system by renting the electrolyte over the life of a project, rather than purchasing it at the outset.

The structure and purpose of the SPV only benefits the private sector entities involved in the establishment of the SPV. No public-private sector SPV has been established to benefit the public entity when considering vanadium leasing models. To benefit a public entity, government participation in such an SPV would have to be facilitated. More than ever, the capture of a greater direct share of the wealth potential of mineral development, along with obtaining more socioeconomic linkages, has topped the agenda of many mineral-rich countries. This re-emergent drive has prompted many governments to revise mineral policy and fiscal instruments as well as renegotiate contractual terms, to ensure the realization of more economic linkages from their mineral resources. One way the South African government aimed to effectively obtain more benefits from the development of its natural resource endowments for present and future generations was through the enactment of the MPRDA. The MPRDA specifies that royalty payments are to be charged when [mineral and petroleum] resources are transferred or sold in accordance with the MPRDA's provision for State custodianship over its mineral resources. The royalty payments collected by this instrument represent an additional revenue stream to the government in conjunction with corporate income tax (CIT) receipts, because both payments are collected in the same time cycle. Thus, in South Africa, the key streams of government revenue from the vanadium leasing model would flow from two sources of levies:

1. Corporate Income Tax: Corporate income tax is charged under the Income Tax Act. For tax years ending before March 31, 2023, the CIT rate applicable to the corporate income of both resident and non-resident companies is a flat 28%. This rate will be reduced to 27% with effect for assessment years ending on or after March 31, 2023. This rate will be payable to vanadium mining and vanadium processing companies.
2. Mineral Royalties: An entity that wins or recovers a mineral resource within the Republic must pay a royalty for such extraction to the South African government under the Minerals and Petroleum Resources Royalty Act. The payment of a mining royalty is aligned with the idea that South Africa's mineral resources are the common heritage of all the people of South Africa, with the State as custodian thereof for the benefit of all South Africans.

Both these sources of revenue are paid at the vanadium extraction and processing phases to the National Revenue Fund for the benefit and use of the South African government. The public sector benefits from such charges in the early stages of the value chain associated with a vanadium leasing model. For the public entity to partake and benefit from a vanadium leasing SPV, without placing an additional financial burden on vanadium mining and processing companies, regulatory reform would be required in the current fiscal regime. Such reforms should enable the exemption or reduction in either the corporate income tax rate or the mineral royalties payable. In exchange for such a tax concession, the government should be allowed to become a member in the vanadium leasing SPV and share in the revenue generated by the SPV. Ideally, the establishment of a vanadium leasing SPV should benefit the vanadium industry and the overall circular business model. Therefore, the possibility of reducing or exempting companies from certain taxes and/or mineral royalties can be explored to support the development of the sector during the extraction and processing phases. The tax reduction or exemption could then be recovered through a vanadium leasing SPV that includes the public entity as a member, reducing the tax liability of the vanadium extraction company during the extraction phase while also ensuring that the public entity benefits from the leasing model during the leasing phase. This concept has been set out in Figure 6.3.

Figure 6.3: Public Entity SPV Model



Source: PwC South Africa

6.7 Estimating the Macroeconomic and Fiscal Impact on South Africa

This section aims to quantify the estimated economic contribution to the South African economy of the electrolyte leasing model through the annual lease fee and recycling of the electrolytes. To do this, a macroeconomic impact assessment (MEIA) was conducted using an internationally accepted approach. The approach was informed by the Global Report Initiative (GRI) standards to quantify the economic value of the investment and operational expenditure in one or more parts of the economy and indicate how this affects other sectors of the economy as well as how those impacts are distributed. The Social Accounting Matrix (SAM) methodology estimated how the activities associated with the investment affect other sectors of the economy and how the revenue is distributed in the economy. The SAM uses national accounts based on data from the South African Reserve Bank (SARB), National Treasury (NT), Statistics South Africa (Stats SA), Labour Force Survey, as well as local and provincial accounts.

6.8 Data Validation, Data Quality, and Data Reliance

PwC received the data used in this analysis from the vanadium leasing company. The company developed a financial feasibility model for a 1 MWh facility, on which the impacts that will be reported on in this report are based. The type of data provided includes capital expenditure, revenue, and operating costs. This information was then checked by the PwC team before allocating it to industries using the globally employed Standard Industrial Classification (SIC) codes. These data were entered the MEIA model to understand the impact.

MEIAs are widely accepted, with several credible international organizations such as the United Nations Food and Agriculture Organization, World Bank, International Model for Policy Analysis of Agricultural Commodities and Trade, and the Organisation for Economic Co-operation and Development employing the methodology. The model is not without its limitations:

- There must be no supply constraints
- Substitution is not allowed
- Prices must be fixed
- The model must be static
- There should be no welfare effects

Figure 6.4: Social Accounting Matrix: Key Concepts

The SAM model outputs were used to estimate total economic impact across the organization

The economic impact is comprised of direct, indirect and induced impacts

The **direct impact** is associated with the investment to get the Vanadium electrolytes ready for leasing and operational expenditure undertaken by the leasing company.

The **indirect impact** includes the second round effects that emanate from the increased demand for goods and services generated by the leasing company.

The **induced impact** results from the employees of the leasing company purchasing goods and services at a household level.

Source: PwC analysis using Social Accounting Matrix methodology

6.9 Economic Contribution[53]

Using data from the leasing company on capital expenditure for preparing the vanadium electrolytes for leasing, the estimated operating costs, and expected revenue, we calculated the following:

- The estimated economic contribution of capital expenditure for electrolyte leasing
- The estimated economic contribution of the electrolyte leasing model through the annual lease fee and recycling of the electrolytes

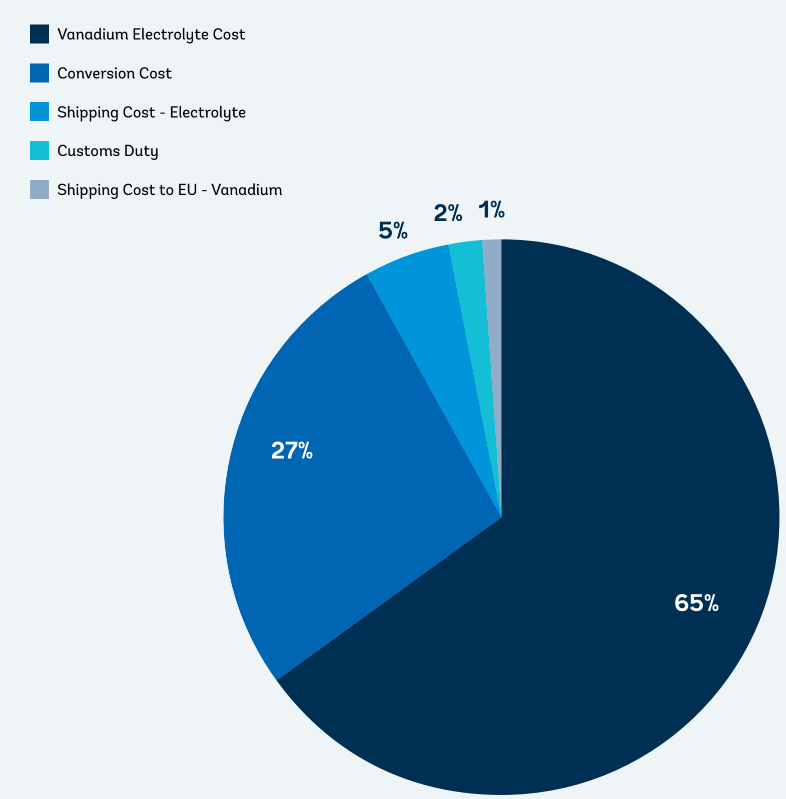
In addition, we modeled the potential long-term impact of continuous leasing of the vanadium electrolytes. The contributions are estimated through the impact on GDP, jobs, household income and public finance.

6.9.1 Estimated economic contribution of capital expenditure, 2022

This section provides insight into the nature and magnitude of the 1 MWh leasing facility's contribution to the economy through capital expenditure and the knock-on effects of this expenditure.

GDP is one of the broadest measures of economic growth. Therefore, it is an all-encompassing measure representing the leasing company's contribution to economic growth in South Africa. In 2022, the estimated economic activity to be generated in South Africa as a result of the investment is around US$293,530. The direct impact accounted for 57% of the total GDP multiplier effect, while the indirect and induced impacts made up the remaining 43%.

Figure 6.5: Contribution of the Leasing Facility to the Economy



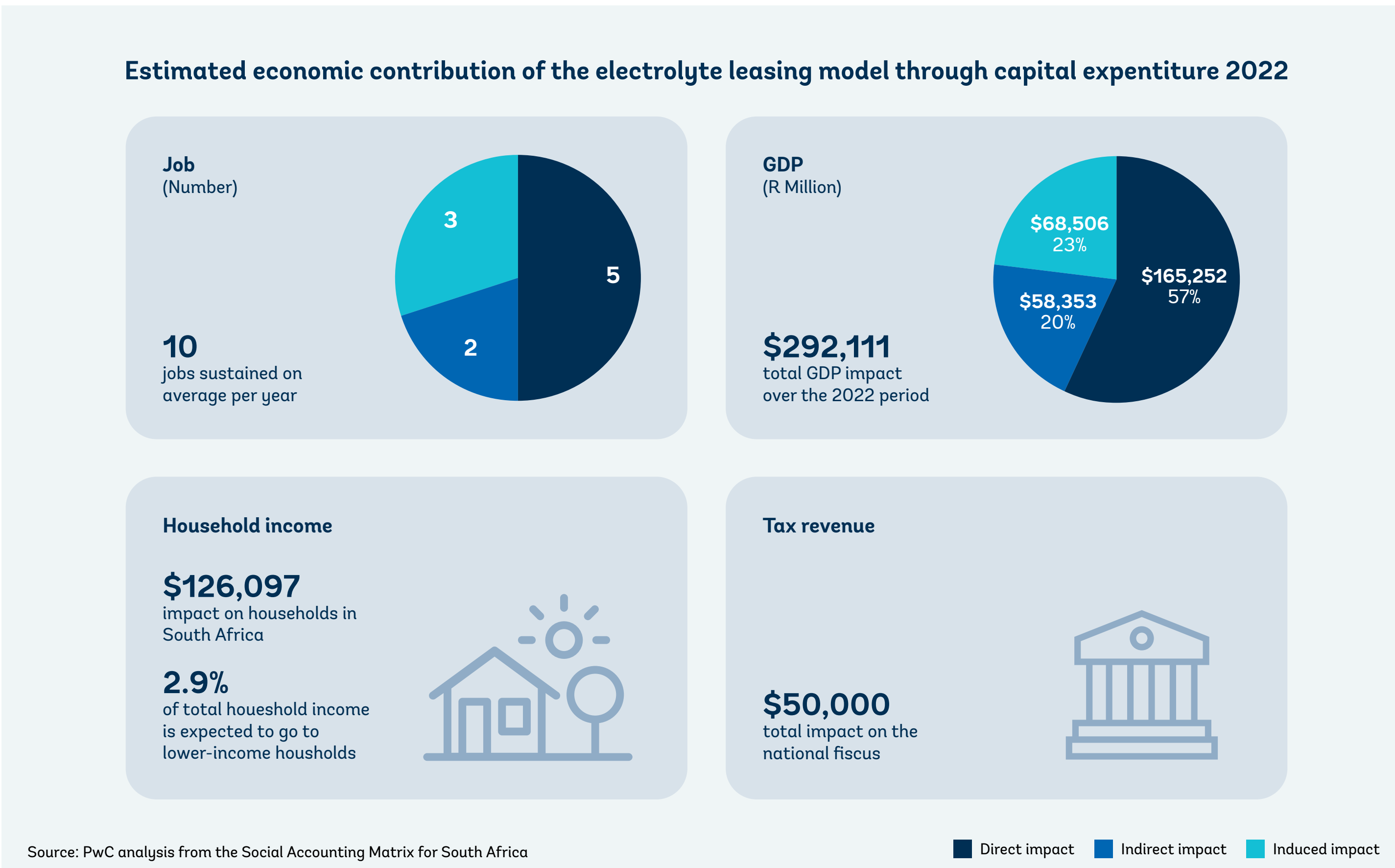
In **2022**, the leasing company is expected to invest **US$293,530** to prepare the vanadium electrolytes for leasing, approximately 65% of the total costs calculated for a leasing company. This is because of the high costs associated with the production of the electrolytes.

The conversion cost is the second most significant cost item, accounting for approximately 27% of the costs related to the vanadium business model. Therefore, the costs for shipping and customs duty account for the balance of total expenditure.

Source: Leasing company, PwC analysis

53 Please note that economic contribution was modelled in South African rand. An average forecasted exchange rate was used to convert the results to US dollars.

Figure 6.6: Analysis from the Social Accounting Matrix for South Africa



Source: PwC analysis from the Social Accounting Matrix for South Africa

Through the investment by the leasing company, job opportunities are expected to be created and sustained in the South African economy. This will directly and indirectly generate income for households. Three types of jobs are expected to be created and/or sustained in the economy:

- Estimated direct jobs that are expected to be created from ongoing investment
- Estimated indirect jobs resulting from the multiplier effects of the investment
- Estimated induced jobs from the increase in household-to-business activity caused by the direct and indirect effects

PwC estimated that because of the expected investment by the leasing company in 2022, about 10 jobs on average will be created and/or sustained. An average of five jobs will be created directly, while two jobs will be sustained indirectly in those sectors that provide inputs to the leasing company. Over the same period, an average of three jobs will be created from economic activity that will result from the payment of salaries and wages to people who are directly employed by these companies and its suppliers.

The contribution to public finance represents a major part of the positive impact on societies in South Africa. This is through the payment of direct and indirect taxes and non-tax revenue mechanisms. The investment by leasing company is expected to result in tax revenue for the government from induced taxes.[54] The contribution is expected to increase by an estimated US$50,000 on average in 2022. This amount is associated with direct and indirect tax collected by the national fiscus from companies in South Africa that are associated with the leasing company's capital expenditure.

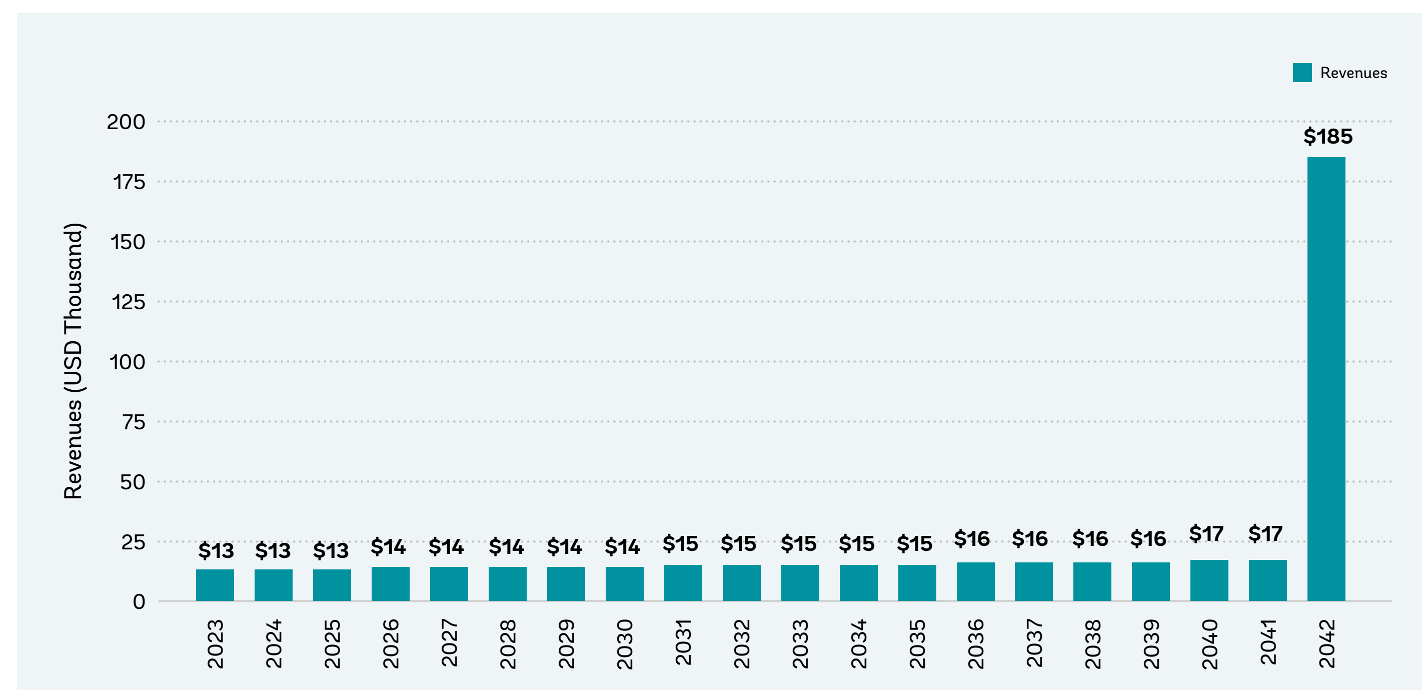
54 Induced taxation: The different rounds of the multiplier effect, from the initial spending in the sector, through to employees spending their salaries on goods and services (and its resultant effects).

The total income to be received by households is estimated at approximately US$126,097.[55] An estimated US$3,714 is expected to go to lower-income households in the country, representing about 2.9% of total household income.

Investment by the leasing company is expected to contribute positively to improving economic development in the country. This could increase the leasing company's output, leading to an increased economic contribution across the sectors in which the leasing company operates and in those sectors that provide inputs to the leasing company. Continuing to lease vanadium electrolytes could have a long-term economic benefits.

As some parts of the value chain, such as mining and transportation, have not been considered, the economic impact could be significantly higher.

Figure 6.7: Leasing company



Source: Leasing company data

6.9.2 Estimated economic contribution from the annual lease fee and recycling of electrolytes

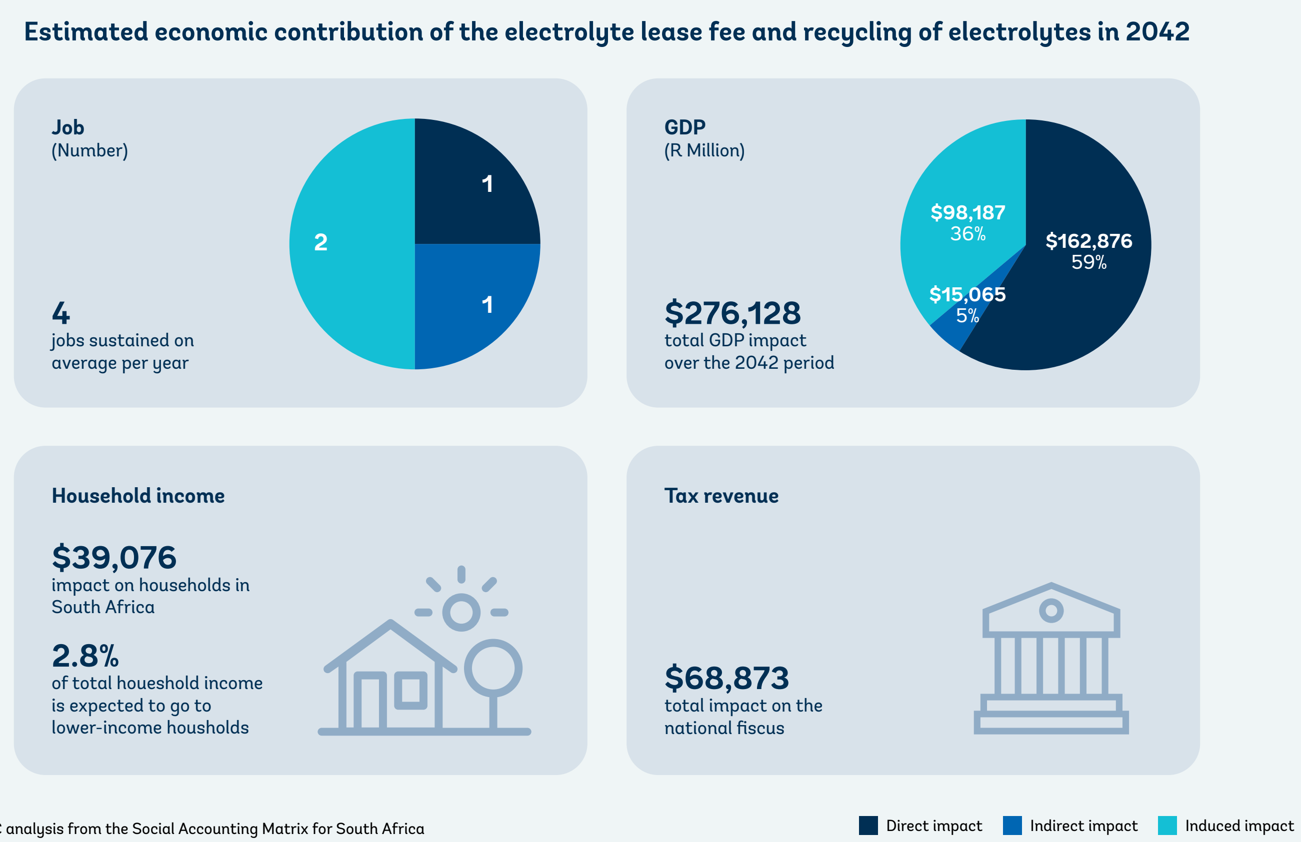
In addition to the economic impacts associated with the capital expenditure of preparing the vanadium electrolytes for leasing, there will also be long-term economic contributions created by the electrolyte leasing model through the annual lease fee and recycling of the electrolytes.

This section of the report considers the leasing company's direct contribution to the economy, in terms of revenue and the administrative function, as well as the knock-on effects of such expenditure over the period 2023–42.

Since leasing is an administrative function, there will be limited impact during the 2023–42 period. However, at the end of the leasing period in 2042, more value is expected because of the recyclable nature of the electrolytes. The impact is greater every time the electrolytes are reused.

55 Estimated average exchange rate for 2022 is R15.88 (Source: IHS Markit Forecast)

Figure 6.8: Analysis from the Social Accounting Matrix for South Africa



Source: PwC analysis from the Social Accounting Matrix for South Africa

The economic activity from vanadium recovery or recycling is estimated at US$276,128[56] in 2042. The direct impact accounts for approximately 59% of the total GDP impact, while the indirect and induced impacts make up the remaining 41%.

During the vanadium recovery/recycling process, the administrative activities by the leasing company are expected to create and/or sustain on average about four jobs in that period. From this, the leasing company is expected to create and/or sustain an average of one direct job, one indirect job in those sectors that will supply inputs to this process, and two induced jobs.

Owing to the planned administrative activities associated with the vanadium recovery/recycling process, total government revenue is expected to increase by an estimated US$67,873[57] in 2042.

Poverty alleviation is one of the main priorities of the South African government. According to the Stats SA national poverty lines report, there are some 30.4 million people in South Africa who are living below the upper-bound poverty line[58] of US$90[59] per person per month. Therefore, it is important to understand how households in South Africa will benefit from the Leasing company's administrative activities associated with the vanadium recovery/ recycling process.

56 Please note that the exchange rate conversion used for these figures was an average exchange rate of R25.01/US$1 for 2042 according to data from IHS Markit.
57 Average exchange rate of R25.01/US$1 for 2042 according to data from IHS Markit.
58 This refers to the food poverty line plus the average amount derived from non-food items of households whose food expenditure is equal to the food poverty line.
59 Average exchange rate of R14.79/US$1 for 2021 according to data from IHS Markit.

The total income to be received by households is estimated at approximately US$39,076.[60] An estimated US$1,111 is expected to go to lower-income households in the country, representing about 2.8% of total household income.

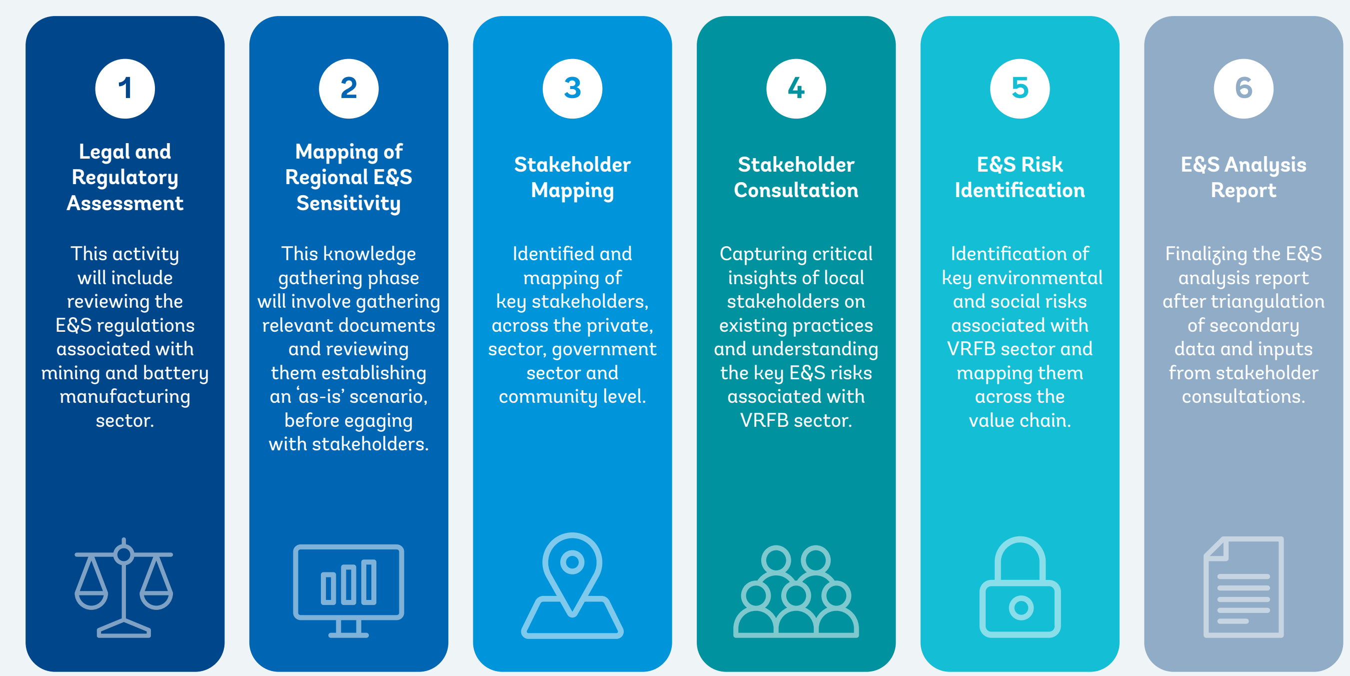
The leasing company's administrative activities associated with the vanadium recovery/recycling process contributed positively to improving economic development in South Africa. This increased the leasing company's output, which led to a greater economic contribution.

This analysis shows that investment in vanadium electrolyte leasing, the resultant administrative activities, and the recycling process is expected to contribute positively to improving economic development in South Africa. In addition, it is expected to have a positive impact on local communities and the South African government in terms of job creation, poverty alleviation, and contribution to public finances.

6.10 Environmental and Social Analysis

The environmental and social analysis focused on evaluating the likelihood of potential impacts associated with the development in VRFB sector in South Africa, considering the regional ecological sensitivity and the socioeconomic, cultural, and environmental health -related beneficial and adverse impacts. The key findings presented in this report have been drawn from a desk review and inputs received from stakeholder consultations. The overall outcome of the environmental and social analysis is linked to the terms of reference requirements and agreed approach and methodology. The findings of the environmental and social analysis have been structured across the segments identified in Figure 6.9.

Figure 6.9: Overview of the Approach for the Environmental and Social Analysis



Source: Approach taken by PwC for E&S Analysis

60 Average exchange rate of R25.01/US$1 for 2042 according to data from IHS Markit.

6.11 Legal and Regulatory Assessment

The key environmental regulations that are likely to be directly applicable to the VRFB value chain were analyzed to understand the extent of the environmental risk assessment and mitigation processes being followed according to the existing regulations. Some of the key regulations that will apply to vanadium mining and the production of vanadium electrolytes are summarized in Table 6.5. The first column references the legislation and guidelines used to determine the legislative background and context of the VRFB sector. The second column gives a brief description of this legislation, and the third column describes the requirements to comply with and respond to the policy and legislative context.

In addition to the relevant environmental legislative and regulatory frameworks, the social regulatory frameworks relevant to the various components of the vanadium mining and VRFB value chain process are compiled in Table 6.6.

Environmental Regulatory Framework

Table 6.5: Overview of Relevant Legislation

	Legislation	Purpose and Relevance	Remarks Regulatory Authority and Permit Requirements
1	**The National Environmental Management Act (NEMA), 1998 (Act 108 of 1998) and amendments. Environmental Impact Assessment Regulations, 2014.**	NEMA has provisions for Environmental Authorisations under section 24 of the act. It also sets out the provisions for conducting an EIA study. The chapter 5 of the NEMA also specifies the general objectives for taking an Integrated Environmental Management approach. Section 24(1) specified that , the potential impact on the environment due to the listed activities must be considered, investigated, assessed, and reported to the competent authority authorised by the NEMA for granting the relevant environmental authorization. In terms of section 24F(1) of the NEMA, no person are allowed to commence any activity listed or specified in terms of section 24(2)(a) or (b), unless the competent authority has granted an environmental authorization for such activity.	**Environmental Authorization**—A full -scale EIA should be conducted for mining activity and for setting up industrial facilities for vanadium electrolyte production. The Scoping Report, Environmental Impact Assessment Report (EIAR), and an Environmental Management Programme (EMPr) are to be developed in line with the requirements of this Act and EIA regulations.
2	**The National Environmental Management: Air Quality Act, 2004 (Act 39 of 2004)**	This act regulates air emissions to protect the environment by providing reasonable measures for preventing pollution and ecological degradation and securing ecologically sustainable development; it provides for national norms and standards that regulate the monitoring of air quality.	**Atmospheric Emission license**
3	**The National Environmental Management: Waste Act, (NEMWA) 2008 (Act 59 of 2008).**	The law regulates waste management to protect health and the environment by providing reasonable measures to prevent pollution. This Act aims to enforce an integrated approach to waste management, with emphasis on the prevention and reduction of waste at the source and, where this is not possible, to encourage reuse and recycling instead of disposal.	A **Waste License** in line with the NEMWA is required. The Regulations and Guidelines specified as part of this Act are also to be complied with, along with the development of an Integrated Water and Waste Management Plan (IWWMP), which is required to obtain the Integrated Water Use Licence (IWUL)

Table 6.5: Overview of Relevant Legislation (continued)

	Legislation	Purpose and Relevance	Remarks Regulatory Authority and Permit Requirements
4	**National Water Act, 1998 (Act No. 36 of 1998) – (NWA)**	The purpose of the NWA, as set out in Section 2 thereof, is to ensure that the country's water resources are protected, used, developed, conserved, managed, and controlled in a way that, inter alia, considers the reduction and prevention of pollution and degradation of water resources.	**Water Usage Licence (WUL) or IWUL** The IWWMP is to be developed in line with regulations and guidelines issued as part of this Act.
5	**The National Environmental Management: Biodiversity Act (NEMBA), 2004 (Act 10 of 2004)**	This Act signifies the reforms in South Africa's laws regulating biodiversity. In terms of Section 57 of the NEMBA, no person may conduct any restricted activity involving any species that has been identified by the minister as "critically endangered species", "endangered species", "vulnerable species" or "protected species" without a permit.	The applicability of the permit is to be assessed on a case-by-case basis.
6	**The National Environmental Management: Integrated Coastal Management Act, 2008 (Act 24 of 2008)**	The Act promotes the conservation of the coastal environment and ensures sustainable development practices and the sustainable use of natural resources.	The applicability of the permit is to be assessed on a case-by-case basis.
7	**The National Environmental Management: Protected Areas Amendment Act, 2009 (Act 15 of 2009) & National World Heritage Convention Act, 1999 (Act 49 of 1999)**	The Act provides necessary protection to the national parks, special parks, and heritage sites of South Africa.	If the project site falls within an area that is formally protected or declared as a nature reserve, certain restrictions under this Act would apply.
8	**National Heritage Resources Act (NHRA), 1999 (Act No. 25 of 1999)**	Section 34 of the NHRA provides for a mechanism for protecting immovable property through an outright prohibition on altering or demolishing any structure or part of any structure that is older than 60 years without a permit issued by the relevant provincial heritage resources authority. If a permit is refused, consideration must be given to designating the place concerned as a heritage site, or protected area or heritage area within three months of such refusal.	The requirement of a **permit or license** is determined by conducting a Heritage Impact Assessment (HIA) study in accordance with Section 38 of the National Heritage Resources Act (No 25 of 1999).
9	**The National Forests Act, 1998 (Act 84 of 1998)**	The Act promotes the sustainable management and development of forests for the benefit of all and creates the conditions necessary to restructure forestry in state forests in relation to protection and sustainable use.	The requirement of a permit or license is envisaged if any protected trees or resources are present in the project area. The same is to be determined according to the provisions stipulated in this Act.
10	**The Occupational Health and Safety Act, 1993 (Act 181 of 1993)**	The purpose of the Act is to provide for the health and safety of people at work or in connection with the use of plants and machinery. According to the provisions of the Act, a Major Hazard Installation Risk Assessment (MHI RA) is to be conducted to ascertain the associated risks and potential impact. According to the provision under this Act, the local fire and emergency services, local Department of Labour, Provincial Department of Labour, and National Department of Labour need to be provided with a copy of the risk assessment.	Conduct an **MHI RA** and follow the guidelines specified in the MHI Regulations.

Note: The table only discusses the key environmental regulations that are likely to be applicable to the VRFB sector. This table does not include all country-specific environmental regulatory frameworks.

Social Regulatory Framework

Table 6.6: List of South Africa's Legislative Mechanisms to Promote Equity[61]

	Legislative Mechanism	Purpose and Relevance
1	**The Promotion of Equality and Prevention of Unfair Discrimination Act 2000 (PEPUDA or the Equality Act, Act No. 4 of 2000)**	Aimed at implementing gender parity by 2030 in accordance with the African Union's Agenda 2063.
2	**Employment Equity Act** **(no. 55 of 1998)**	The Act aims to support the promotion of equal opportunity and fair treatment in employment through the elimination of unfair discrimination. Implementation of affirmative action measures to redress the disadvantages in employment experienced by designated groups in order to ensure their equitable representation in all occupational categories and levels in the workforce.
3	**Code of Good Practice** **(Labour Relations Act (66/1995)**	The Act highlights the following: • The need to ensure equal pay for work of equal value within the next five years • The need for women at the forefront, including procurement changes • The need for inclusion for women to reach universal financial access by 2020 • The need for gender-responsive budgets
4	**Broad-based Black Economic Empowerment (B-BBEE) Act 53 of 2003**	Empowerment Charter for the South African Mining and Minerals Industry or the Mining Charter: for transformation of the mining industry
5	**Department of Social Development 2020/21 — 2024/25 Strategic Plan**	Aimed at addressing poverty reduction, unemployment, and inequality. However, it does not have a particular framework for or mention poverty, unemployment, and inequality (there is no mention of mining as an occupation or social protection and/or development for mining communities or workers).
6	**The National Youth Policy (NYP) 2020-2030**	This is a cross-sectoral policy aimed at effecting positive youth development outcomes for young people at the local, provincial, and national levels in South Africa
7	**The Adult Basic Education and Training (Abet) Act (Act 52 of 2000)**	This Act highlights the regulation of basic education and training for adults and supports the establishment, governance, and funding of public adult learning centers
8	**Small, Medium and Micro Enterprises (SMMEs) policy and legal framework**	This framework provides the institutional structure to address the needs of urban and rural women -owned SMMEs and accelerate funding.
9	**The Department of Employment and Labour comprise: The Basic Conditions of Employment Act of 1997**	The legislation highlights provisions that support the regulation of labor practices that outline the rights and duties of employees and employers. It is aimed at ensuring social justice through the provision of the basic standards for employment pertaining to working hours, wages, dismissal, leave, and conflict resolution.
10	**The Occupational Health and Safety Act of 1993**	This legislation is aimed at providing for the health and safety of persons at work who work closely with the plants and machinery, and against hazards to health and safety emerging out of the activities that the persons are engaged with.
11	**Social Labour Plan (SLP)** **South Africa's Mineral and Petroleum Resources Development Act 2002**	Companies are required to plan an SLP under Regulation 42 of the Minerals and Petroleum Resources Development Act (MPRDA) and to devise and submit the SLP to the Department of Mineral Resources and Energy (DMRE)5 8[1] as a prerequisite for the granting of a mining right.

Note: The table only discusses the key social regulations that are likely to be applicable to the VRFB sector. This table does not include all country-specific social regulatory frameworks.

61 https://www.gov.za/

Mapping of Regional Environmental and Social Sensitivity

South Africa's commitment to improving the environment and social landscape through sustainable development goals (SDGs)

South Africa, according to its new set of commitments, aims to limit GHG emissions to 398–510 $MtCO_2e$ by 2025, and 350–420 $MtCO_2e$ by 2030 with a 28% reduction in GHG emissions from the 2015 NDC targets.[62] Compared to its first NDC, it targeted an GHG emissions level in the range of 398–614 $MtCO_2$ equivalent during 2025–2030.[63] The country accounted for 1.31% of the world's fossil carbon dioxide (CO_2) emissions in 2019 — about 480 million metric tons of CO_2.[64]

As specified in publication by accord, Africa is one of the most vulnerable continents to climate change and climate variability, with almost all the top 10 world's most vulnerable countries based in Sub-Saharan Africa. Several African regions are considered climate change hotspots, exposed to conflicts and violence, and face a state of water scarcity, damaged coastal infrastructure, and poorer crop yields and production.[65,66] Keeping the sustainability goals on par with the NDC, the country can harness the huge resource potential and market opportunities, from major institutional investors and private sector players[67]

Some of the human development challenges in South Africa relating to the SDGs[68] have been compiled to highlight the critical development challenges in analyzing the risk, opportunity, and safeguards to be considered while leveraging the potential of the VRFB value chain .

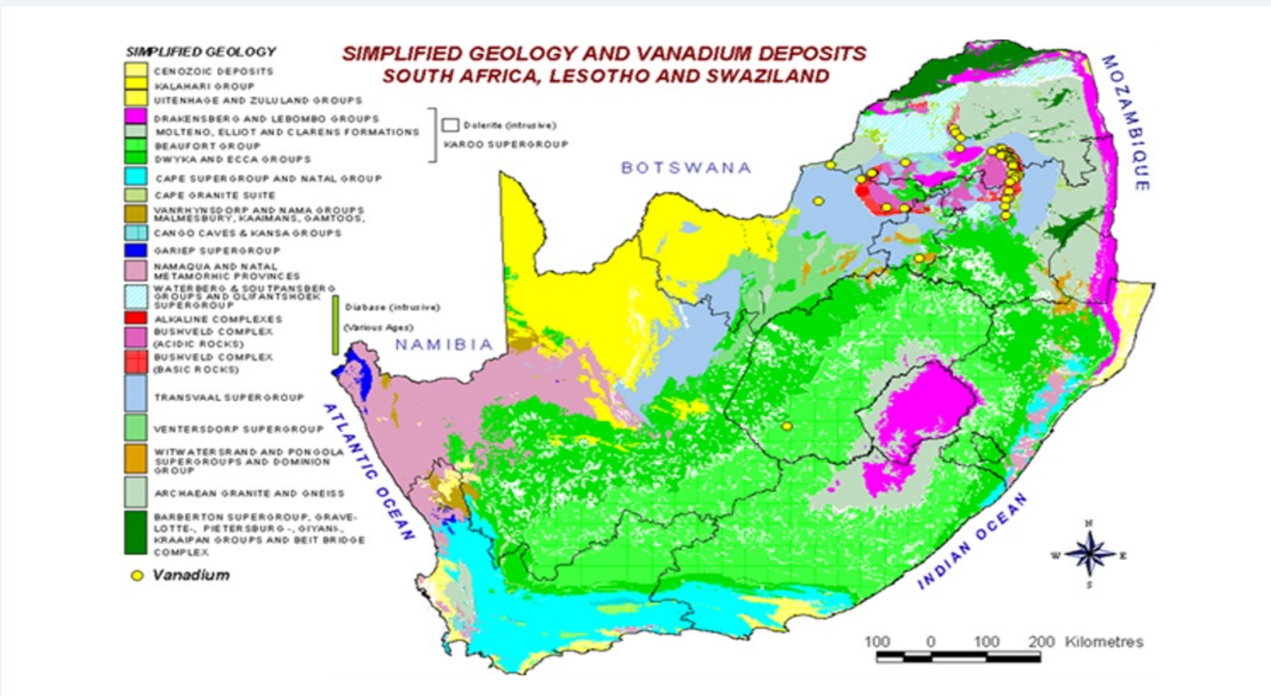
Some of the SDGs most critical to addressing the environmental, social, and economic concerns in the present country context have been identified in Table 6.7. Scaling up of the VRFB industry would increase the vanadium mining activtites which is likely to improve the following areas of human development over the next few years through poverty reduction, improved access to education, gender equality, better sanitation and water, and energy affordability, and inclusive and economic opportunities, while scaling up industry and infrastructure.

Table 6.7: South Africa's Progress on some Critical Sustainable Development Goals

Sustainable Development Goal	South Africa's Progress
Goal 1: No Poverty	Poverty has steeply declined, although it remains high among Black Africans, female-headed households, the poorly educated, and the rural population.
Goal 4: Quality Education	Access to education and literacy has increased, as has the overall share of children benefiting from early education. However, completion rates in the upper secondary grades and enrolment rates in tertiary education are still low combined and demonstrate inadequate skill levels.
Goal 5: Gender Equality	Despite considerable progress, women continue to have unequal access to income, which impedes the full attainment of women's human rights and dignity and gender-equitable opportunities.
Goal 6: Clean Water and Sanitation	Despite improved access to safe water and sanitation services, poor conservation practices affect the sustainability of water resources.
Goal 7: Affordable and Clean Energy	Access to electrical power has increased, although informal settlements and rural areas face cost constraints that hamper accessibility. While the use of renewables has risen sharply, the electricity grid remains highly dependent on coal.
Goal 8: Decent Work and Economic Growth	Low skill levels, limited competition, inadequate infrastructure, and inconsistent government policies hinder productivity and growth and result in high levels of unemployment, particularly among women and youth.
Goal 9: Industry, Innovation, and Infrastructure	Public services infrastructure, such as in transport facilities, is weak and there has been a decline in the share of manufacturing in output over the past 25 years.
Goal 10: Reduced Inequalities	Despite targeted policies and legislative frameworks, discriminatory practices persist. Women, especially young African women, face disparities in unemployment and poverty due to discrimination based on race and ethnicity

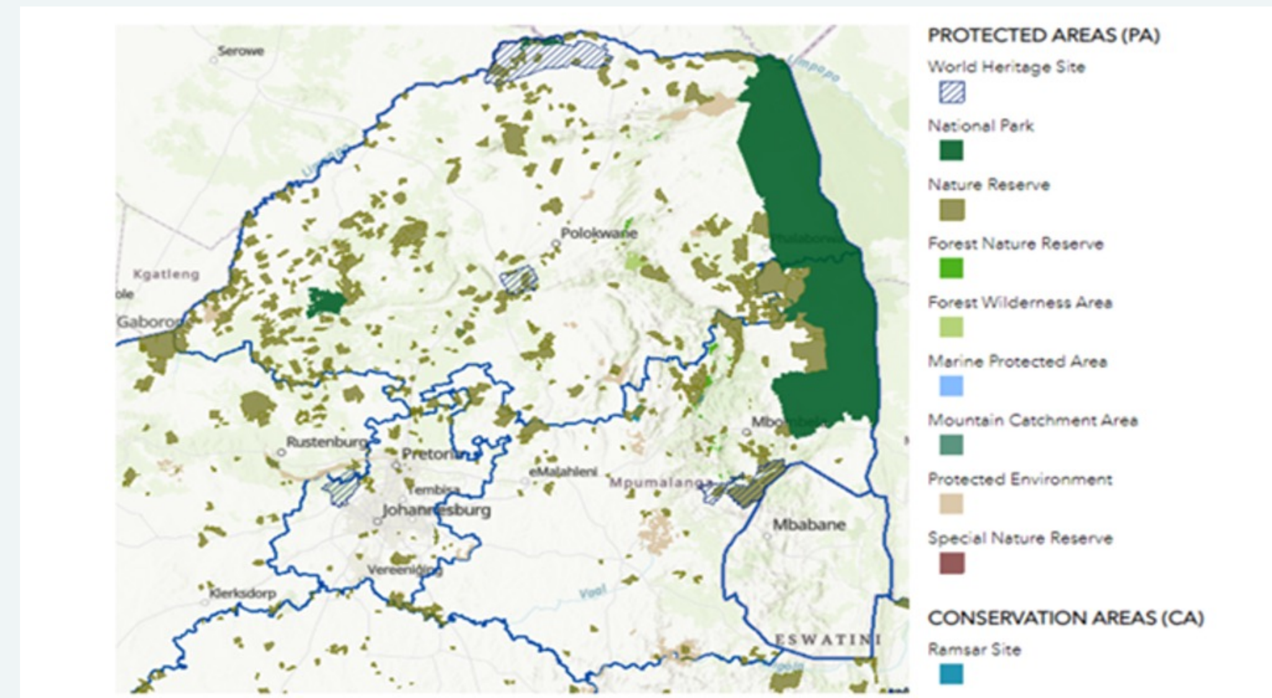
62 https://www.dffe.gov.za/mediarelease/creecy_indc2021draftlaunch_climatechangecop26
63 https://climatepromise.undp.org/what-we-do/where-we-work/south-africa#:~:text=The%20 revised%20 NDC%20 includes%20the,its%20 Low%2DEmission%20Development%20 Strategy
64 https://www.downtoearth.org.in/news/climate-change/cop26-progress-china-south-africa-boost-climate-action-momentum-but-global-ambition-remains-inadequate-79421
65 https://www.accord.org.za/analysis/cop26-an-african-perspective/
66 https://www.accord.org.za/analysis/cop26-an-african-perspective/
67 https://unfccc.int/news/climate-change-is-an-increasing-threat-to-africa
68 https://sustainabledevelopment.un.org/content/documents/23402RSA_Voluntary_National_Review_Report___The_Final_24_July_2019.pdf

Map 6.1: Geology and Vanadium Deposits in South Africa



Source: Council for Geoscience

Map 6.2: Areas of Ecological Importance in the Vanadium-rich Geographies of South Africa



Source: Protected and Conservation Areas Database, https://egis.environment.gov.za/protected_and_conservation_areas_database

Contextualizing SDG Opportunities for the Vanadium Sector

At **COP26–the Glasgow Climate Pact**, there was a move to end international support for fossil fuels and redirect funds to cleaner energy. A declaration signed by over 30 countries and development banks calls for a halt to overseas funding for unabated fossil fuels next year. Reducing or eliminating the use of fossil fuel as a source of energy is the one of the key initiatives for moving toward a sustainable future.

The negative environmental impact of carbon dioxide emissions from burning of fossil fuels leads to a continuous expansion of renewable energies. According to the International Energy Agency (IEA), the share of renewables in global electricity generation jumped to 29% in 2020, up from 27% in 2019.[69]

However, renewable energy sources, such as wind and solar energy, are subject to considerable fluctuations, so storage technologies are required. These technologies must be able to store energy during times of overproduction and feed it back into the power grid during peak loads, thus ensuring the stability of the grid. This is currently achieved by flexibly operated thermal power plants and pump storages. With the rising share of renewable energy in electricity generation, however, additional energy storage facilities are necessary, especially for short-term storage. VRFBs offer an interesting option for energy storage technology.[70]

69 https://www.iea.org/reports/global-energy-review-2021/renewables
70 Preparation of Electrolyte for Vanadium Redox-Flow Batteries Based on Vanadium Pentoxide, Jan Martin,* Katharina Schafner, and Thomas Turek

Vanadium Deposits in South Africa and Regional Environmental and Social (E&S) Sensitivity

South Africa has **nine provinces**, which differ considerably in size. The smallest is Gauteng, a highly urbanized region, and the largest is Northern Cape, which takes up almost one third of South Africa's total land area. Each province has its own Legislature, Premier, and Executive Council.[71] Based on the **Council of Geoscience, the vanadium deposits** are predominantly located in the **Limpopo, Mpumalanga, Gauteng, and Northwest provinces.** This section will focus on the **environmental sensitivity of these four provinces.** Map 6.1 highlights the areas with vanadium deposits.

There is likelihood of an increase in vanadium mining activity with the increased market demand for VRFB. Thus, increased mining activity is likely to have a direct impact on the regional environmental conditions and ecological resources. It must also be noted that the regions with predominant vanadium deposits exhibit greater ecological richness compared to the other provinces in South Africa. Map 6.2 showcases the protected areas, natural reserves, world heritage sites, and other protected environments in vanadium -rich deposits in South Africa.

Some of the key findings from a social development perspective include information related to the availability of basic facilities, the incidence of poverty, and employment data from the national statistics that emerge across the regions of Limpopo, Mpumalanga, and Northwest provinces.

71 https://www.gov.za/about-sa/south-africas-provinces

6.12 Stakeholder Mapping

The selection process for stakeholders included the identification of key governmental departments, private market players (in the industry of mining and battery production), and nongovernmental organizations.

Seventeen stakeholders were identified based on these categories, and requests for consultations were sent to individual stakeholders. However, availability consultations was low, and consultations was conducted with seven stakeholders: the Department of Water and Sanitation; Department of Mineral Resources and Energy; Department of Trade, Industry and Competition; Department of Public Enterprises (DPE); the Council for Scientific and Industrial Research (CSIR); Bushveld Vanadium; and Largo.

Appendix G provides a list of the stakeholders identified, consultations undertaken, and stakeholder outreach initiatives.

Stakeholder Consultations

This stakeholder consultation process was launched to obtain a concrete understanding of the environmental and social impacts of vanadium mining and vanadium processing and the manufacture and transportation of VRFBs and other materials associated with VRFBs in South Africa. Moreover, the stakeholder consultation process aimed to ascertain regional environmental and social sensitivity and potential opportunities, and to include E&S safeguards as regulatory requirements and good practice in the country.

While the previous activities offered a diagnostic and holistic view of the E&S sensitivity and landscape at the country and regional levels, this activity aimed to provide critical insight, relying on local understanding, across the spectrum of stakeholders —from the private sector, government, and civil society.

The consultations were conducted to strengthen the sector baseline and E&S risks as established during secondary research and understand potential bottlenecks in improving E&S performance.

The consultation was completed with seven stakeholders. During the consultations, the stakeholders clearly communicated that their sector-specific understanding of VRFBs was limited because of the evolving maturity and limited scope in the current context. The stakeholders consulted demonstrated a willingness to provide a broad picture of E&S risks associated with mining and industries and the current provisions to safeguard the environmental and social aspects. Table 6.8 notes the key takeaways based on the stakeholder consultations. Appendix H provides details about the objective of the consultations and a summary of the outcomes.

Table 6.8: Key Outcomes of Stakeholder Consultation

	Stakeholder	Key Takeaways
1	**Department of Water and Sanitation**	The Integrated Water Usage Licence (IWUL) must be secured for the industries associated with V-electrolyte production or processing and associated activities. The industry needs to ensure that the conditions stipulated in the WUL regarding water conservation (WC) and water demand management (WDM) are complied with and that a WC and WDM plan are in place. Compliance with the WC or WDM should be submitted annually as part of the Integrated water and waste management plan (IWWMP) to ensure the productive and efficient use of water resources. The effluent or wastewater discharge of the industrial setup must comply with the General and Special Effluent Standards gazetted in 1984. The IWUL and the General Authorization for waste -related activities will specify which standards a user must respect depending on the type of discharge or disposal, irrigating with wastewater, discharging into a resource, or storing in a pollution -control dam. The user is required to comply with the effluent discharge standards as stipulated in IWUL y. The consultation reflected on the general aspects of mining-related processes. There was no insight on the workforce, gender, or social impacts in the mining sector, nor issues specific to VRFBs and vanadium mining.
2	**Department of Mineral Resources and Energy**	No specific insight was provided by the stakeholders regarding the VRFB value chain.
3	**Department of Trade, Industry & Competition**	The presence of limited battery -recycling facilities and the absence of government -owned or -operated recycling units can present a challenge at a later stage. Furthermore, the current regulations in South Africa are limited in terms of addressing the environmental safeguards needed for lead -acid batteries and are yet to consider the impacts associated with the VRFB market to formulate the relevant policies. The incentives available regarding the establishment of production or manufacturing plants in special economic zones were highlighted during the consultation, although no clear insight was provided regarding the benefits of introducing sustainable energy storage solutions promoting the renewable energy sector.
4	**Department of Public Enterprises**	No specific insight was provided by the stakeholder regarding the VRFB value chain. However, the DPE specified that no areas of concerns are foreseen in the upcoming investments in vanadium-related sectors, whereas there are concerns relating to the coal mining sector.
5	**CSIR**	South Africa has an existing framework for various types of energy storage solutions and promotes their collection and recycling using the existing legislative framework. These frameworks do not encompass stationary battery solutions such as VRFBs, which calls for reforms in the framework that include VRFBs to ensure the implementation of safety provisions in the VRFB industry and monitor the operation and recycling of VRFBs from an environmental standpoint.
6	**Bushveld Vanadium**	The key environmental concerns across the VRFB value chain are concentrated in the mining stage, until the production of vanadium extract. Off-gassing during the mining stage is considerably higher and includes the emission of gases such as carbon monoxide (CO) and carbon dioxide (CO_2); flammable gases such as methane (CH_4), CO, and hydrogen (H_2); suffocating gases such as CO_2, nitrogen (N_2O), and CH_4; and toxic gases such as CO, nitrogen oxides (NOx), and hydrogen sulfide (H_2S). Furthermore, SO_2 is the primary gaseous emission during the V-electrolyte production stage, released as a result of the chemical reactions during electrolyte production. These pollutants have the potential to significantly decrease the air quality of the area and are a major contributor to the carbon footprint in the VRFB sector. The uncontrolled emissions of these gases can have detrimental impacts on the workers and the local population. Both mining and electrolyte production must be authorized through an Air Emission License issued by the regulatory body in South Africa and must take steps to ensure the implementation of mitigation measures (installation of stack) and adequately monitor emissions. The calcine tailings generated by the extraction process are considered contaminated material (hazardous waste) in South Africa according to the waste classification. To dump such waste onto the ground, permits are required according to the regulatory norms. The disposal of this hazardous waste requires an HDPE -lined surface, in accordance with the waste classification, as this waste category is deemed to have significant potential to pollute groundwater.

Table 6.8: Key Outcomes of Stakeholder Consultation (continued)

	Stakeholder	Key Takeaways
6	**Bushveld Vanadium**	Mining, processing, and V-electrolyte production involve transportation, handling, and storage of hazardous material. The inappropriate storage and handling of hazardous substances (such as sulfuric acid, other chemicals) can pose a significant threat to health and safety. On whether Baseline studies have been conducted by Bushveld on labor, demographics, and social sensitivity and other parameters for assessment in one or more of the areas or provinces - A baseline study was conducted for Vametco in 2020, and Bushveld is finalizing the scope for a revised Socio-Economic Development This body of work will be completed in mid-2023. There are no Click here to enter text.baseline studies yet on the workforce and diversity both in vanadium mining and VRFB value chain in their current locations – Britztown, Northwest Province, Wit Bank (Mpumalanga province), and East London. Moreover,there are no specific safeguard practices for enterprise development for Black women (as was shared by Bushveld during consultation. Some documents were shared on ring -fenced opportunities for local entrepreneurs at Vametco for the operation to meet its local procurement targets once the VRFB operations start, and priority for these opportunities will be given to companies owned by Black women and youth. There are no procedure and assessment conducted for their upcoming project in Limpopo. However, some opportunities for enterprises for women have been earmarked as part of the Bushveld Incubation program, aimed at developing women into seasoned entrepreneurs. The Vametco SLP document includes commitments regarding the health and safety of workers (page 23), but does not mention communities settling around the mine or human rights policies. The operation has an Employment Equity Plan in place; some of the commitments can be found on pages 35–40 of the attached SLP. A socioeconomic baseline study that was conducted for Vametco in 2020 was shared. Bushveld is finalizing the scope for a revised SED study that will include ESD. This body of work will be completed in mid-2023. Currently, no literature is available on gender and equity or the social perspectives critical to VRFB workforce and diversity in Britztown, Northwest Province, Witbank (Mpumalanga province), and East London. The overall finding that has emerged from the consultation is that their baseline studies may be useful to refer to and draw from in future VRFB and vanadium operations, particularly for certain provinces, such as Mpumalanga, Limpopo, and the Northwest province, which PwC identified as vanadium geographies faces challenges with unemployment, poverty, and a lack of decent living conditions in our mid-term report.
7	**Largo**	Largo's annual report 2021 (shared by Largo) on sustainability serves as a reference document on the management of material ESG risks, opportunities, and impacts in their major operations in Brazil. These operations are not specifically relevant to the VRFB sector and are not contextually relevant in terms of sharing or replicating best practices relating to VRFBs. The key takeaways from the information sources shared by Largo are in line with the assessment carried out as part of secondary research. These key points are also mentioned below: The key E&S risks such as extraction of raw material, usage of water, generation of off gases, generation of solid waste i.e. waste rock and burden are significantly associated with the production of Vanadium pentaoxide. Whereas, at the VRFB assembly stage (the prodcution of battery assembly components, other than the V-Electrolyte, is not considered in this document) the pollution generation potential is on lower side as comapred to the Vandium Pentaoxide production. Thus, the environmental impacts associated with VRFBs are majorly associated till the vanadium pentoxide production stage. The primary practices at the mining and processing stages of vanadium -bearing ores are key to reducing the associated environmental and social impacts. The findings of LCA studies6 9 estimate that when the VRFB is connected to a wind energy source, it produces 31 kg CO_2eq less than an LiB for every MWh of electricity produced; when connected to a solar source it saves 11 kg CO_2eq/MWh more than LiB for every MWh of electricity produced.As specified in the study document, the study and corresponding results are Click here to enter text. subject to the assumptions: (a) VRFB battery with a rated power of 1 MW and a storage capacity of 8.3 MWh . (b) the carbon savings assciated with the use of recycled materials for both the LiB and VRFB.

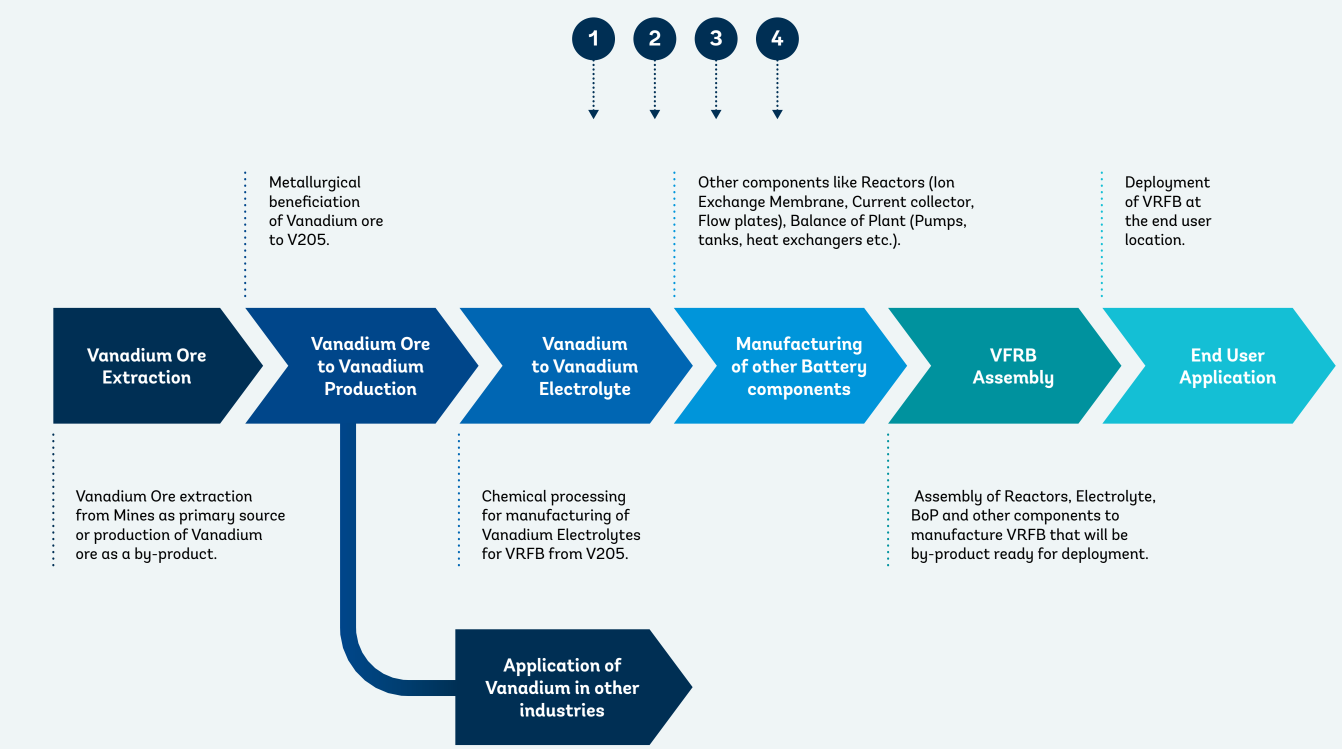
6.13 E&S Risk Identification

The environmental and social impacts were mapped by conducting a broad-based material flow analysis across the VRFB value chain. The material flow analysis majorly focused on the raw material requirements for manufacturing V-Electrolyte and the methodology or process flow for manufacturing VRFBs, as illustrated in Figure 6.10.

The E&S risk assessment for vanadium mining, processing (vanadium electrolyte), recycling VRFB and vanadium electrolyte, and the disposal of waste (tailings) focused on the use of or the impact on natural resources, effluent generation, pollution emission, and waste generation caused by the VRFB value chain. The key focus areas with enironmental implications are specified in Figure 6.11.

Based on our findings from the **study of the social scenario** so far, although the number of women working in the mining sector has increased significantly over the years, from approximately 11,400 in 2002 to 56,691 in 2019, the participation of women in the sector is still quite low. In South Africa, women represent only 12% of South Africa's total mining labor force of 454,861 people.[72] Furthermore, as the VRFB sector is an emerging industry, based on our reviews of secondary literature and stakeholder consultations, women are still not engaged in the VRFB workforce. There is a greater need for improving skills development among women in the mining and mineral sector.[73]

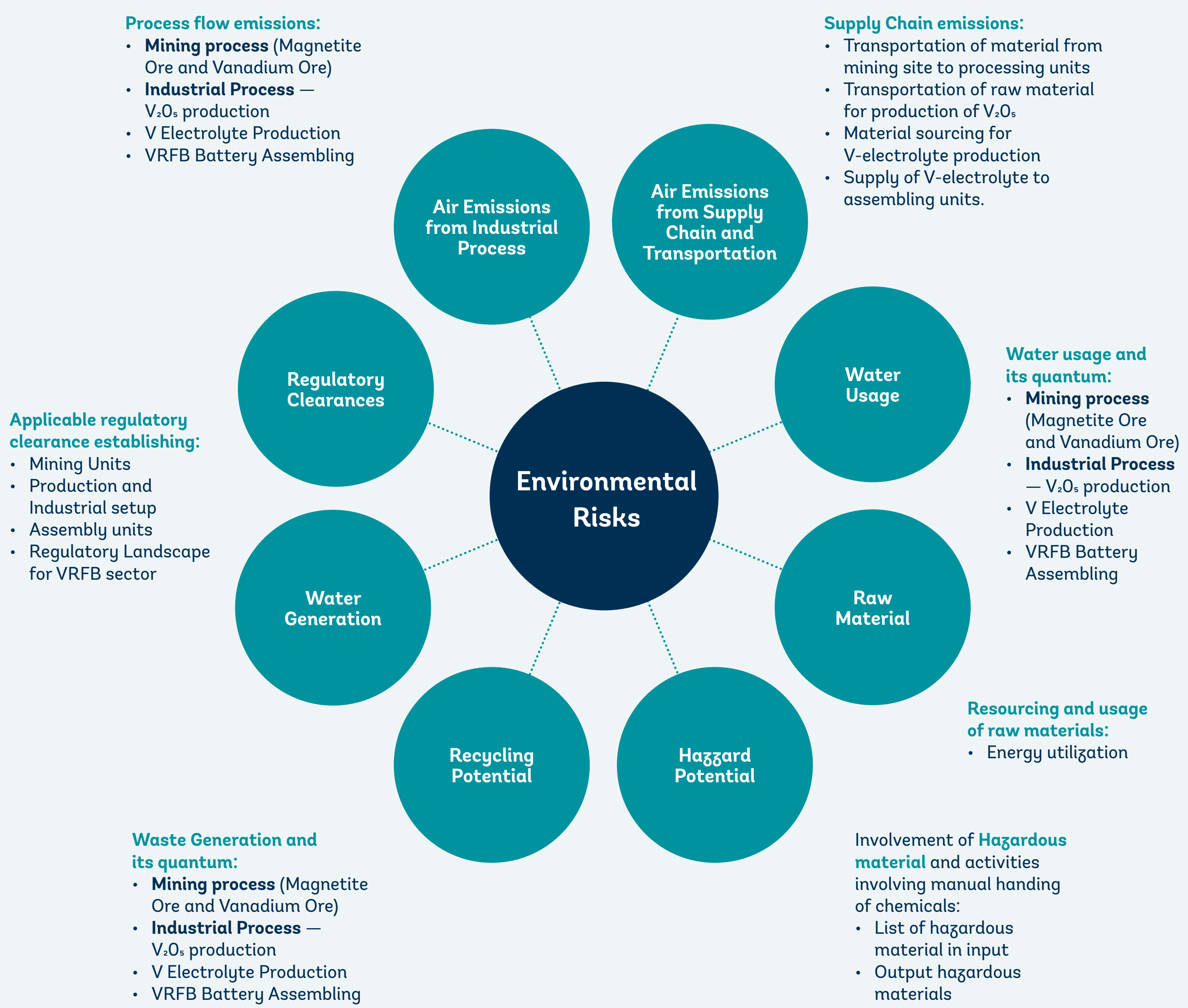
Figure 6.10: Process Flow for VRFB Manufacturing



Source: Stakeholder Consultations (Bushveld Vanadium, Largo)

72 minerals-council-women-in-mining-sa-2022.pdf
73 https://www.gov.za/speeches/deputy-minister-nobuhle-nkabinde-13th-annual-women-mining-conference-career-expo-23-feb

Figure 6.11: Key Focus Areas of the Assessment



Source: PwC Analysis

Environmental concerns mapped across the VRFB value chain[74]

6.14 Vanadium Mining

With titaniferous magnetites ore and vanadium ore, mining is generally done through traditional mining methods in South Africa. This involves drill and blast, as well as load and haul procedures to mine the magnetite ore. In this process, waste rocks or overburden are generated. **High -level environmental risks associated with this stage include open void areas, dumps, and the use of explosives, which could contaminate groundwater (nitrates).**

The legal, environmental requirements for mining state that an environmental impact assessment must be done prior to mining. Once the impact assessment is in place, the environmental management plan is compiled, which details the management of impacts. After approval, an environmental authorization is issued.

The environmental impacts during the mining stages are more intensive than during VRFB manufacturing and recycling. Only 18% of the vanadium is extracted from v-ore; the rest is a co-product or secondary production.

6.15 Concentrate Production

The primary activities in this phase include crushing processes (to downsize the ore or the rock into manageable pieces), screening (to sort the crushed material by size), milling (pulverizing the product into powder), and separation of the magnetic and nonmagnetic forms.

The main inputs for concentration production are magnetite **ore, raw water, and electricity, and the main outputs are vanadium -bearing magnetite and tailings.** The nonmagnetic tailings are stored in a **slimes dam or a tailings storage facility,** which are kept adjacent to the mining areas, while the **ore is transported to the processing area via trucks and then on road,** which creates a transportation safety risk.

6.16 Extraction Process

During the extraction process, the vanadium is extracted from the magnetite. The main inputs include a kilning/roasting process where roasting agents and coal are used. The outputs include **scrubber sludge.**

Calcine is generated from the kilning process, which is followed by the leaching process. The **kilning stacks generate off-gas** during this process, which is likely to be monitored according to the stipulations of the Air Emission License.

In the leaching process, the major input materials are acids and wash water. This will generate **calcine tailings as a waste or by-product.** From the output, leaching of calcine tailings is performed and the solid material from tailings is extracted.

Finally, the soluble vanadium (vanadium converted from a solid to liquid form) can be extracted. The next step is precipitation, which will again require the addition of water along with AMSUL (ammonium sulfate). This process will also **produce off-gas from the stacks.** The output of the precipitation process will be mother liquor along with continuous recovery of **ammonium metavanadate** (through AMV dryers) using **LPG gas as an input.**

6.17 Recovery Process

During the recovery process, a barren dam feeds into a sulfate recovery plant. This process also produces **off-gas** and **requires water, softeners, and coal** (for burning). Most of the liquid in this process is evaporated to extract vanadium in a solid state.

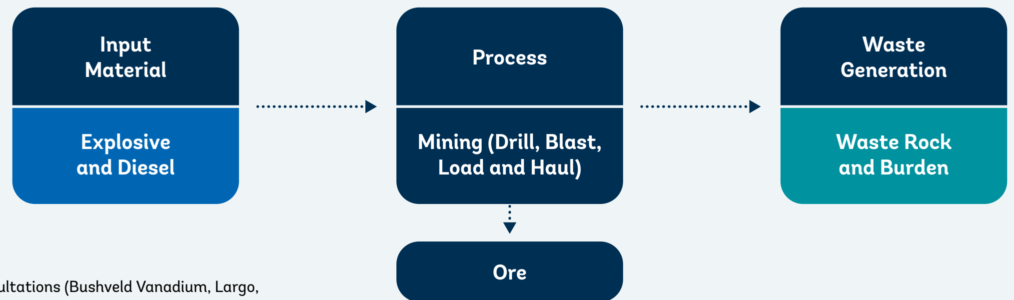
6.18 Refinery Process

The main input in this process is LPG. In this process, the vanadium oxide reactors produce V_2O_5 and MVO powder. The MVO powder is added to the mix plant, which requires **proven air, starch binders, and water.** The final extracted product is then shipped to consumers using road transportation.

Most consumption of the vanadium batteries (VRFB) occurs in the form of V_2O_5 or as vanadium ore, which contains high amounts of waste, or milled and concentrated products.

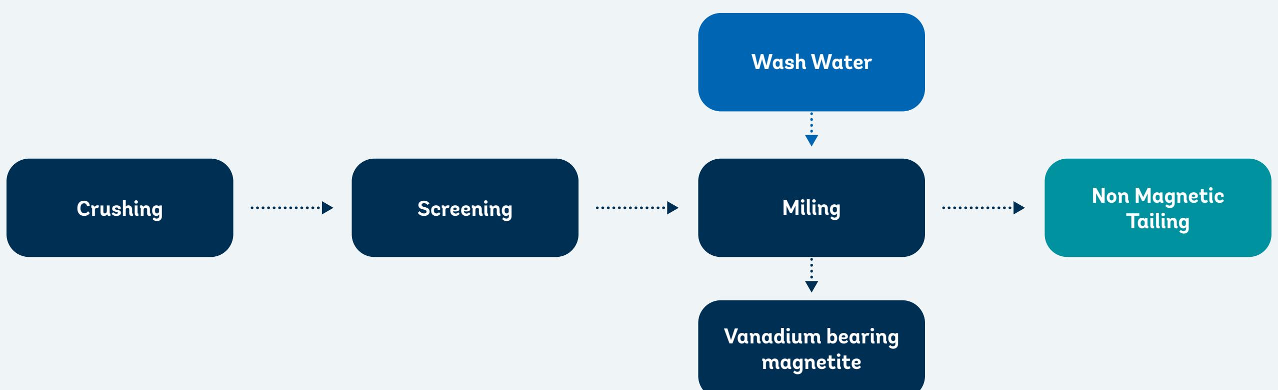
74 Stakeholder Consultation with Department of Water and Sanitation and Bushveld Minerals

Figure 6.12: Input and Output Material Flow of Vanadium Mining—Environmental Context



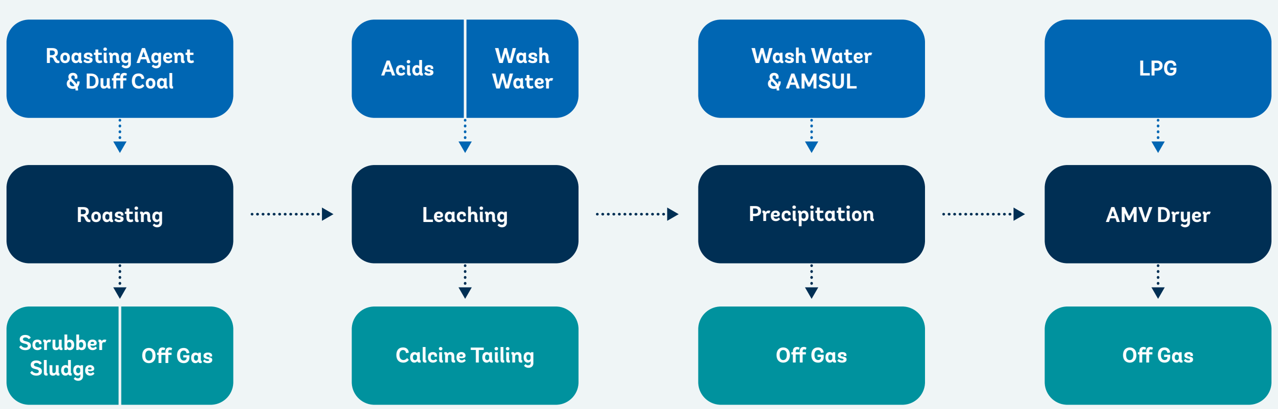
Source: Stakeholder Consultations (Bushveld Vanadium, Largo, Department of Water and Sanitation)

Figure 6.13: Input and Output Material Flow of Concentrate Production—Environmental Context



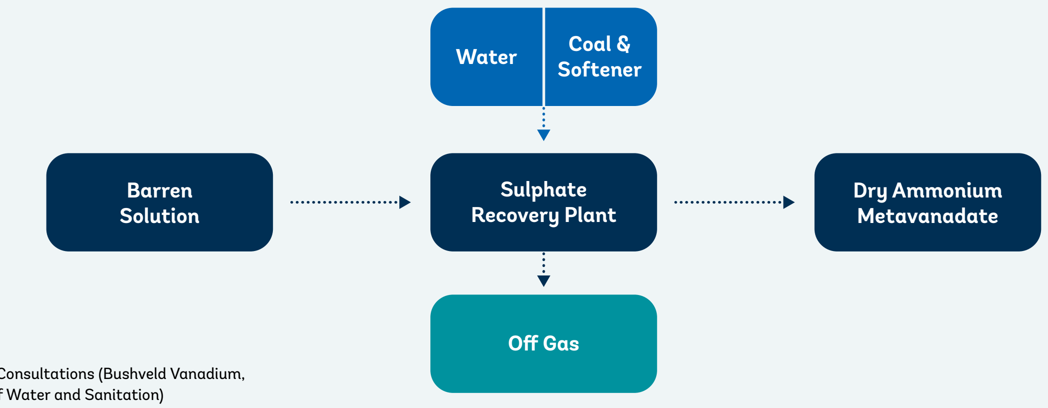
Source: Stakeholder Consultations (Bushveld Vanadium, Largo,Department of Water and Sanitation)

Figure 6.14: Input and Output Material Flow of the Extraction Process—Environmental Context



Source: Stakeholder Consultations (Bushveld Vanadium, Largo, Department of Water and Sanitation)

Figure 6.15: Input and Output Material Flow of the Recovery Process—Environmental Context



Source: Stakeholder Consultations (Bushveld Vanadium, Largo, Department of Water and Sanitation)

Figure 6.16: Input and Output Material Flow of the Refining Process—Environmental Context

Source: Stakeholder Consultations (Bushveld Vanadium, Largo, Department of Water and Sanitation)

6.19 Vanadium Electrolyte Production

Vanadium electrolyte production requires the pre-purification of vanadium ore feedstock to produce the vanadium compounds ammonium polyvanadate (APV) and ammonium metavanadate (AMV), then further purification of AMV to produce high -purity vanadium oxide. Production of the vanadium electrolyte is achieved by dissolution of vanadium oxide in acid.

To produce the electrolyte to be used in the manufacture of the VRFBs, the high -purity vanadium oxide is soluble in acid. This process can be undertaken by following one of three methods: electrochemical dissolution, chemical reduction, and thermochemical reduction.

The key environmental risks associated with V-electrolyte production involve the transportation, handling, and storage of hazardous chemicals such as **sulfuric acid, hydrochloric acid, and hydrogen peroxide**.

Furthermore, the production of V-electrolyte will also result in the **generation of acidic waste and effluent with higher sulfuric acid content**. This can have a noticeable impact on the sewerage infrastructure, groundwater, and soil quality if not handled and treated properly before disposal.

Considering the chemical reactions occurring in the production of V-electrolyte, **air emissions will be higher for SO2 and SO3.** These pollutants have the potential to significantly decrease the quality of the air in the surrounding area.

Figure 6.17: Key Components of VRFBs

Power

- Membrane - Generally Nafion®
- Electrode - PAN Carbon Felt
- Bipolar Plate
- Current Collector - Copper
- Cell Frame - PVC
- Gasket
- Stack Frame - Steel

Energy

- Electrolyte Vanadium-based
- Tank - Glass Fiber

Periphery

- Pump Plastic-Coated Steel
- Pipes Steel, Teflon® lining
- Inverter
- Cables Copper
- Heat Exchange Stainless Steel

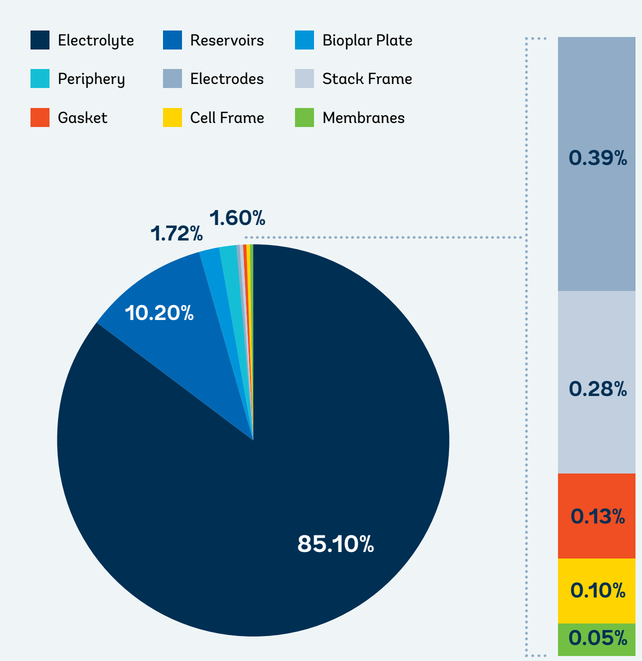
Source: Stakeholder Consultations (Bushveld Vanadium, Largo)

6.20 VRFB Assembling or Manufacturing

The VRFB battery composition can be broadly divided into three functional areas: the power function, the energy function, and the periphery of the battery. While the manufacturing of VRFB components, other than the electrolyte, is not taken into consideration, the assembly of VRFBs is subject to health and safety norms and is likely to have low environmental impacts. Figure 6.17 outlines the key components of these functional areas.

The **vanadium electrolyte in VRFBs has reuse potential of 100%**[75] and requires reprocessing and purification before being reused in VRFBs or as V_2O_5. The recycling efficiency of the **metal parts of VRFBs is approximately 95%,** and the metal component of VRFBs can be **dismantled (mechanical separation on a macro scale)** with a lower energy input.[76] The **plastic components, such as polyvinyl fluoride and other waste plastic, are likely to be incinerated** and disposed of in a landfill or recycled, while the **electronic component can be recycled and used.** Figure 6.18 presents a breakdown of VRFB components in terms of their weight distribution (assuming a total weight of 6.52 kg/MWh for VRFB system).[77]

Figure 6.18: Weight Distribution of VRFB Components[78]



Source: Merchant Research & Consulting

75 https://www.storen.tech/the-modern-energy-market
76 https://pubs.acs.org/doi/pdf/10.1021/acs.est.8b02073
77 https://reader.elsevier.com/reader/sd/pii/S0959652621037082?token=A991739764533EFA0C9627F1332B4537FF1B810E8759CAECF290446BF95C50CA749003399A09E03595568E6AD869BCED&originRegion=eu-west-1&originCreation=20220727070623
78 https://reader.elsevier.com/reader/sd/pii/S0959652621037082?token=A991739764533EFA0C9627F1332B4537FF1B810E8759CAECF290446BF95C50CA749003399A09E03595568E6AD869BCED&originRegion=eu-west-1&originCreation=20220727070623

Social concerns mapped across the VRFB value chain

The overall aim was to identify opportunities and risks in vanadium mining and the VRFB sector and value chain, envisioning a transformation within the miningindustrial sectors in South Africa, via a vertically integrated mineral supply chain. South Africa's Social Regulatory Framework is aligned with the Sustainable Development Goals (SDGs) 2030 prioritizing poverty reduction, gender equality, and accelerating economic growth for human development. In this context, some of the key findings from the current scenario indicates the following:

- The **desk research and secondary literature** (drawn from the Republic of South Africa's Department of Statistics, and other public or archival documents and information) offers insights into the scenario in the South African labor market, indicating that youth continue to be vulnerable in the labor market as the **number of unemployed youth has increased in the first quarter of 2022**. Child labor has declined considerably.
- Overall, the **number of unemployed people in South Africa has been high** although some of the sectors in the country offering employment opportunities include trade, finance, construction, and social services.
- The **National Development Plan (NDP) calls for local governments to promote inclusivity and greater participation by women**, and to make budgetary priorities; however, gender discrimination continues to be pervasive in key sectors such as mining.

Table 6.9: The Road ahead for the VRFB Supply Chain

Aspects of VRFB supply chain	Current scenario and way forward
Domestic competitiveness in VRFB technology	• Vanadium mining and, thus, the VRFB supply chain is yet to gain momentum • Small business development and micro entrepreneurship have not accelerated but can offer opportunities for community investment for vulnerable and socioeconomically marginalized populations • Promote investment in enterprises that are owned by women and other vulnerable groups in less developed municipalities and provinces in the country
Labor market and workforce	• There is a workforce gap and unemployment among youth • There are gender gaps in the labor market, which is currently more advantageous to men than women
Mapping E&S sensitivities across South Africa	• Some of the poorest provinces that host vanadium deposits (but are not yet actively mining them) are vulnerable to poverty, show higher unemployment trends, and lack basic access to education and health care • Migration, education, income and social grants, employment, mortality, housing conditions, and access to and quality of basic services are some of the key indicators to assess the social risks and opportunities in South Africa
Access to energy storage solutions	• Mapping of vulnerable and economically disadvantaged communities is crucial to assess communities' needs and access to energy storage solutions in households and marginal housing areas in poor municipalities • Concurrently, enterprises can have sustained business operations if energy storage is made more accessible and affordable
Human rights, equity, and social safeguards	• A strong gender bias and lack of equity persists in the workforce, where women lack opportunities • Female employment is lower in the mining sector compared to the service sectors • Interrelated economic linkages (which are currently lacking) can be accelerated through mining,
Recyclability	• Not yet emerged as an active element, but is potential in model leasing and for a sustainable, circular economy • Recycling the battery can promote small business development and opportunities for micro entrepreneurship • Recyclability will increase the overall demand for raw materials for battery production • The involvement of local players will increase, which will enhance the possibility of utilizing locally sourced components, enabling a higher degree of micro entrepreneurship • Recycling will benefit communities as it will accelerate skill development

6.21 Environmental and Social Analysis: Key Takeaways

1. Water Usage: Water usage across the entire process, from mining until the production of V_2O_5, is carried out in a circular manner. Based on the consultation with Bushveld Minerals, approximately 60% of the water used in this process is recycled water or water recovered from the process itself, while about 30% of water is lost through evaporation. Water is sourced from an open pit as sub seepage, as well as water from the third parties (municipalities) and or boreholes.

2. Waste Disposal: The overburden or waste rock generated from this process is disposed of or dumped at the nearest point within the mining area. During the concentration process, non-magnetic tailings are generated as waste. The nonmagnetic tailings are more like silica sand in nature and is likely to be used for backfilling into the pit after closure of the mine.

3. Hazardous Waste Management and Handling: During the extraction process, calcine tailings are generated, which are considered contaminated material (hazardous waste) in South Africa according to the waste classification. To dump such waste onto the ground, permits are required according to the regulatory norms. The disposal of this hazardous waste requires an HDPE -lined surface, in accordance with the waste classification, as this waste category is deemed to have significant potential to pollute groundwater

4. Hazardous Material Management: The transportation, handling, and storage of hazardous material during the mining, processing, and V-electrolyte production process is required. The inappropriate storage and handling of hazardous substances (such as sulfuric acid, other chemicals) can pose a significant threat to the health and safety of the employees of the facility and surrounding tenants.

5. Gaseous Emissions: Off gassing during the mining stage is considerably higher and includes the emission of gases such as carbon monoxide (CO) and carbon dioxide (CO_2); flammable gases such as methane (CH_4), CO, and hydrogen (H_2); suffocating gases such as CO_2, nitrogen (N_2O), and CH_4; and toxic gases such as CO, nitrogen oxides (NOx), and hydrogen sulfide (H_2S). Furthermore, SO_2 is the primary gaseous emission during the V-electrolyte production stage, released as a result of the chemical reactions during electrolyte production. These pollutants have the potential to significantly decrease the air quality of the area and are a major contributor to the carbon footprint in the VRFB sector. The uncontrolled emissions of these gases can have detrimental impacts on the workers and local population. Both mining and electrolyte production must be authorized through an Air Emission License issued by the regulatory body in South Africa and must take steps to ensure the implementation of mitigation measures (installation of stack) and adequately monitor emissions.

In line with the section 6.13 of this report, the key E&S risks such as extraction of raw material, usage of water, generation of off gases, generation of solid waste i.e. waste rock and burden are significantly associated with the production of Vanadium pentaoxide. Whereas, at the VRFB assembly stage (the prodcution of battery assembly components, other than the V-Electrolyte, is not considered in this document) the pollution generation potential is on lower side as comapred to the Vandium Pentaoxide production. Thus, the environmental impacts associated with the VRFB are associated unil the vanadium pentoxide production stage. The primary practices at the mining and processing stages of vanadium -bearing ores are key to reducing the associated environmental and social impacts.

The findings of LCA studies[79] estimate that when the VRFB is connected to a wind energy source, it produces 31 kg CO_2eq less than an LiB for every MWh of electricity produced; when connected to a solar source it saves 11 kg CO_2eq/MWh more than LiB for every MWh of electricity produced. (These results are directly taken from the secondary research. These results are subject to the assumptions: (a) VRFB battery with a rated power of 1 MW and a storage capacity of 8.3 MWh[80]. (b) the carbon savings assciated with the use of recycled materials for both the LiB and VRFB.

79 Selina Weber, Jens F. Peters, Manuel Baumann, and Marcel Weil Environmental Science & Technology 2018 52 (18), 10864-10873 DOI: 10.1021/acs.est.8b02073 David A. Santos, Manish K. Dixit, Pranav Pradeep Kumar, Sarbajit Banerjee, Assessing the role of vanadium technologies in decarbonizing hard-to-abate sectors and enabling the energy transition, iScience, Volume 24, Issue 11, 2021, 103277, ISSN 2589-0042, https://doi.org/10.1016/j.isci.2021.103277

80 Weber et al., 2018 - Life Cycle Assessment of a Vanadium Redox Flow Battery, Environmental Science & Technology

Figure 6.19: Recycling and Reuse Potential of VRFB

Source: PwC Analysis

6. Recycling and Reuse Potential: The waste and effluent generated from vanadium mining has limited potential for re-use, while disposal requires a strict monitoring mechanism to ensure the pre-treatment of acidic effluent and calcine tailings. However, the recycling potential of VRFBs is certainly higher: 85% of the battery component is V-electrolyte with 100% recycling potential, and the other metallic components and electrical components can be easily recycled for further use through mechanical separation.

7. Job Opportunities and Entrepreneurship: The 2030 Agenda for Sustainable Development aims to promote sustained economic growth by attaining higher levels of productivity through technological innovation. Additionally, it aims to promote policies that boost entrepreneurship and small businesses and create jobs in South Africa across sectors[81] Scaling up vanadium mining and the VRFB value chain can boost employment opportunities for communities in economically vulnerable provinces where vanadium deposits are found, but where mining activities have not yet begun. The Agenda can also create opportunities for women in the mining sector and the VRFB supply chain. Furthermore, the procurement of batteries will boost skills development among local communities in economically disadvantaged areas, particularly in economically vulnerable municipalities and provinces. Additionally, energy storage can benefit communities in municipalities with a weak grid, an unreliable energy supply, inadequate housing and sanitation facilities, weak infrastructure, and a lack of employment opportunities.

81 https://www.statssa.gov.za/?p=14606#:~:text=According%20to%20the%20expanded%20definition,the%20second%20quarter%20of%202021.

8. Geography and Vulnerability of Mining Communities:
The need for scaling mining

- The mining communities are estimated to comprise nearly 5.4 million people, which is more than 10 percent of the country's population[82]
- An estimated forty-one host communities, of over 1.3 million people, are "mining towns" that are mainly dependent on mining for jobs, income, and even public services[83]

In regions with vanadium deposits, such as **Limpopo province, Mpumalanga province, and Northwest province**, poverty, inadequate nutrition, poor access to education and health care, and unemployment have been historically persistent issues.

9. Women in Mining and the need for strengthening gender equity in the sector

The limited involvement of women in the vanadium and VRFB sector is evident. However, it also remains an area of opportunity for expansion when plans are developed, as the sector gains momentum. The following gaps regarding women's current position within the mining sector have been identified :

- The mining sector in South Africa continues to be among the industries with the least gender diversity.[84]
- In South Africa, the percentage of women graduating with STEM degrees exceeds their representation in the mining workforce.[85]
- Gender-based violence and harassment (GBVH), an occupational safety and health risk, is faced by women in mines "above and below ground" (ILO 2021), and the gender pay gap is pervasive in the mining sector.[86]
- Women make up only 12% of the mining industry in South Africa, up from 6% in 2008.[87]

Considering the above trends, research on women's participation in the mining sector is yet to gain momentum. Parallelly, when plans for vanadium mining and VRFB expansion are developed, communities in the vulnerable provinces will most likely benefit through wider gender inclusivity. in the VRFB supply chain as vanadium mining and VRFBs gather momentum.

10. Gender-equitable Participation and Inclusion for an Inclusive Value Chain[88, 89]

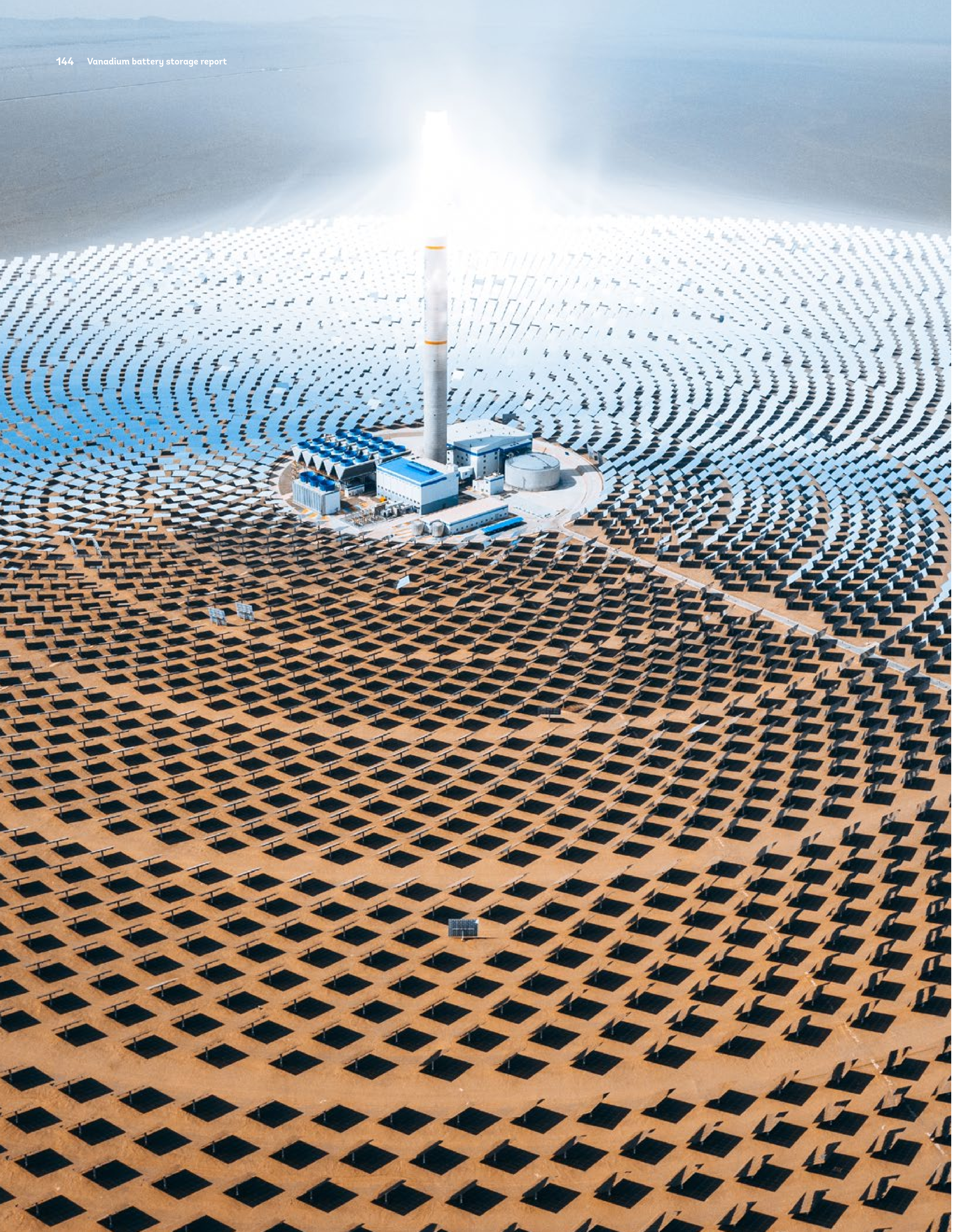
According to a study by the DMRE,[90] research by the Commission for Gender Equality (CGE) on South African mining companies' progress toward gender mainstreaming indicates that the mining industry has historically faced challenges in gender transformation. Furthermore, the secondary literature identifies the following key findings that reveal the gaps in workforce inclusivity and employment trends, particularly over the past two years:

- National reports indicate that the rate of unemployment among women is 48.7 %, 0.1 percentage points higher than their male counterparts as of the second quarter of 2021.
- Women face gender-based hindrances in accessing employment opportunities. A report by the Quarterly Labour Force Survey of the second quarter of 2021 concludes that South Africa's labor market is less advantageous for women.[91] Women's labor force participation is lower than men's.
- During the national lockdown in 2020, three million people in the country lost their jobs of which 2 million were women employed in the informal sector.
- In the second quarter of 2021, male workers (51.3%) were more likely to have received pension/retirement fund than women, compared to 45.8% of women[92, 93] Considering that the gender diparity in labour was already visible and reinforced during the pandemic, we gather scaling up vanadium mining can boost women's employment opportunities in the mining sector as well as create a robust and inclusive VRFB supply chain.

82 Cole MJ, Broadhurst JL. Mapping and classification of mining host communities: a case study of South Africa. Extractive Ind Soc. 2020;7(3):954–64
83 Cole MJ, Broadhurst JL, 2020.
84 The Minerals Council South Africa (2020) https://internationalwim.org/iwim-reports/committed-to-change-for-women-in-mining Accessed on 26 July 2022
85 https://www.igfmining.org/women-mining-workforce-future/ Accessed on 26 July 2022
86 https://www.industriall-union.org/sites/default/files/uploads/documents/2022/GBVH/gbvh_mining.pdf Accessed on 26 July 2022
87 https://internationalwim.org/iwim-reports/committed-to-change-for-women-in-mining/ Accessed on 26 July 2022
88 https://www.statssa.gov.za/?p=14606#:~:text=According%20to%20the%20expanded%20definition,the%20second%20quarter%20of%202021.
89 https://www.statssa.gov.za/publications/P0211/P02111stQuarter2022.pdf
90 https://www.dmr.gov.za/news-room/post/1950/keynote-speech-by-dr-nobuhle-nkabane-mp-deputy-minister-of-mineral-resources-energy-of-the-republic-of-south-africa-at-the-13th-annual-women-in-mining-conference-career-expo-held-on-23-february-2022-at-indaba-hotel-fourways
91 https://www.statssa.gov.za/?p=14606
92 https://www.statssa.gov.za/?p=13690
93 https://www.statssa.gov.za/?p=14606

11. Social Findings: The social findings conclusively reveal that the mining sector and services supply chain can create employment. In the case of South Africa, VRFBs for energy storage solutions possess considerable potential to benefit historically disadvantaged communities, with a focus on youth, women, and suppliers. In this context, the supply chain, and in particular, the local supply of components, is critical and can advance and accelerate the growth of SMMEs in the country. This would promote opportunities for women and other economically disadvantaged groups who are likely to benefit from the promotion of energy storage solutions, and the VRFB value chain through local supply chain procurement. This will simultaneously create a space for skilling or upskilling. Mining companies can expand local (battery) manufacturing capabilities through localized supply chain development. Local industrialization and related businesses in the economic hubs of South Africa within local communities can create sustainable job opportunities and skills upliftment. It should be noted that secondary academic research on SLPs in South Africa reveals that historically, there has been limited research on SLPs[94] in the country context, and that most communities are not well-informed about the SLP system. In strengthening the vanadium mining and VRFB sector, SLPs can help communities benefit from mining and, eventually, from the VRFB value chain and community development. As indicated in the social analysis, scaling up the vanadium mining and VRFB sector will naturally widen the scope for local manufacture or local supply chain procurement, thereby improving livelihood opportunities for communities in vanadium-rich provinces as well those living as in other socio-economically vulnerable areas.

94 https://www.wits.ac.za/cals/our-programmes/environmental-justice/social-and-labour-plans/



7 Roadmap to Scale up the Circular Business Model

The roadmap suggests an approach for scaling up the proposed business model for a company and for government intervention required to promote VRFB technology through regulatory changes and policy reforms for a growing VRFB sector in energy storage.

In developing the roadmap, South Africa is used as an example to illustrate the approach required by a government in terms of the regulatory and policy framework, the economic and fiscal impact, and the social and environmental impact in a growing VRFB sector. In addition, the roadmap provides insight from global markets such as the BESS market and the growth of VRFBs as a stationary energy storage system, global vanadium supply chain and financial aspects of leasing business were also taken up in the roadmap preparation.

7.1 Critical Success Factors for Growth of the VRFB Market

Although the technology has been available since the 1980s, commercial application of VRFBs is relatively new. The growth of the VRFB market will be the most crucial factor in creating an ecosystem for a circular business model in the VRFB space. Challenges such as low demand, relatively low consumer confidence, the higher cost of energy storage, fluctuating vanadium prices, and the absence of a regulatory framework for BESS inhibit the widespread use of VRFB technology. Government intervention will be critical for sustainable growth of the VRFB market, in addition to strong traction from the industry.

A potential initiative is to launch a Center of Excellence (CoE) for structured growth of the VRFB market. The CoE will oversee and manage the activities to promote growth and implementation of a circular business model. The CoE will aim to achieve the following:

- Drive the growth of the VRFB market by generating demand for VRFBs and increasing the supply through cost reduction.
- Drive R&D activities in the VRFB space.
- Establish procedures for sustainable growth of the VRFB market.
- Provide insight to the government to develop the necessary regulations and policies aligned with national development plans and energy transition plans.
- Help (suggestive in nature) the industry players connect with investors to explore the development of partnerships.
- Evaluate the growth of the VRFB market, assess (as required and agreed) the challenges or bottlenecks faced by industry players, and suggest possible remedies during the initial implementation phase.

The CoE should consist of the following team members to gather the requisite expertise from the VRFB market. This is a suggestive and non-exhaustive list that could be amended periodically as needed, in line with actual requirements during the implementation phase.

1. Battery storage market expert
The stationary storage battery market is poised to grow rapidly in the near future. Creating a space for VRFBs by replacing other battery technologies will be easier and critical for the growth of the VRFB market. For this purpose, a battery storage market expert will be required to provide insight from the battery storage industry on a granular scale and identify opportunities for VRFB technology. The expert shall also be responsible for the other avenues and sectors where VRFBs can be sustainably deployed.

2. VRFB industry expert
Given the commercial application of VRFBs in the recent past, the maturity of the technology is significantly lower than the competing battery solutions. The industry has ample opportunity to have a high learning rate . Significant R&D effort will be required to reduce the cost compared to the competing battery technologies. VRFB industry experts to set-up a scalable R&D facility in association with major VRFB producers, educational institutes, and the government.

3. Regulatory and policy expert
The development of new technology requires government support in the form of capital expenditure, taxation methodologies, funding, policies, and regulations. The same applies to VRFBs; direct legal regulatory intervention will be required as most of the countries do not have a standard regulatory framework for VRFBs. The regulatory expert will provide the CoE with critical intervention from the government to create demand centers for VRFBs by providing:

- Guidance on increasing uptake of VRFBs and restricting the unwanted outcomes by establishing controlling measures throughout the VRFB value chain

- Incentives to VRFB manufacturers to promote its production and availability at competitive prices
- Incentives for the end users of VRFB to promote its consumption
- Assistance to the government in drafting the requisite frameworks and policies in this space following the necessary approvals.

4. Social expert

As the VRFB market is at a nascent stage of its development, social inclusion at this stage will be key for its growth. The social expert will be responsible for increasing the representation of the disadvantaged communities, establishing the skill development framework in the VRFB value chain, and providing the necessary input in framing regulations and policies for social growth of the VRFB market.

5. Environmental expert

From the extraction of vanadium to the production of VRFBs and the recycling of vanadium, all stages will have an environmental impact. The environmental expert will have the important task of containing or minimizing the environmental impact from the VRFB value chain by providing the environmental impact monitoring framework and providing inputs for framing environmental regulations for the VRFB value chain.

The CoE will focus on the four thematic areas in which governments need to intervene and work with the industry to grow the market and eventually develop the circular business model suggested.

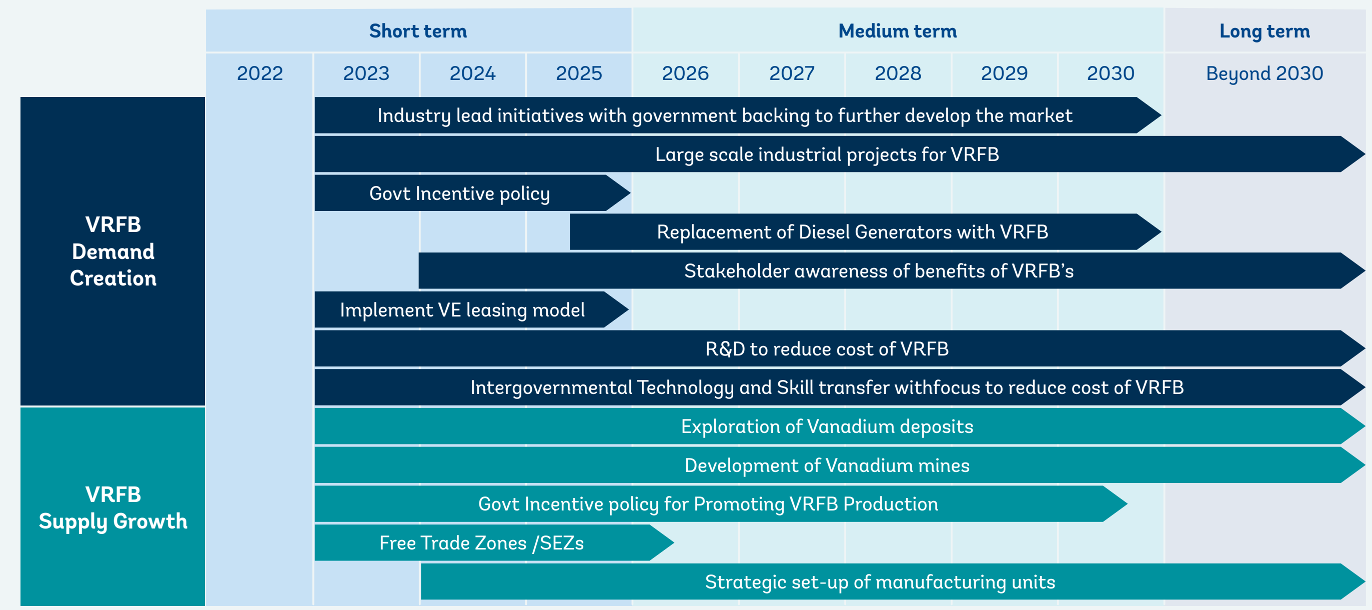
Figure 7.2 presents key activities under each theme. At the start of the roadmap, there are multiple coinciding activities for the following reasons:

- Some activities will gain momentum at the start of the timeline; these activities are expected to be completed sooner.
- Some activities will gain momentum over time and in line with the achievement of other milestones.
- These key thematic areas are not mutually exclusive and require attention in the near future to launch the process.

Figure 7.1: Milestones required to Implement and Scale up the Circular Model for Vanadium Leasing

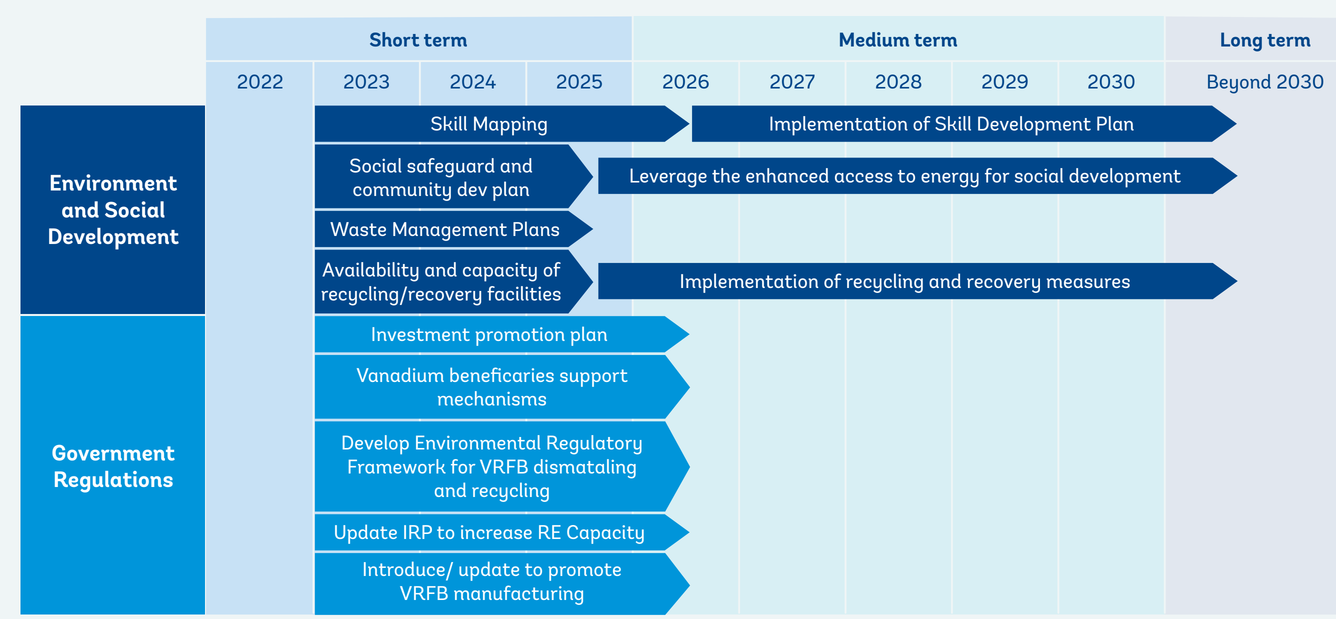
Source: PwC

Figure 7.2: Roadmap for Scaling up of the Circular Business Model for VRFBs through Demand Creation and Supply Growth



Source: PwC

Figure 7.3: Roadmap for Scaling up the Circular Business Model for VRFBs through Environmental and Social (E&S) and Regulatory Reforms



Source: Applicable to the South African context.

Implementing and scaling up the circular business model will require seven milestones from the industry side. Table 7.1 offers a snapshot of these milestones.

The key thematic areas and milestones mentioned above are for the VRFB industry and apply on globally. From the South African perspective, the overall supply of energy is critical to the economic growth of the country. The energy supply crisis in South Africa will not be solved by battery storage alone; however, battery storage will play a key role in the country's future. The CoE mentioned above needs to be established to support and help solve the energy crisis with a focus on battery storage as part of this solution. As mentioned earlier, through the IRP, South Africa has specified the inclusion of renewable power and batteries in the energy plan. The proportion of battery storage to renewable power is not well

Table 7.1: Milestones required to Implement and Scale Up the Circular Model for Vanadium Leasing

2022-23 Model Acceptance	Secure support from major stakeholders: • Vanadium suppliers • VE manufacturers • VRFB manufacturers • Industrial end users • Regulators and the government • Vanadium industry forum • Establishment of the CoE for market development
2022-23 Establishing Procedures	Set up the procedure for defining responsibility for damages and loss of the vanadium or the electrolyte: • VE end -use procedures for the standardized use of VE during operation to maximize recovery • Regular quality checks to verify the quality of the VE during operations
2022-23 Revenue Model	Set up the revenue model • CAPEX and OPEX estimates • Financial model preparation • Market sounding with prospective investors and commodity traders to understand the revenue models, return levels, and investment considerations.
2023 Onboarding Investors	Attract investment from prospective investors: • Educate prospective investors • Provide the business case for the leasing model
2023-24 Distribution Channels	Create distribution channels • Identify prospective end -use locations, such as RE -based power generation, a power distribution hub, and potential VRFB manufacturing or assembly locations • Onboard distributor partners • Implement forward logistics, from manufacturing to distributors to end users
2024 onward Sales & Marketing	Launch sales and marketing: • Create a sales and marketing strategy • Implement the strategy
2027 onward Reverse Logistics	Develop a strategy for collection at the end of the lease term: • Set up VE collection centers at the end of lease duration • Identify locations to set up VE quality assessment and recycling units to make VE reusable in new VRFBs • Optimize VE transport by specialized containers or other means

balanced for battery storage. South Africa possesses significant potential for renewable power. The Northern Cape province is well suited to solar power interventions, while the coastlines of the Eastern and Western Cape provinces favor wind power. Private organizations, such as large mining and industrial power users, are investing in their own renewable power plants in these provinces. Major global energy players have established renewable power plants and have active Power Purchase Agreements (PPAs) with the national utility through the Renewable Energy Independent Power Producer (REIPP) program. The future of battery storage in South Africa will require that the CoE focus on the four thematic areas outlined in Figure 7.1 by engaging the following relevant stakeholders. This list is neither exclusive nor exhaustive.

Table 7.2: List of stakeholders, organizations and with their thematic area

	Stakeholders	Organization	Thematic Area
1	Department of Water and Sanitation	Government	E&S Development, Government Regulations
2	Department of Mineral Resources and Energy	Government	Demand Creation, Supply Growth
3	Department of Trade, Industry & Competition	Government	Demand Creation, Supply Growth
4	Department of Public Enterprises	Government	South Africa
5	Council for Scientific and Industrial Research (CSIR)	Government	Demand Creation
6	Department of Science and Innovation	Government	Demand Creation
7	Department of Environment, Forestry and Fisheries	Government	E&S Development, Government Regulations
8	South African Human Rights Council	**Government**	E&S Development, Government Regulations
9	Mineral Council South Africa	**Government**	Demand Creation, Supply Growth
10	TIPS trade and industrial policy strategies	**Non-Profit Organization**	Demand Creation
11	NGOs working in the mining Industry, battery industry, environmental and social sectors	**Non-Profit Organization**	E&S Development, Government Regulations
12	Universities (research and educational institutions)	**Government & Private**	E&S Development, Government Regulations
13	Centre of Environmental Rights	**Non-Profit Organization**	E&S Development, Government Regulations
14	Municipalities	**Government**	Demand Creation
15	Power utilities and independent power producers	**Government & Private**	Demand Creation
16	Energy Council of South Africa	**Government & Private**	Demand Creation
17	Mining companies in South Africa	**Private**	Demand Creation, Supply Growth
18	South African Energy Storage Association	**Non-Profit Organization**	Demand Creation, Supply Growth
19	South African Photovoltaic Industry Association	**Non-Profit Organization**	Demand Creation, Supply Growth
20	Industrial Development Corporation of South Africa	**Government**	Demand Creation, Supply Growth
21	Central Energy Fund	**Government**	Demand Creation, Supply Growth
22	Banking industry	**Private**	Demand Creation, Supply Growth
23	Energy Intensive Users Group of South Africa	**Non-Profit Organization**	Demand Creation, Supply Growth

7.2 Applicability of the Circular Business Leasing Model for other Critical Minerals

Table 7.3 provides a high-level, qualitative view of the possible application of a circular leasing model to other critical minerals needed for the clean energy transition.[95] This analysis addresses the use of these minerals or metals in energy storage applications only as this was the focus of this report. Further detailed analysis would be required to determine the applicability and impact of applying a circular leasing model to these metals.

Establishing circularity with VRFBs is comparatively easy as vanadium contributes a significant portion in the electrolyte (30% to 50%), facilitating the overall recovery process. It is typically used in large -scale stationary applications for ease of metal logistics and recovery.

With other prominent metals (Li, Co, Ni, Mn) used as active materials in the cathodes of prominent Li-ion cell chemistries, circularity is challenging because the spent batteries undergo a hydrometallurgical or pyrometallurgical recycling process (involving dismantling of the entire battery) after which the metal salts of lithium, cobalt, nickel, and manganese are extracted with an efficiency of 80% to 90%. The cost of recovery from these processes would directly impact lease pricing, likely making it unattractive (further financial and economic analysis would be required). These metals would typically be used in the mobile space, with significant involvement in EV applications. The logistics of collecting and recycling the leased metal would present an additional challenge in applying a leasing model. The battery -grade recycled materials (such as Li, Co, Ni, Mn, and graphite with 99% purity) are sold to the same battery cell or cathode manufacturers or to traders who supply them to battery cell manufacturers. Alternatively, some of the extracted minerals are sold at commodity prices in the health care, ceramics, steel, and other industries.

95 Hund, Kirsten, et al. Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition. 2020. The Mineral Intensity of the Clean Energy Transition

Table 7.3: Applicability of the Leasing Model to Critical Minerals

Mineral	Battery storage application	Specific usage in battery	Leasing applicability	Applicability of the mineral in a circular leasing model
Vanadium	Yes	**Active metal, VE**	High	• High overall cost towards battery • Large volumes of electrolyte in a single location (not mobile) • Ease of extraction, recycling, reuse • High quality extraction of metal for reuse
Aluminum	Yes	Primarily used as a current collector in cathode and anode in Li-ion chemistries	Medium	• High overall cost towards battery • Large volumes of electrolyte in a single location (not mobile) • Ease of extraction, recycling, reuse • High quality extraction of metal for reuse
Chromium	No		NA	Not applicable to energy storage (Not part of this assessment)
Cobalt	Yes	Active cathode material in Li-ion batteries such as NMC, NCA, LCO	Medium	• Cost contribution to battery is relatively significant and thus leasing could possibly apply to reduce overall cost of electricity • Recycling occurs and is reused by battery manufacturers for reuse in batteries • Metallurgical processes required for extraction increases the cost of the overall cost lease possibly making this an unattractive leasing model • Logistics for collection of metal is challenging due to use of batteries in mobile applications (EVs etc.)
Copper	Yes	Used as current collector in Li-ion chemistries and VRFB anode. Also used in manufacturing cell stack for VRFBs	Low	• Contribution to overall cost of storage is not significant enough to lease the metal • Extensively recycled • Mature market on both supply and demand. • High use in industrial application • Circular leasing model would not typically be applied to this metal as it is used extensively in multiple industries and not specific to battery storage
Graphite	Yes	Primarily used as an active material in anode for all major Li-ion battery types. In VRFBs, graphite is used in bipolar plates and in anode as carbon fiber	Low	• Contribution to overall cost of storage is not significant enough to lease the metal • Recycling occurs and is reused by battery manufacturers for reuse in batteries
Indium	No		NA	Not applicable to energy storage (Not part of this assessment)
Iron	Yes	Active cathode material in popular LFP battery chemistry	Low	• Contribution to overall cost of storage is not significant enough to lease the metal • Mature market on both supply and demand • High use in industrial applications • Extensively recycled • Circular model would not typically apply to this metal as it is used extensively in multiple industries and is not specific to battery storage
Lead	Yes	Used as anode material in lead acid batteries. Also used in lead dioxide as cathode material in the same battery	Low	• Battery not regarded as advanced cell chemistry (ACC) • Extensively recycled in smelters • High toxicity metal • Circular lease model would not typically apply to this metal as the metal price is on a downward trend

Table 7.3: Applicability of the Leasing Model to Critical Minerals (continued)

Mineral	Battery storage application	Specific usage in battery	Leasing applicability	Applicability of the mineral in a circular leasing model
Lithium	Yes	Active cathode material in all major LiBs—FP, LMO, LCO, NMC, NCA, LTO	Medium	• Cost contribution to battery is relatively significant so leasing could apply to reduce the overall cost of electricity • Recycling occurs and is reused by battery manufacturers for reuse in batteries • Metallurgical processes required for extraction increase the cost of the lease, possibly making this an unattractive leasing model • Logistics for collection of metal are challenging because of the use of batteries in mobile applications (EVs, etc.)
Manganese	Yes	Active cathode material in LiBs—LMO and NMC	Medium	Not applicable to energy storage (Not part of this assessment)
Molybdenum	No		NA	Not applicable to energy storage (Not part of this assessment)
Neodymium	No		NA	Not applicable to energy storage (Not part of this assessment)
Nickel	Yes	Active cathode material in LiBs—NMC and NCA	Medium	• Recycling occurs and is reused by battery manufacturers for reuse in batteries • Metallurgical processes required for extraction increase the cost of the lease, possibly making this an unattractive leasing model • Logistics for collection of spent batteries are challenging because of the use of batteries in mobile applications • Circular model would not typically apply to this metal as it is used extensively in multiple industries and is not specific to battery storage
Silver	No		NA	Not applicable to energy storage (Not part of this assessment)
Titanium	Yes	Used as an active material in anode in LTO chemistry. Also used as a current collector in zinc flow batteries.	Low	• Circular model application would be difficult in this case because of low volumes of LTO technology, limited contribution in battery composition, and limited players operating in the recycling space with widely dispersed facilities • Technology is relatively new with little demand at present
Zinc	Yes	Active metal in zinc flow battery. (Zinc bromide electrolyte)	Low	• Circular model would not typically apply to this metal as it is relatively inexpensive • Contribution to overall cost of storage is not significant enough to lease the metal

7.3 Dissemination Plan

The VRFB market is expected to mature over time, with substantial growth by 2030 depending on various factors, such as the development and promotion of RE and VRFB technologies. This VRFB market growth will need to be supplemented with the required raw material, including the development of vanadium mines for primary vanadium production. Development of VRFB market will create employment opportunities throughout the VRFB value chain and can be very beneficial for local communities. It will also support the sustainable development of clean energy and reduce the carbon footprint. In the future, VRFB technology and the VRFB market will flourish, but investment policies must be established now to facilitate this future state by 2030 at a considerable level. To achieve the outcomes and new possibilities associated with VRFB technology, the government must start formulating and amending policies, SOPs, rules, regulations, and guidelines over the next two to three years to eventually attain this desirable state. In addition, the large industrial base in the energy storage sector needs to create demand and adapt to such technology to achieve clean energy and a sustainable future.

Table 7.4: Dissemination Plan

Theme	Notes	Success Factor	Audience	Target Date
Demand Creation	• The VRFB market is relatively new in terms of commercial application, thus creation of the demand for VRFB is needed	• Sizeable pilot VRFB -based projects for proving technology • Increased RE penetration through stationary storage • VRFBs as a viable alternative technology solution	• Industry bodies • Government • Power utilities • IPPs • Mining industry • Large industrial clients (See Table 6.5)	2023–30
Supply Growth	• Growth of raw material supply with growing demand to contain the prices for sustainable growth of the VRFB market • No downstream processing and manufacturing facilities in the VRFB sector	• Development of vanadium reserves and mine production • Manufacturing growth throughout the VRFB value chain		2023–30
E&S Development	• Equitable growth with a holistic view of reducing the net environmental impact and ensuring social development would be critical as the VRFB sector grows in South Africa	• Employment opportunity for local community in the VRFB value chain • Improved and equitable access to services • Waste management and its environmental impacts		2022–30
Regulation	• Misalignment of NDP to support battery storage, coupled with renewable power in South Africa • Regulations for BESS are lacking in the country. Evolving policies	• Regulations for environmental impact of the VRFB value chain • Energy regulations to promote RE and VRFBs • Industrial regulations for the growth of VRFB (e.g., free trade zones)		2022–25

8 Conclusion and recommendations

Understanding the Vanadium Battery Market

The global VRFB market is expected to reach around 111 GWh, with an annual demand of 27 GWh, accounting for 2.4% of the total required stationary storage capacity by 2030. Long-duration services (>4 hours) spanning grid uses, RE integration, power backup, and UPS are some of the major applications for VRFBs. Although the current upfront cost is not comparable to Li-ion battery chemistries, the cost of VRFBs is expected to decline by 50% by 2030 on account of a reduction in the cost of stack and electrolyte manufacturing, improved efficiency in processes through automation, economies of scale, and R&D efforts to improve power density. All these cost reduction factors are expected to assist in the commercialigation of VRFB batteries, gradually increasing market penetration. Considering the high cost contribution of recyclable VE in overall CAPEX (40% to 80%), there is a strong business case for leasing to make the battery solution more financially viable.

The Vanadium Leasing Models

Achieving over 99% recovery of the vanadium electrolyte after its use in the battery creates an ideal case for its leasing. We proposed two business models for circular vanadium ownership with three different leasing scenarios, which can promote recyclability of the metal and reduce the upfront cost for VRFB manufacturers. The two models are Leasing VE to VRFB Battery Manufacturers and Leasing VE directly to End Users.

The Vanadium Supply and Demand Market Dynamics

Battery storage demand currently accounts for 2% of global vanadium demand but is expected to increase to 10% of global demand by 2030, equaling 16,391 mtV. To meet this demand and to keep price growth capped below US$30,000 per metric ton by 2030, the supply of vanadium must increase by a CAGR of 6.9% during 2022-2030. These growth rates in production have been seen in recent history. Secondary production has grown significantly over the past two years, with a strong focus globally on recycling industrial wastes, and it will play a key role in increasing global output volumes going forward.

The Economic and Financial Implications of the Leasing Models

Our financial analysis found that the upfront cost of acquiring the vanadium, together with the lease duration and lease rate, had the largest impact on the leveligzed cost of storage and Project IRR. A key consideration in understanding the financial viability of the model will be the rates of return expected by prospective investors in such a model, and we believe that market sounding with prospective investors and financiers would be beneficial as a next step to better understand the attractiveness of the projected returns.

Based on the economic cost-benefit analysis (CBA) for the 1 MWh facility leasing model, using economic prices with a financial discount rate of 2.4% over a 20-year period, we concluded that the 1 MWh facility leasing model is economically viable as the benefits outweigh the costs incurred. VRFB leasing will act as a mitigant to load shedding, particularly for industries that are heavily reliant on electricity, such as mining and manufacturing.

Regulatory and Legal Requirements for Implementing the Leasing Models (specific to South Africa)

In order to support a circular vanadium business model, urgent regulatory reforms would be required to support VRFB manufacturing and VE leasing. The South African regulatory review revealed that its legislative environment is not conducive to the implementation of a circular vanadium business model, nor to the deployment of large utility -scale VRFBs. Reforms can include the introduction of a set of regulations under section 19(1) of the National Energy Act specifically aimed at promoting the deployment of BESS. Additionally, regulatory incentives, in the form of income tax breaks, and other industrial mechanisms, such as free trade gones, can be introduced to increase the competitiveness of VRFB technologies.

Macroeconomic and Fiscal Impact of the Leasing Models

A macroeconomic impact assessment (MEIA) was carried out for the proposed leasing model for a 1 MWh facility to determine the estimated economic contribution of a 1 MWh facility leasing model through capital expenditure, the annual leasing fee, and the recycling of electrolytes. The leasing company's capital expenditure is expected to contribute to increased tax collection and will have long-term economic impacts on economic growth, sustained employment, and poverty alleviation. Moreover, the leasing model's estimated revenue from the annual leasing fee and recycling of electrolytes is expected to have a positive impact on local communities and the government in terms of job creation, poverty alleviation, and contribution to public finance. Furthermore, an increase in demand for vanadium will bring added benefits, including increasing the value chain economic contributions.

Environmental and Social Impact of the Leasing Models

Based on our analysis of the environmental and social (E&S) regulatory landscape in South Africa, the main potential E&S concern across the VRFB value chain is the lack of a regulatory framework around the recycling of VRFB (such as Extended Producer Responsibility (EPR) for stationary battery storage solutions). This must be included in the existing EPR regulation for monitoring the VRFB market VRFB and recycling. As the environmental impacts associated with VRFBs are strongly correlated with the VE production stage, the primary practices at the mining and processing stages of vanadium bearing ores are key for reducing the associated environmental and social impacts. The social analysis revealed that by strengthening the vanadium mining and VRFB sector, SLPs can help communities benefit from mining and, gradually, from the VRFB value chain and community development. Scaling up the vanadium mining sector and VRFBs will naturally widen the scope for local manufacture and/or local supply chain procurement, thus scaling up opportunities for women and other economically disadvantaged groups and building a socially inclusive value chain. The VRFB value chain for a circular business model can accelerate the emergence of economic opportunities for youth and women, groups which are presently underrepresented in South Africa's labor market. The various consultations demonstrated that there is inadequate research on social and gender inclusivity in mining, even though there are semi-skilled people who can be engaged in the VRFB value chain. It also emerged from the consultations that overall, there is a lack of gender equity in the mining sector which needs more attention. These, we understand, can widely improve as the VFRB value chain and leasing models can be established. Short-term leasing and focused market leasing in specific geographies can increase the demand for jobs and the supply of opportunities.

Conclusions

To understand which business model scenario is best suited for implementation, the associated Financial, Economic, Regulatory, Environment, and Social parameters were analyzed. It was concluded that long -term leasing (scenario A) is the most suitable option for leasing VE as it provides the most economical storage solution for the end user. In the current market conditions, the application of VRFBs is limited to long -term deployment, which supports scenario A, as the best option for implementation in the near future. It is also expected that with the development of VRFB technology, short -term leasing opportunities may arise, for example, as a battery back-up solution for UPS systems. In such conditions, focused market leasing (scenario C) would be the better leasing option as it provides more social benefits to the end -use location as a result of the increased frequency of movement within the locality and the associated employment opportunities.

The roadmap presented highlights the four key thematic areas to focus on in order for vanadium battery storage solutions to be deployed. These are:

- **Demand Creation** - Showcase the technology and models to key stakeholders in order for the demand for VRFBs to be created.
- **Supply Growth** - As demand increases, the supply of vanadium must match the demand to ensure low pricing and availability of the metal.
- **Environmental and Social Development** - As VRFBs are adopted, skills mapping is required to meet the needs of the industry. Environmental regulations are required to ensure that BESS value chains guarantee the protection and enhancement of environmental quality.
- **Government regulation** - Governments need to ensure that policies are in place to support the BESS solution as a part of the energy plans in their countries.

A Center of Excellence (CoE) should be established to support the growth and development of VRFBs and understand the market and investment opportunities to further build on the leasing models through various stakeholder engagements.

Appendix A:

Methodology for Detailed Cost -Benefit Analysis

A CBA is an appraisal tool that analyzes the social gains and losses that could arise from a project. The aim of a CBA is to assign a monetary value to the benefits expected from a project and compare these to the expected costs. If the benefits exceed the costs, there is economic justification for the project to proceed. Projects that result in an increase in aggregate real income are always desirable because the potential exists to make society better off. Reasons for adopting a CBA approach could include:

- **To describe a project that is currently under consideration but has not begun.** This type of a CBA is referred to as ex-ante and is used to assist in decision-making and in the evaluation of the costs and benefits of a project.
- **To evaluate a project after a project ends**. In cases such as these, all project-related costs have been invested in the project and the benefits accrued. This type of CBA primarily provides lessons learned and assists in gathering information for assessing future similar projects. This type of CBA is referred to as ex-post.
- **To evaluate a project during the operational period, when the project is already under way but is not complete**. The analysis helps determine the efficiency of a project in achieving its objectives. Where there is an additional investment made during the life of a project, the CBA helps to evaluate the viability of additional investment. This is done by looking at the project performance before additional investment and after additional investment.

The evaluation of the proposed circular vanadium business model involves the use of an ex-ante CBA, whereby the costs and benefits of the proposed investment projects are assessed. The CBA was carried out at economic prices. An economic CBA uses shadow or economic prices and real prices. Shadow pricing is preferable where prices do not reflect the actual value of a good or commodity or no market value for a good or commodity exists.

Shadow pricing is a proxy value of a good, often defined by what an individual must give up to gain an extra unit of the good. The shadow prices reflect the true scarcity of resources. These prices are a better reflection of actual demand and supply conditions in the market that should determine the real commercial viability of the project. Market prices rarely give a true representation of the scarcity values of resources because of interference in market price setting, such as government tax regulation, and artificial adjustments, such as electricity tariffs and minimum wage levels.

The economic CBA was conducted over a 20-year period using economic prices (shadow prices), and an economic discount rate of 2.41%. The shadow factors used in the analysis are provided in Appendix D. Three standard CBA evaluation criteria as well as two additional criteria were used to determine the economic viability of the proposed circular vanadium business model.

The steps taken through the economic CBA to determine the economic viability of the proposed circular vanadium business model are outlined below:

Step 1—Define the project

Under Step 1, the objective is to conduct an economic analysis demonstrating the costs and benefits of the proposed circular vanadium business model for energy storage.

Step 2—Identify and quantify costs and benefits

The team identified the costs and benefits that are directly attributable to the proposed circular vanadium business model for energy storage. A monetary value was then assigned to the costs and benefits identified. It is important to note that not all costs and benefits could be quantified. These costs and benefits, however, are still an important aspect of the CBA and are discussed in this section.

Step 3—Discount costs and benefits

Discounting

The standard approach to placing a value on costs and benefits that occur in different periods assumes that:

- One rand today would be worth more than one rand tomorrow because of inflation. This means that immediate income is preferable to future income (i.e., social time preference).
- An investment always has an opportunity cost. This means that the investment could earn a better rate of return doing something else if it was not locked in the current project (i.e., opportunity cost).

The discounting approach, therefore, was used to value the costs and benefits related to the proposed circular vanadium business model over a 20-year period to a comparable amount in rand prices. This amount is the present value (PV) of the future costs and benefits that are attributable to the proposed circular vanadium business model for energy storage.

The formula for the calculation of PV of costs and benefits is presented below:

$$PV\ costs = \sum_{n=0}^{N} \frac{Cn}{(1+r)n}$$

$$PV\ benefits = \sum_{n=0}^{N} \frac{Bn}{(1+r)n}$$

Where:

C_n = cost in year n expressed in constant terms

B_n = benefits in year n expressed in constant rand values

r = real discount rate

n = time in years

N = number of years over which project is evaluated

Appropriate discount rate

The following assumptions were made in determining the economic discount rate:

- For this project, to determine the appropriate discount, we have opted to use the South African 10-year bond yield rate of 10.5% as of July 25, 2022, as a representation of the nominal discount rate, and inflation of 7.9% y-o-y. The calculation is as follows:

$$o = \left(\frac{\text{South Africa 10 - year bond}}{\text{Inflation rate}} - 1 \right) X\ 100$$

$$o = \left(\frac{1.105}{1.079} - 1 \right) X\ 100$$

$$o = 2.4\%$$

The CBA was conducted at current prices (i.e., nominal rand values) at a real discount rate of 2.4%[96] per annum, which reflects the current estimated cost of capital. The nominal discount rate calculation is in line with the criteria outlined in the CBA Manual for South Africa[97], which recommends that if costs and benefits are measured in nominal (or current) rand value terms, then a nominal discount rate (including inflation) should be used.

Step 4—Calculate the Net Present Value (NPV) and Benefit -Cost Ratio (BCR)

Using the information collected, we then considered the following criteria that could be used to reflect the cost effectiveness of the proposed circular vanadium business model:

- Net Present Value
- Benefit -Cost Ratio, and
- Internal Rate of Return (IRR)

Net Present Value

NPV is the sum of the discounted project benefits less the discounted project costs. It indicates whether a project has financial and economic merit. The following formula is used to calculate the NPV of a project:

$$NPV = \sum_{n=0}^{N} \frac{Bn - Cn}{(1+r)n}$$

96 Financial discount rate we provided in the financial model provided by the company developing this new business model.

97 A Manual for Cost Benefit Analysis in South Africa with Specific Reference to Water Resource Development, Third Edition (Updated and Revised), Conningarth Economists for the Water Research Commission

Where:

B_n = benefits in year n expressed in constant rand values

C_n = costs in year n expressed in constant rand values

r = real discount rate

n = time in years

N = Number of years over which project is evaluated.

As shown in Table 8.A, in order for the proposed circular vanadium business model to be considered cost-effective, its NPV should be positive (i.e., greater than zero) as this indicates that its overall benefits derived through the proposed circular vanadium business model outweigh its overall costs over time.

Table A.8.1: Decision Rule for NPV

If	Meaning	Action
NPV > 0	The proposed circular vanadium business model would be viable	Accept the proposed circular vanadium business model as planned or continue with its current implementation
NPV < 0	The proposed circular vanadium business model would not be viable	Review the proposed circular vanadium business model and make changes to its implementation
NPV = 0	The proposed circular vanadium business model would neither add value to nor take away value from the economy	The proposed circular vanadium business model could be accepted since the required rate of return is equal to opportunity cost

Benefit -Cost Ratio

The BCR is the ratio of the present value of benefits attributable to a project to the present value of its costs. The BCR, therefore, indicates the expected return for every US$1 invested in a project. The proposed circular vanadium business model would be considered viable if its BCR is greater than 1.

BCR is calculated as follows:

$$BCR = \frac{PVBenefits}{PVCosts}$$

Where:

$$PV\ benefits = \sum_{n=0}^{N} \frac{Bn}{(1+r)n}$$

$$PV\ costs = \sum_{n=0}^{N} \frac{Cn}{(1+r)n}$$

Internal Rate of Return (IRR)

IRR is the discount rate at which the present value of both the costs and benefits are equal. For a project to be considered viable, the IRR must be greater than the discount rate.

The IRR is the discount rate at which the present value of costs and benefits are equal. It is the value of the discount rate, r, which satisfies the following criteria:

$$\frac{\Sigma bj}{(1+r)j} - \frac{\Sigma cj}{(1+r)j} = 0$$

Only projects with an IRR higher than the social discount rate, which forms a limit, will be considered for funding. The IRR must be handled carefully, because there are situations in which the mathematical solution of the above equation is not unique. This happens when the stream of net benefits over the assessment period changes its sign (positive or negative) more than once.

Appendix B:

Global Warming Impact of the Supply and Lifecycle of Lithium-Ion and VRFBs

	Supply Phase	Life Cycle	Total Impact	Total Cost (US$)
Lithium-Ion Battery Global Warming (kg CO_2 eq)	56.3	95.0	151.3	1,371.99
Vanadium Redox Flow Battery Global Warming (kg CO_2 eq)	57	100.8	157.8	1,430.93

Note: Total cost is calculated at US$9.07 per metric ton carbon dioxide equivalent

Appendix C:

Range of Calculated (CoUE) and (CoLS) on the South African Economy

Research entity	Approach used	Cost per kWh (US$)	Potential CoUE (unplanned): Total cost in rand (real 2015)	Potential CoLS (planned): 50% ratio (real 2015)	Economic impact of planned interruptions (real 2015)	Estimated opportunity cost in job numbers
NERSA total (2020 proposed)	**CoUE**	6.86	17.23 billion	8.6 billion	2.9%	350,000
NERSA direct (2020 proposed)	**CoUE**	1.96	4.75 billion	D2.5 billion	0.8%	100,000
NERSA total (previously approved)	**CoUE**	5.69	14.37 billion	7.43 billion	2.4%	290,000
SAIEE / UCT (2017 figure inflated to 2021)	**CoLS**	5.81	12.16 billion	6.28 billion	2.3%	280,000
NOVA Economics	**CoLS**	0.59	1.56 billion	810 million9 4	0.4%	50,000

Note: Calculations.

Appendix D:

Shadow Prices

	Diesel	Petrol	Petroleum products (includes petrol and diesel)	Electricity	Unskilled labor	Exchange rate	Customs duty	Weighted shadow price factor
A. ASSETS CONTAINED IN THE SOUTH AFRICAN								
SOCIAL ACCOUNTING MATRIX								
1. Furniture	0.000	0.000	0.005	0.007	0.001	0.569	0.569	1.099
2. Rubber products	0.000	0.000	0.062	0.022	0.016	0.426	0.426	1.064
3. Structural metal products	0.000	0.000	0.005	0.002	0.015	0.475	0.475	1.077
4. Other fabricated metal products	0.000	0.000	0.020	0.014	0.015	0.190	0.190	1.029
5. Machinery and equipment	0.000	0.000	0.021	0.005	0.010	0.668	0.668	1.109
6. Electrical machinery and apparatus	0.000	0.000	0.022	0.004	0.010	0.458	0.458	1.073
7. Manufacturing of transport equipment	0.000	0.000	0.005	0.001	0.007	0.844	0.844	1.142
8. Other manufacturing and recycling	0.000	0.000	0.005	0.003	0.011	0.279	0.279	1.045
9. Buildings	0.000	0.000	0.023	0.001	0.016	0.136	0.136	1.014
10. Civil construction	0.000	0.000	0.048	0.002	0.020	0.138	0.138	1.009
11. Business activities (architects, attorneys, etc.)	0.000	0.000	0.025	0.001	0.011	0.10	0.10	1.009
B. WATER AUGMENTATION COMPONENTS								
12. Bulk water (dams)	0.120	0.060	0.000	0.020	0.130	0.000	0.000	0.934
13. Reservoirs	0.030	0.000	0.000	0.000	0.170	0.070	0.070	0.956
14. Pump stations (water & sewer)	0.030	0.000	0.000	0.000	0.170	0.100	0.100	0.961
15. Bulk pipelines (water & sewer)	0.070	0.000	0.000	0.000	0.170	0.170	0.170	0.964
16. Treatment works (water & sewer)	0.030	0.000	0.000	0.000	0.170	0.070	0.070	0.956
17. Reticulation (water & sewer)	0.030	0.000	0.000	0.000	0.170	0.100	0.100	0.961
18. Storm water	0.100	0.050	0.000	0.010	0.130	0.000	0.000	0.936

	Diesel	Petrol	Petroleum products (includes petrol and diesel)	Electricity	Unskilled labor	Exchange rate	Customs duty	Weighted shadow price factor
A. ASSETS CONTAINED IN THE SOUTH AFRICAN								
SOCIAL ACCOUNTING MATRIX								
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2. Rubber products	0.000	0.000	0.062	0.022	0.016	0.426	0.426	1.064
3. Structural metal products	0.000	0.000	0.005	0.002	0.015	0.475	0.475	1.077
4. Other fabricated metal products	0.000	0.000	0.020	0.014	0.015	0.190	0.190	1.029
5. Machinery and equipment	0.000	0.000	0.021	0.005	0.010	0.668	0.668	1.109
6. Electrical machinery and apparatus	0.000	0.000	0.022	0.004	0.010	0.458	0.458	1.073
7. Manufacturing of transport equipment	0.000	0.000	0.005	0.001	0.007	0.844	0.844	1.142
8. Other manufacturing and recycling	0.000	0.000	0.005	0.003	0.011	0.279	0.279	1.045
9. Buildings	0.000	0.000	0.023	0.001	0.016	0.136	0.136	1.014
10. Civil construction	0.000	0.000	0.048	0.002	0.020	0.138	0.138	1.009
11. Business activities (architects, attorneys, etc.)	0.000	0.000	0.025	0.001	0.011	0.10	0.10	1.009
B. WATER AUGMENTATION COMPONENTS								
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16. Treatment works (water & sewer)	0.030	0.000	0.000	0.000	0.170	0.070	0.070	0.956
17. Reticulation (water & sewer)	0.030	0.000	0.000	0.000	0.170	0.100	0.100	0.961
18. Storm water	0.100	0.050	0.000	0.010	0.130	0.000	0.000	0.936
C. Other assets								
19. Roads	0.210	0.120	0.000	0.000	0.120	0.000	0.000	0.902
20. Parks and recreation	0.210	0.120	0.000	0.000	0.120	0.000	0.000	0.902
21. Schools, crèches, etc.	0.080	0.020	0.000	0.050	0.140	0.000	0.000	0.956
D. Costs associated with construction								
22. Maintenance and operation	0.160	0.090	0.000	0.020	0.170	0.000	0.000	0.909
23. Earth works	0.000	0.000	0.111	0.000	0.102	0.065	0.065	0.959
24. Research and development	0.000	0.000	0.007	0.018	0.017	0.022	0.022	1.004
25. Relocation costs	0.000	0.000	0.009	0.000	0.044	0.062	0.062	0.996
Shadow price adjustment factor	0.791	0.844	0.804	1.337	0.704	1.222	0.950	

Appendix E:

Detailed Economic Impact Methodology

With an internationally accepted approach, informed by the Global Reporting Initiative (GRI) standards, PwC will quantify the estimated economic contribution of the proposed project from extraction and processing and the VRFB battery manufacturing and recycling stages to the South African economy using a macroeconomic impact assessment (MEIA). The analysis allows us to capture the proposed project's macroeconomic and fiscal contribution by showing the industry's interdependencies within different sectors of the economy. The structure of the MEIA is incorporated into a national accounting system. The approach demonstrates the economically related industry clusters and key or target industries that are most likely to increase the internal coherence of the economy.

The MEIA makes use of the Social Accounting Matrix (SAM) methodology to analyze the economic contribution of the project. The SAM methodology estimates how the project's activities associated with investment and operational expenditure in one or more parts of the economy affect other sectors of the economy and how the impacts are distributed. It highlights the economic linkages within the economy and indicates the direct, indirect, and induced effects of a given expenditure.

The size of the added economic activity generated is measured through a multiplier effect. The different rounds of the multiplier effect—from the first spending at the extraction and processing phase through the worker spending his or her salary on goods and services (and its resultant effects)—is then estimated as the direct, indirect, and induced contributions.

The sum of the direct, indirect, and induced impacts is the total impact. According to Keynesian economic theory, any injection into the economy via investment capital or government spending, for example, will result in a proportionate increase in overall income (measured through GDP) at a national level. The basic principle of this theory is that increased spending will have carry-through or multiplier effects, which result in even greater aggregate spending over time. The multiplier itself is an attempt to measure the size of those carry-through effects or impacts. The multiplier considers all direct and indirect benefits from that investment or from the change in demand. The size of the impact or the effect on the economy depends on the size of the multiplier in the economy.

We will use this theory as the basis for estimating the macroeconomic and fiscal impact of the proposed business model.

The South Africa SAM can estimate how the activities of the proposed business model, in one or more parts of the economy, could affect other industries of the economy, and how the impact is distributed in the economy. It highlights the economic linkages within the economy and indicates the direct, indirect, and induced effects of a given expenditure on the following economic factors:

A forward linkage exists where a particular firm or industry uses the products produced through the vanadium value chain as an input or raw material. Conversely, a backward linkage occurs where the value chain uses the product of another firm or industry as raw materials or inputs during the production process. There are specific linkages based on the sector in which a company operates. These linkages are based on the sector's average spending pattern. The number of linkages and the size of each linkage influence the multiplier effect of the specific sector. The spending categories are defined according to the internationally accepted SIC classifications.

Direct Impact
The direct impact includes the first round effects where increased demand for particular goods/services leads to increased business activity and thus a direct change in sectoral production. This is the impact associated with the operational expenditure and infrastructure investment undertaken by the various phases of the project.

Indirect Impact
The indirect impact includes the second round effects that change the demand for factors of production and household income, which can be explained by the inter-linkages of sectors in the economy. With reference to this project, these impacts emanate from the increased demand for goods and services acquired from external service providers, as well as increased employment opportunities created on the back of this economic activity.

Induced Impact
The induced impact includes the multiplier effect that arises through the first and second round of spending. This is the increase in household income, and the additional spending that arises from the change in income levels, from the new employment opportunities created due to expenditure.

Economic factors

Gross Domestic Product (GDP)
GDP is a good indicator of economic growth and welfare — it represents, amongst others, the remuneration of employees and gross operating surplus (GOS) (profits) as components of value added to the economy

Employment
Labour and entrepreneurship form an important part of the primary production factors needed for the project's operations. The additional number of people employed as a result of investment spending and operational activities is determined by the EIA

Public finances
The impact on public finances is the direct tax contributions. In addition, there is indirect contribution to public finance quantified through the analysis

Low-income households
One of the components of the EIA is to determine whether the investment and operations have a positive impact on poverty alleviation. We show how the project benefit low-income households through the additional income that these households receive

Appendix F:

Comparative Analysis with Gold

Gold is a precious metal and is one of the least reactive chemical elements, remaining solid under standard conditions. Gold often occurs in its native form as nuggets or grains, in rocks, veins, and alluvial deposits. Gold has widespread use in jewelry, technology, investment, and instruments of monetary exchange in various transactions in banks.

Table F.1: Source of Gold (2017-21)

Gold (metric tons)	2017	2018	2019	2020	2021
Mine production	3,573	3,655	3,595	3,476	3,582
Net producer hedging	-25.5	-11.6	6.2	-39.1	-22.7
Recycled gold	1,112	1,132	1,276	1,293	1,136
Total supply	**4,660**	**4,775**	**4,877**	**4,730**	**4,696**

Source: Metals Focus, World Gold Council

Table F. shows that approximately 75% of the total supply of gold is from primary sources (mine production) and the rest of the gold supplied is recycled gold. In 2021 around
4.7 kt of gold was supplied, of which 1.1 kt was recycled gold.

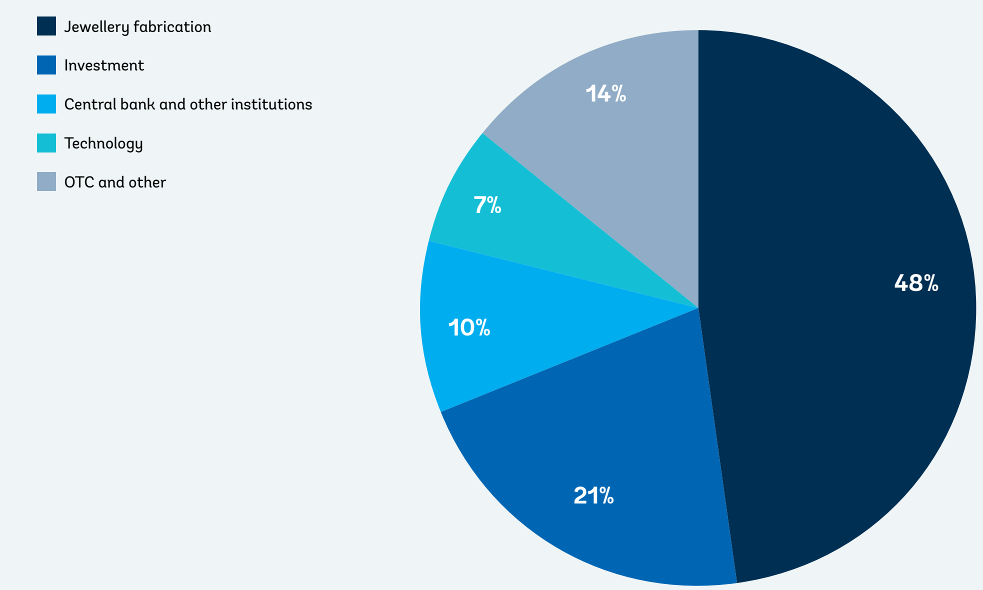
Table F.2: Gold Mine Production, metric tons (2017–21)

Country	2017	2018	2019	2020	2021
China	429	404	383	368	332
Russia	280	295	327	331	330
Australia	292	313	325	327	315
Canada	171	191	185	173	192
United States	236	222	200	193	186
South Africa	147	126	113	102	113
Others	2,163	2,228	2,174	2,081	2,223
Total	**3,573**	**3,655**	**3,595**	**3,475**	**3,580**

Source: Metals Focus, World Gold Council

China is the major primary producer of gold, producing around 9.3% of total gold produced globally in 2021. China is followed by Russia (9.2%), Australia (8.8%), Canada (5.4%) and the United States (5.2%) in production of primary gold in 2021. South Africa is contributing only around 3.2% of total primary gold production.

Figure F.8.1: Demand for Gold, by sector (2021)



Source: Metals Focus, Refinitiv GFMS, ICE Benchmark Administration, World Gold Council

According to the demand data, around 4.7 kt of gold was consumed in 2021. About 48% of gold demand is coming from the jewelry industry, followed by investment (21%), central banks and others (10%), technology (7%), and over-the-counter (OTC) transactions and others combined (14%). Based on past gold consumption trends, only about one tenth of the total gold is being consumed in the manufacturing of electronics, dentistry, and other industrial use (excluding jewelry fabrication).

Appendix G:

Stakeholder Mapping and Outreach

	Stakeholder	Contact person	Initial email/ phone call	Follow -up email/phone call	Consultation date	Request for feedback sent	First follow up	Second follow up	Information Received?
1	**Department of Water and Sanitation**	Departmental Spokesperson: Mr Sputnik Ratau (RatauS@dws.gov.za), KritzingerI@dws.gov.za MuirA@dws.gov.za manusl@dws.gov.za	June 1	June 6	June 9	June 13	June 15	June 17	Yes (July 1)
2	**Department of Mineral Resources and Energy**	Regional Manager (Limpopo): Mr Azwihangwisi Mulaudzi	June 1	June 9					N/A
		David Msiza (David.Msiza@dmr.gov.za) Mmadikeledi Malebe (Mmadikeledi.Malebe@dmr.gov.za) Kagiso Menoe (Kagiso.Menoe@dmre.gov.za) Setepane Mohale (Setepane.Mohale@dmre.gov.za) Ntokozo Ngcwabe (Ntokozo.Ngcwabe@dmr.gov.za)	July 26	July 27	August 3	August 3	August 19	September 21	No
3	**Department of Trade, Industry and Competition**	Ms Maggie Mabuela Mr Shane Raman	June 1	June 6					N/A
		Brian Soldaat (Brians@thedtic.gov.za) Annelize van der Merwe (AvdMerwe@thedtic.gov.za) Mahendra Shunmoogam (MShunmoogam@thedtic.gov.za) Umeesha Naidoo (UmeeshaN@idc.co.za) Yunus Hoosen (YHoosen@thedtic.gov.za) Bharti Daya (BDaya@thedtic.gov.za) Rashmee Ragaven (RRagaven@thedtic.gov.za)	July 26	July 27	August 1	August 3	August 19		No
4	**Department of Public Enterprises**	Esther.Nenungwi@dpe.gov.za Nadia.Valley@dpe.gov.za Donald.Nkadimeng@dpe.gov.za Funeka.Mothoa@dpe.gov.za jacky.molisane@dpe.gov.za Johannes.Mahlangu@dpe.gov.za Kedibone.Magaqa@dpe.gov.za Nonhlanhla.Mokoena@dpe.gov.za	June 1	June 6	June 13	July 5	July 8		No
		Director General: Mr Kgathatso Tlhakudi Intergovernmental Relations: Mr Tsholofelo Motlogelwa Provincial Manager (Limpopo): Mr Victor Mavhidula HQ research contact: Martin Nsibirwa	June 9	July 15					N/A
5	**CSIR**	Hartmat Brodner	June 1	June 6					N/A
		Renesh Thakoordeen: RThakoordeen@csir.co.za MmalewaneModibedi: MModibedi@csir.co.za Mesfin Kebede: MKebede@csir.co.za	July 15	July 18	August 1	August 3	August 19		No
6	**Bushveld Vanadium**	Fredrick Mphephu (fredrick.mphephu@bushveldminerals.com) Rudzani Mudau (Rudzani.Mudau@bushveldminerals.com) Johanna Maloba (Johanna.Maloba@bushveldminerals.com) Mikhail Nikomarov (Mikhail.Nikomarov@bushveldminerals.com) Bonani Nyabane (Bonani.Nyabane@bushveldminerals.com)	June 17	June 23	June 29 (Environmental)	June 29	July 1	July 5	Yes (July 18)
					July 13 (Social)	July 15	July 18		
		Dr P.J Cox	June 1	June 6					No
7.	**Largo**	Facilitated by Adriana Unzeuta Saavedra (aunzuetasaavedra@worldbank.org) aguthrie@largoinc.com eric.watson@largoinc.com f.dalessio@largoinc.com pv@largoinc.com stephen.prince@largoinc.com	July 18	July 26	August 30				Yes
					September 10	September 12	September 14		
8	**First National Battery**	charlesv@battery.co.za russellb@battery.co.za	Contact from CSIR			September 23			No
9	**Dept of Science and Innovation**	mbangiseni.mabudafhasi@dst.gov.za	Contact from CSIR			September 23			No
10.	**Department of Environment, Forestry and Fisheries**	General contact	June 1	June 6					N/A
		Marc Gordon	July 26	July 29					N/A
		Ntando Mhkize	July 26						N/A
11	**South African Human Rights Council**	ceo@sahrc.org.za, wbaloyi@sahrc.org.za, hkhumalo@sahrc.org.za, mngobeni@sahrc.org.za, vmavhidula@sahrc.org.za	July 26	July 27					N/A
12	**Mineral Council South Africa**	Department of Environment: Babalwa Matiwane	June 1	June 9					N/A
13	**TIPS- trade and industrial policy strategies**	Mbofholowo Tsedu	June 1	June 6					N/A
14	**Just Share**	Robyn Hugo	June 1	June 6					N/A
15	**Wits (School of Mining)**	Professor Genc	June 1	June 6					N/A
		bekir.genc@wits.ac.za, carl.beaumont@wits.ac.za, bryan.watson@wits.ac.za, clinton.birch@wits.ac.za, cuthbert.musingwini@wits.ac.za, huw.thomas@wits.ac.za, kelello.chabedi@wits.ac.za	July 26	July 29					N/A
16	**University of Pretoria**	mpm.ntsoane@up.ac.za, joseph.makhasa@up.ac.za	July 19	July 26					N/A
17	**Centre of Environmental Rights**	Matome Kapa, Catherine Horsfield and Leeane Govindsamy	June 1	June 6					N/A

Appendix H:

Summary of Stakeholder Consultation

1. Department of Water and Sanitation (DWS)	
Date of Consultation	June 9, 2022
Category of Stakeholder	Government Stakeholder
About Department of Water and Sanitation	"The Department of Water and Sanitation is the custodian of South Africa's water resources. It is primarily responsible for the formulation and implementation of policy governing this sector. While striving to ensure that all South Africans gain access to clean water and dignified sanitation, the department also promotes effective and efficient water resources management to ensure sustainable economic and social development." The Water and Sanitation Division is responsible for the bulk water supply, sanitation services, and water and sanitation infrastructure planning and implementation in the city. Source: https://www.dws.gov.za/about.aspx
Key Focus Area of Consultation (Environment)	The consultation focused understanding natural resource utilization (water) and waste generation in the existing mining and processing operations within the vanadium industry in South Africa. In addition to this, the consultation aimed to understand the scope of improving the current practice for effective and efficient use of water and management of effluent generated from the sector. Furthermore, the consultation focused on understanding the extent of applicability of the National Water Act, 1998 (Act 36 of 1998) and National Water Amendment Act, 2014 (June 2014) across the VRFB value chain. The consultation also aimed to focus on the existing practices towards regulatory provisions stipulating the need of water recycling or the mandate of installing an WTP/ETP as part of water usage license.
Consultation Summary (Environment)	Consultation Summary 1. The applicability of Water Use License (WUL) applications according to the National Water Act, Act no. 36 of 1998 for mining activity and the industry operations associated with V Electrolyte Manufacturing. No insight into the applicability of this license was obtained for battery assembly operations. 2. The WUL includes specific provisions for discharge and disposal limits from the mining area and the industrial setup, which needs to be respected. Furthermore, separate standards are available for non-potable water and potable water the Department includes drinking water standards (General and Special Effluent Standards gazetted in 1984). 3. DWS specified that a typical vanadium processing industry (processing unit) withdraws approximately 1511 m^3/day of water for its operation. The typical source of this water extraction is surface and groundwater (rivers and dams). 4. The communities near mining intensive catchments, such as the Mpumalanga (due to coal mining), Gauteng (Western, Central and Eastern Basins) and Northwest (Platinum belt) region, are identified as critically polluted areas. The key contributors to pollution are the dysfunctional wastewater treatment plants and unlawful mine water discharges. DWS also shared that complaints have been received in the past about unregulated effluent disposal resulting in water pollution. 5. DWS does not recommend the technologies relating to water conservation for the VRFB sector; however, it encourages the industries to focus technology on water conservation. For the mining sector, DWS has developed the Water Usage Benchmarks[915] for the coal, gold, platinum and other mines within the same commodity group. The new (greenfield) mines in South Africa have been compelled to consider environmental and energy aspects and are incorporating cleaner technology into their operations. 6. DWS is also working on addressing the impacts of Acid Mine Drainage (AMD) by developing mitigation measure. Based on the current scenario, three AMD treatment plants are operating in the western, central and eastern basins (Krugersdorp, Germiston and Springs), treating a combined volume of between 150 ML/day and 200 ML/day and a few treatment plants in the Mpumalanga region—the Emalahleni Water Reclamation Plant, New Vaal Colliery Treatment plant, Middelburg Water Reclamation Plant are operational to address the treatment of AMD.
Consultation Summary (Social)	Consultation Summary The aim of the consultation was to gain insight into the deployment of energy storage technologies and identify risks and opportunities for VRFB batteries in the South African context. The objective of the consultation on social aspects was to identify risks, challenges, and opportunities that are prevalent or likely to arise in the VRFB domain and its supply chain and in vanadium mining. 1. On the impact of water contamination on settlements near mining areas related to agricultural production, farming, and crop quality, DWS cited the example of West Rand goldfields (Krugersdorp/Randfontein area), where residents have been found ingesting mine tailings, washing laundry, and irrigating their crops with mine-impacted water. However, there have been few studies on this subject to date. 2. Additionally, irrigation using mine-impacted water is site-based; thus, the effects on health and other aspects among the communities living in proximity may differ from one site to another. As stated by the stakeholders, further studies are needed to determine the extent of the impact. 3. On any provision of services, such as water and electricity, among occupational communities (mineworkers and other labor groups) who lack access to water and sanitation in the areas, DWS stated that these communities fall within the mandate of the water services authorities and the local government—DWS does not have this information readily available. 4. On whether the provision of water has improved conditions for women in the households and additionally (maybe) employed as mineworkers, DWS does not have this information readily available. https://www.imwa.info/docs/imwa_2019/IMWA2019_Annandale_71.pdf

1 [95] file:///C:/Users/navrozk266/Downloads/benchmarks-report-06june2018.pdf

2. Department of Mineral Resources and Energy (DMRE)	
Date of Consultation	August 3
Category of Stakeholder	Government Stakeholder
About DMRE	"DMRE is a leader in the transformation of South Africa through economic growth and sustainable development in the mining and energy sectors. DMRE aims to develop a mineral resources and energy sector that promotes economic growth and development, social equity and environmental sustainability. The mission of DMRE is to regulate, transform and promote the minerals and energy sectors, providing sustainable and affordable energy for growth and development, and ensuring that all South Africans derive sustainable benefit from the country's mineral wealth." Source: https://www.dmr.gov.za/about-dmre/overview
Key Focus Area of Consultation (Environment)	The consultation aimed to achieve the following: Understand the policy and technology interventions in VRFB and the mining industry in South Africa and the role of DMRE in promoting sustainable energy storage solutions. The key focus of consultation also included technology limitations regarding pollution prevention and control in view of the stakeholders. Gain insight into the deployment of energy storage technologies and identify risks and opportunities for VRFB batteries in the South African context. Understand the existing pollution prevention and control technologies/interventions in place across the VRFB value chain. Understand the national interventions regarding the decommissioning of coal -powered plants and the transition toward renewable energy with integrated energy storage solutions and proposed policy around streamlining the sustainable energy storage solutions. Another target area for discussion included policies and technical interventions around battery recycling and reuse; current disposal mechanisms for battery waste, electronic waste, and electrical waste; the policy framework for e-waste disposal and current implementation approaches to extended producer responsibility (EPR) in VRFB batteries.
Consultation Summary (Environment)	Consultation Summary The objective of the consultation on social aspects was to identify the risks, challenges, and opportunities that are prevalent or likely to arise in the VRFB domain and its supply chain and in vanadium mining. 1. The DMRE representative and team shared that their department does not deal with environmental and social aspects related to the sector, but more with the economics, import/export, financials, and production information, etc. 2. The representative at the DMRE further conveyed that their colleagues at the Mineral and Petroleum department may provide insights into the environmental and social aspects related to the subject. 3. Last, the DMRE confirmed the receipt of the consultation questionnaire and agreed to share the answers, in discussion with other members of the department. PwC has received no response from DMRE post multiple follow -ups.
Consultation Summary (Social)	Consultation Summary On social safeguards and social equity in VRFB and the vanadium value chain, DMRE did not have the necessary information as they were not experts in VRFB or vanadium mining

Appendix H:

Summary of Stakeholder Consultation

3. The Department of Trade, Industry & Competition (the dtic)	
Date of Consultation	**August 1**
Category of Stakeholder	**Government Stakeholder**
About dtic	"The mission of the dtic is to promote structural transformation, towards a dynamic industrial and globally competitive economy; provide a predictable, competitive, equitable and socially responsible environment conducive to investment, trade and enterprise development; broaden participation in the economy to strengthen economic development; and continually improve the skills and capabilities of the dtic to effectively deliver on its mandate and respond to the needs of South Africa's economic citizens." Source: http://www.thedtic.gov.za/
Key Focus Area of Consultation (Environment)	The consultation aimed to understand the role of the Department of Trade, Industry and Competition (the dtic) in promoting the VRFB sector of the sustainable energy storage solution sector by creating and implementing an environmentally friendly policy framework. The purpose of the consultation was to understanding various policy interventions in line with the operations of the dtic to reduce the environmental impacts associated with the transport and logistics services in mining and industries and to understand the challenges faced by the renewable energy sector in South Africa in terms of transmission loss, energy storage, and key constraints. Furthermore, the consultation aimed to understand the key provisions and steps made by the government and department toward meeting energy demands in South Africa (focusing on the growth of renewable energy resources) with due consideration of environmental degradation alongside increased energy production and mineral exploitation. In addition, the consultation aimed to understand the key challenges faced in trading batteries and battery parts and the regulatory provisions for battery assembling units with respect to international conventions and the revised Preferential Procurement Policy Framework Act (PPPFA) regulations (focusing on Vanadium Redox Flow Battery).
Consultation Summary (Environment)	Consultation Summary Providing insight into the dtic's role in the mineral sector, the representative from the dtic specified that the department provides support to various investors in establishing the industrial facilities within the dtic -facilitated SEZs. While their involvement is limited to guiding the investor in ensuring regulatory compliance and mandatory compliances towards the regulations. The dtic further supports investors by facilitating stakeholder engagements and meetings with various government departments that will be impacted or will have an impact because of the investment. The dtic also supports investors with outlining the regulatory permissions needed to obtain such as environmental authorization, water usage licenses, etc. With respect to the VRFB sector, the Industrial Development Corporation (IDC) has facilitated one such investment in the dtic -facilitated special economic zone (IDZ), where Bushveld is setting up a vanadium electrolyte manufacturing plant. With respect to promoting the investment in SEZs, investors receive certain benefits, such as tax incentives. With respect to the plans to add VRFB to the power grid, Bushveld is interested in setting up VRFB through an ESKOM -based program. Based on the limited information available, one such testing program for installing energy storage batteries have been discontinued by the ESKOM, while the results or performance of that program are not known to the dtic. In terms of public sector procurement, VRFBs are not a designated product; however, a number of materials associated with the battery are designated and will be subject to trade regulations and guidelines. The government is promoting the localization of resources available in South Africa and creating promising job markets, and there is an intention to have a specific window in terms of localization. For energy storage solutions and battery development, dtic DMRE and IDC are working with primary minerals to spar localizing battery development, energy storage solutions, and other renewable projects. This also includes a focus on vanadium. In terms of circularity, dtic is reviewing circularity policies, but it is not focusing specifically on the VRFB market or such products. With reference to recycling facilities, as a government entity, there is no recycling unit for the battery market, but there are some private players involved in the recycling of lead batteries, and a policy to this effect has been created by the department of environment specifying the process for recycling and the rationale for it.
Consultation Summary (Social)	Consultation Summary The aim of the consultation was to gain insight into the deployment of energy storage technologies and identify risks and opportunities associated with VRFB batteries in the South African context. The objective of the consultation on social aspects was to identify risks, challenges, and opportunities that are prevalent or likely to arise in the VRFB domain and its supply chain and in vanadium mining. In the vanadium mining sector and in VRFB usage in industry storage solutions, it was revealed that dtic does not have a role in direct mining. The stakeholders indicated that mining-related concerns are handed by DMRE. Policy interventions generally do not fall within the purview of dtic. dtic facilitates various stakeholder engagements of the mining companies once they make decisions about establishing "manufacturing facilities." The dtic engages in energy sector investments in South Africa and oversees the full value chain of the investment lifecycle, including those in the SEZ in specific areas . The dtic could not provide specific responses to the questions on social aspects. The stakeholders indicated that the socially relevant aspects fall under the DMRE's mandate.

4. Department of Public Enterprises (DPE)	
Date of Consultation	**June 13**
Category of Stakeholder	**Government Stakeholder**
About DPE	"The DPE is the shareholder representative for the Government and is mandated by the Executive to oversee a number of SOCs that operate in core sectors of the economy like Mining, Defence, Energy, Logistics and others. The DPE is the primary interface between Government and the SOCs concerned and, in addition to oversight, provides input to the formulation of policy, legislation and regulation. The vision of DPE is to create an enabling environment in which SOCs add real economic value by focusing on operational excellence, commercial viability and fiscal prudence. This will drive developmental objectives, industrialization, job creation and skills development." Source: https://dpe.gov.za/about/
Key Focus Area of Consultation (Environment)	DPE was consulted on social safeguards considering its involvement in the job creation and skills development sector. The primary objective from an environmental standpoint was to gain insight into the presence of State-owned enterprises (SOE) in the vanadium market and their key concerns. The consultation also aimed to understand the policy interventions regarding sustainability or the circular economy and upcoming investments relating to VRFB.
Consultation Summary (Environment)	Consultation Summary The DPE specified that, at present, there is only one SOE involved in the diamond mining industry. The DPE representatives further specified that they are not aware of any environmental and social concerns regarding the vanadium mining industry that may affect investments in the sector. However, there are issues relating to investments in coal mining, and there are no new coal mining investments in the pipeline. It was noted that the DPE relies on national regulations and policies on environmental and social aspects and only monitors or provides oversight on compliance-related matters.
Consultation Summary (Social)	Consultation Summary The aim of the consultation was to gain insight into the deployment of energy storage technologies and identify risks and opportunities for VRFB batteries in the South African context. The objective of the consultation on social aspects was to identify risks, challenges and opportunities that are prevalent or likely to arise in the VRFB domain and its supply chain and in vanadium mining. From the consultation, we understand that: In South Africa, State-owned enterprises (SOEs) are a mandate for social and economic development. They are aligned with the National Development Plan (NDP) of South Africa. Currently, there are no SOEs involved in vanadium mining. SOEs need to comply with all necessary legislative prescripts that come from various departments for policies across the various departments. DPE ensures that companies adhere to business activities incorporating the socioeconomic objectives outlined in the national policies in the country and monitors them closely. Accelerating skills development is part of SOEs for local employment opportunities. Broadly, these objectives are aligned with the SDGs relevant to the country's context. SOEs have their own hiring processes. DPE aims to ensure that SOEs have the right personnel overall (from a skills perspective, rather than a demographic one).

Appendix H:

Summary of Stakeholder Consultation

5. Council for Scientific and Industrial Research (CSIR)	
Date of Consultation	**August 1**
Category of Stakeholder	**Government Stakeholder**
About CSIR	"The Council for Scientific and Industrial Research (CSIR) is a leading scientific and technology research organization that conducts research, develops, localizes, and diffuses technologies to accelerate socio economic prosperity in South Africa. The organization's work contributes to industrial development and supports a capable state. The CSIR undertakes directed, multidisciplinary research and technological innovation that contributes to the improved quality of life of South Africans." Source: https://www.csir.co.za/csir-brief
Key Focus Area of Consultation (Environment)	The consultation with CSIR focused on three broad areas: (1) Streamlining the legislative requirements for safeguarding in the environment, while the establishment and operation of the energy storage facility, energy storage solution to the existing power generation facility and VRFB assembling facility. (2) Understanding the policies and technical interventions around battery recycling and reuse with a focus on gaining insight into the number of battery recycling units processing in SA; technological research around the recycling of VRFB; the disposal mechanism for battery waste, electronic waste, and electrical waste; the implementation of extended producer responsibility (EPR); recycling and the reuse potential of waste generated from mining and ore processing. (3) Understanding the ecological sensitives of vanadium-rich regions of SA, i.e., Limpopo province, Mpumalanga province, Gauteng province and Northwest province and gaining insight into critically polluted areas in the region.
Consultation Summary (Environment)	Consultation Summary The representative of CSIR indicated that they are currently not involved in research about VRFBs, but they envision incorporating something similar to VRFBs as part of their outdoor testing facility. The CSIR was approached by multiple companies to look at sodium sulfur batteries and is, therefore, now considering sodium sulfur batteries as part of an outdoor testing facility. Regarding energy storage solutions, the CSIR is looking at developing cathode material for batteries and they are also setting up a testing facility for Li-ion and lead-acid batteries. By the end of 2022, they intend to establish a small-scale unit around this. The outdoor facilities for testing larger batteries are still in the conceptual stage and are planned for the future. The CSIR also conveyed that the only work on vanadium flow batteries done by the CSIR focused on the battery chemistry, which had been done a long time ago, and they are not sure about the availability of findings around this subject. Furthermore, no recent work has been done on vanadium or VRFBs by the CSIR team. As far as the CSIR understands, there are no policies related to energy storage, but there is policy related to lead-acid batteries, which follows IEC standards. In terms of lead-acid batteries, there is a regulation on recycling, the size of the required ventilation, the temperature of rooms, monitoring of gas produced, the type of flows needed, the spark resistant tools to be used in the storage facility, acid proof dentures, legislation around the safety provisions and the need to use personal protective equipment (PPE) and access control, etc. The aim is to ensure that policies and legislation about the specific batteries will address the chemistry behind the batteries. Regarding recycling, the representative of the CSIR informed the PwC team that there is a pre-established mechanism for the collection of spent lead -acid batteries in the battery centers, where the used batteries can be deposited, and a new battery can be collected at a discounted price. From the battery centers, the recyclers (such as First National Battery) collect the spent battery. Furthermore, the disposal of batteries in the environment is not allowed; they must be collected and recycled after use according to the Consumer Protection Act (section 59). With respect to recycling, companies like First National operate under ISO 14001 (2004 EMS) for recycling. As of now, there is one for Li-ion and there is debate around that, National northern standards for disposal of waste under government regulation 636 of 2018. There is a framework for secondary batteries, such as Li-ion, Ni-cadmium, and Ni-metal hydride, that falls under this umbrella framework for heavy metal batteries. found the recycling for batteries. The CSIR specified that they will not be able to provide input into environmental pollution related to the VRFB sector as they are not involved in this sector. They referred to another division that may have insight into waste generation and waste and water recycling solutions. The CSIR also informed the team that there are areas in South Africa where the threat of water insecurity is high, but a direct link to the mining sector or vanadium mining sector cannot be established.
Consultation Summary (Social)	Consultation Summary The aim of the consultation was to gain insight into the deployment of energy storage technologies and identify risks and opportunities for VRFB batteries in the South African context. The objective of the consultation on social aspects was to identify risks, challenges, and opportunities that are prevalent or likely to arise in the VRFB domain and its supply chain and in vanadium mining. The CSIR offered broad insights into the development challenges in South Africa. 1. The CSIR is not involved in the VRFB sector, nor are they involved in research on vanadium or mining specifically. 2. As observed by the CSIR, there is a large segment of semi-skilled people who can benefit from engagement in the VRFB sector. 3. There are a few incentives to promote gender equity. 4. Due to load shedding in South Africa, energy storage in homes will benefit large communities, with markets expected to grow exponentially until 2035 (the CSIR referred to the World Bank report). 5. The CSIR observed that energy storage will not be affordable for all income groups because of the vast economic divide. For low-income groups, energy storage is out of reach. 6. Africa has an employment rate of 30% and is hence very indicative of the energy storage battery space in South Africa.

6. Bushveld Vanadium	
Date of Consultation	**June 29 (Environmental) July 13 (Social)**
Category of Stakeholder	**Private Sector Market Player**
About Bushveld Vanadium	"Bushveld Minerals is a low-cost, vertically integrated primary vanadium producer. It is one of only three operating primary vanadium producers, owning two of the world's four operating primary vanadium processing facilities. In 2021, the Company produced more than 3,592 mtV, representing approximately three per cent of the global vanadium market. With a diversified vanadium product portfolio serving the needs of the steel, energy and chemical sectors, the Company participates in the entire vanadium value chain through its two main pillars: Bushveld Vanadium, which mines and processes vanadium ore; and Bushveld Energy, an energy storage solutions provider. Bushveld Vanadium is targeting to materially grow its vanadium production and achieve an annualized steady state production run rate of between 5,000 mtV per annum and 5,400 mtV per annum by the end of 2022. Growth plans to 8,000 mtV per annum will be pursued, subject to funding and market conditions. Bushveld Energy is focused on developing and promoting the role of vanadium in the growing global energy storage market through the advancement of vanadium-based energy storage systems, specifically Vanadium Redox Flow Batteries ("VRFBs")." Source: https://www.bushveldminerals.com/company-profile/
Key Focus Area of Consultation (Environment)	The primary objective of this consultation was to understand the process of VRFB production and understand material flow analysis. The focus areas during the consultation were: Process flow emissions, i.e., air emissions associated with the VRFB value chain (Mining process (Magnetite Ore and Vanadium Ore), Industrial Process—V_2O_5 production, V Electrolyte Production, VRFB Battery Assembling) Applicable regulatory clearance for establishing industrial setup associated with the VRFB value chain in SA Estimated waste generation and its quantum spread across the lifecycle of VRFB manufacturing and usage Potential to recycle waste generated from various processes Involvement of hazardous material and activities involving manual handling of chemicals Resourcing and usage of raw materials, including energy utilization and water usage Supply chain emissions and associated emissions
Consultation Summary (Environment)	The representative of Bushveld specified that their input in the VRFB value chain is in vanadium ore extraction and ore to production processes. Their main mining and processing facilities, Bushveld Vametco, are in Brits, South Africa. During the process of ore extraction, ore is mined through open -cast mining methods, using drill and blast, as well as load and haul procedures to mine the magnetite ore. The major waste generated in this process is waste rocks or overburden. The key environmental risks associated with this stage are open void areas, dumps, and the use of explosives, with the potential for groundwater contamination. The applicability of various regulatory licenses, such as Air Emission License, Integrated Water Usage License and Environmental Authorization, were also confirmed during the consultation. Furthermore, the representative of Bushveld Vanadium explained the process of Vanadium Electrolyte Production (Vanadium Mining, Concentrate Production, Extraction process, Recovery Process and Refinery Process) and specified the key input material requirements (such as water) and emissions and effluent generation associated with the entire process. The main inputs for concentration production are magnetite ore, raw water, and electricity, and the main outputs would be vanadium bearing magnetite and tailings. During the extraction process, the vanadium is extracted from the magnetite using a kilning/roasting/leaching process. The entire extraction process uses input material such as roasting agents, coal, LPG gas, wash water, and acids, while the outputs include scrubber sludge, emission of OFF gas from the kilning stacks, and calcine tailings as a waste or by-product in the leaching process. The major output during the recovery process is off-gas, and this process requires water, softeners, and coal (for burning) as inputs. Furthermore, most of the liquid used in this process is lost through evaporation in the sulfate plant to extract vanadium in a solid state. During the final stage (refinery), the main inputs are LP gas proven air, starch binders, and water. The representative of Bushveld also specified the pollution prevention measures implemented during the process of vanadium electrolyte generation, such as the provision of a kilning off -gas scrubber system to minimize SO2 and particulate matters and the provision of black houses for the boilers. The majority of water used during vanadium extraction is recycled water. Water is generally sourced from open pits as sub seepage, from third parties (municipalities—mostly untreated water not suitable for human consumption), and boreholes. Water is recovered using a return water dam during the process and is recirculated into the process. As part of the current practice, the overburden or waste rock generated as part of the mining activity is not being used elsewhere, but is being used as backfill into the pit and for post mining, i.e., mine closure activity, while the calcine tailings generated as part of the extraction process are considered hazardous waste according to the waste classification (pH of 3 and sulfate concentration of 200). Therefore, this waste is disposed of in line with the regulatory requirements (HDPE lined cells). Furthermore, the water from calcine tailings is recovered through underdrainage seepages in HDPE -lined cells. All the seepage from calcine tailings is recirculated into the process as wash water input. Since the water is of poor quality, it is recycled within the extraction process. Bushveld is currently following a water management procedure to use the resource efficiently, which includes circulation of reuse of water and the reduction of the amount of water required from external sources. The services also generate sewer effluent, and the water recovered from the sewer effluent is fed into the leaching process. Overall, approximately 60% is recovered/recycled water and 10 % of the water is sourced from within the mining area as part of the pollution bloom management program. The source of such water is scavenger boreholes and abstract, polluted groundwater from within the mining area. Furthermore, about 30% of the water is lost during the process through evaporation. The representative of Bushveld further conveyed that electrolyte production is new territory for them and is more closely aligned with chemical engineering. In terms of legislative requirements, there is a need for environmental authorization, water usage licenses, atmospheric emission licenses, and hazardous substance handling licenses.

Appendix H:

Summary of Stakeholder Consultation

6. Bushveld Vanadium	
Date of Consultation	**June 29 (Environmental) July 13 (Social)**
Category of Stakeholder	**Private Sector Market Player**
Consultation Summary (Social)	Consultation Summary The aim of the consultation was to gain insight into the deployment of energy storage technologies and identify risks and opportunities for VRFB batteries in the South African context. The objective of the consultation on social aspects was to identify risks, challenges, and opportunities that are prevalent or likely to arise in the VRFB domain and its supply chain and in vanadium mining. In the South African context, there are a few regulatory frameworks in the social space to which mining companies must adhere. Additionally, a large part of the frameworks outline what companies can adhere to, what communities can and cannot expect from mining companies, and so on. SLPs according to Regulation 46 under the Mining Charter Act that companies need to comply with, including HR development, employment equity, mine community development, management of down-scaling, and housing and living conditions. Cites the example of housing and living conditions—in terms of legislation, mines aim to support the accessibility of affordable housing for employees, but communities expect that mining companies will assist entire communities with access to housing, which is not in line with the legislation. According to the Charter, companies are expected to contribute 1 percent of net profit after tax to community development initiatives. Currently, according to the Mining Charter 2018, the SLPs mines need to follow community development programs. There is a gap between communities' expectations from mining companies in Over and above integrated development plan of municipalities (earlier between local government and constituencies), companies need to have direct contact with communities about their needs, which often creates conflict between the local government and communities. Companies are asked to approach local governments instead of communities (which is contrary to the legislation). There are challenges in the VRFB and mining industry in terms of women securing more opportunities in the mining workforce. Cites examples from their own operations—women in historically disadvantaged contexts, mines are not making technical and management roles available to women. The social and economic dynamics of mine locations present challenges: women find it difficult to work in the areas far north of Limpopo as it is remote or very rural, and women cannot access certain basic amenities in the work environment. Most women prefer work opportunities in the urban areas. Stakeholders stated that Bushveld is still at the mining stage, but has not yet delved into the VRFB space. Not yet a VRFB operation phase. Gender diversity in the workforce is thus not yet applicable in the VRFB sector, but only in the upcoming electrolyte plant in one of the provinces. In terms of human resources and labor, the Employment Equity Act and Broad -Based Black Economic Empowerment (B-BEE) are mandates for workforce diversity. The Integrated development Plans (IDPs) of the Madibeng municipality indicated that more men enter the workforce as migrant workers. The baseline study revealed social concerns such as teenage pregnancy and HIV prevalence, among others. There are economic spin-offs, such as more disposable income in Madibeng compared to 2011. Health initiatives can have social impact. In terms of documentation, Bushveld/Vametco Alloys has provided a baseline study conducted in 2020 in its Vametco Alloys operation in Madibeng Municipality, Northwest province aimed at improving its SLP. The study focuses on key socioeconomic indicators related to population and demographics, community well-being, employment and income, employment and employability, access to infrastructure and related public services, economic development, and the impact of the COVID-19 pandemic.

7. Largo	
Date of Consultation	**August 30 and September 10**
Category of Stakeholder	**Private Sector Market Player**
About Largo	"Largo Inc. produces and supplies vanadium. The Company focuses on the production of VPURE™ and VPURE+™ products, which are sourced from one of the world's highest-grade vanadium deposits at the Company's Maracás Menchen Mine in Brazil. The company also offers renewable energy storage solutions through clean energy and vanadium redox flow battery systems. The Company is in the process of implementing a titanium dioxide pigment plant using feedstock sourced from its existing operations in addition to advancing its US-based clean energy division with its VCHARGE vanadium batteries." Source: https://www.largoinc.com/About-Us/Overview/default.aspx
Key Focus Area of Consultation (Environment)	The objective of the consultation was to understand the key sectoral environmental concerns in processing vanadium. The focus areas for this discussion included Occupational Health, Safety, Emissions, Effluent Discharge, Transportation of Raw Material (Vanadium) and Transportation of Final Product. The consultation also aimed to understand the major global concerns about the VRFB market, such as international regulations/ treaties governing the transboundary movement of V_2O_5, V-electrolyte, and VRFB, as well as the key issues faced by Largo in the transportation of materials and transboundary movement (V_2O_5, V-electrolyte, VRFB.). Furthermore, the consultation sought to understand the GHG emissions associated with the production of VRFBs and the key interventions for reducing GHG emissions involved in the production, transportation, and operation of VRFBs.
Consultation Summary (Environment)	In the beginning of stakeholder consultation, the representative of Largo specified that they would prefer to provide a written response to the questionnaire after discussing the questions with technical experts at their energy department and referring to their sustainability report. It was also made clear that Largo is yet to deploy a battery and are in process of doing so; therefore, the E&S data points related to the V- electrolyte and VRFB manufacturing and functioning are not readily available. The representative of Largo emphasized the sourcing and supply of vanadium and its effect on the overall cost of VRFBs. Largo is currently attempting to create a financial mechanism to reduce the cost of vanadium and, thus, the cost of VRFBs by 30% to 50%, expediting adaptation to VRFBs. Moreover, the volatile nature of the vanadium market and its ever-changing pricing was put forth as one reason for limited adaptation, in addition to the size of the battery, in the commercial space. To address this issue, Largo has introduced the concept of physical vanadium as a separate company through which investors can invest in physical vanadium. This company is aligned with Largo clean energy and Largo Inc. As a result, the customers of Largo will benefit as they will not have to pay for the vanadium in the VRFBs. Furthermore, Largo provided insight into the surge in enquiries from Europe about the need for renewable energy storage solutions. Thus, Largo is looking to Europe and the United States as major drivers of the VRFB market. The representative of Largo emphasized the reuse and recycling potential of vanadium after the battery life cycle. Although there are no current examples of this, pilot studies are available. Largo is transporting vanadium flakes and powder and is planning to ship its first electrolyte batch. Considering the toxic nature of vanadium, shipping the electrolyte is difficult as it is heavier, so Largo intends to focus on mobile mixing operations so that powdered vanadium can be shipped. The transboundary movement of vanadium in electrolyte or powdered form has some constraints related to its movement, such as the need to be REACH certified and have ownership title documentation In light of the safety aspects of transportation, certain taxes apply. The availability of shipping containers, staff, ports, and parts for VRFBs are some of the major supply chain challenges. Regarding GHG emissions, Largo has just launched the Scope 1 and Scope 2 review of the VRFB business, while the representative was not sure about the overall coverage area of study emission review for VRFB has been picked up by Largo while its data points is not yet available. A Largo representative mentioned an existing study on the life cycle assessment of vanadium redox flow batteries, which is already considered part of the desk review and assessment study.
Consultation Summary (Social)	Consultation Summary The aim of the consultation was to gain insight into the deployment of energy storage technologies and identify risks and opportunities for VRFB batteries in the South African context. The objective of the consultation on social aspects was to identify risks, challenges, and opportunities that are prevalent or likely to arise in the VRFB domain and its supply chain and in vanadium mining. The second consultation with Largo (September 10) proved useful in terms of their inclination in the social impacts. However, as was shared by the organization, Largo is yet to venture into the VRFB space and has not yet delved into the social impacts of vanadium mining or VRFBs.

Appendix I:

Roadmap—Key Activities required for Uptake of VRFB, Demand Creation

	Activity	Impact	Timeline
1	Government-led pilot projects to support the roll out of renewables to support demand	Supporting increased RE penetration through stationary storage	2023-2030
2	Project tendering: Government to initiate long-term offtake/tenders of VRFB technology of sizeable capacity to ensure long-term price stability		2023 onwards
3	Policy -based incentives (tax exemptions, special tariff, etc.) for VRFB to increase customer demand		2023-25
4	Deploy VRFB as a potential replacement to diesel generators in microgrids for remote/isolated communities	Promotion of VRFBs as a viable alternative technology solution	2025-30
5	Build stakeholder awareness on benefits of VRFB vs Li-ion technology, including emphasis on LCOE rather than upfront cost		2023 onwards
6	Implement electrolyte leasing model	Reducing upfront cost of VRFB system	2023-2025
7	Conduct R&D on critical subcomponents-stack and electrolyte by working on cheaper alternatives		2023 onwards
8	Intergovernmental collaboration to transfer technology and skills for techno-commercial development of VRFB technology		2023 onwards

Appendix J:

Roadmap —Key Activities required for Uptake of VRFB, Supply Growth

	Activity	Impact	Timeline
1	Promoting investment in exploration of vanadium	Growth of vanadium reserves & mine production	2023 onwards
2	Development of new mines in Australia, SA , Russia, China, and Brazil		2023 onwards
3	Tax incentives to promote production of VRFBs	Production growth throughout the value chain	2023
4	Incentives to set up production facilities and promote production growth		2024
5	Free trade zone to increase the commercial feasibility of exporting vanadium electrolytes to end users		2023-2025
6	Mapping of land and locations for setting up the manufacturing facilities to promote VRFB production		2024

Appendix K:

Roadmap —Key Activities required for Uptake of VRFB, Environment and Social Development

	Activity	Impact	Timeline
1	Skills mapping aligned to market needs and the demand for skills and jobs and preparation of a skills development plan	Increased employability of the local community in the VRFB value chain	2022-2025
2	Implementation of a skills development plan		2025-2030
3	Social safeguard and community development plan focusing on gender equality, Indigenous, and disadvantaged	Improved and equitable access to services	2022-2024
4	Leveraging access to energy for enhanced social development outcomes particularly health, education, and economic development		2025-2030
5	Development of industry-specific Waste Management Plans to facilitate the concept of Extended Producer Responsibility (EPR)	Minimizing waste generation and the impact on the environment	2022-2024
6	Identifying the availability and capacity of recycling facilities to implement the recycling and recovery measures at the post-consumer stage.		2022-2024
7	Setting up procedures, processes to implement the recycling and recovery measures at the post-consumer stage (collection, transportation, storage, recycling, recovery, treatment, reuse, upcycling, and disposal)		2025-2030

Note: Applies to the South African context

Appendix L:

Roadmap —Key Activities required for Uptake of VRFB, Regulatory Framework

	Activity	Impact	Timeline
1	Introduce an investment promotion plan in accordance with the Draft Exploration Strategy for the Mining Industry in South Africa	Vanadium extraction and downstream beneficiation growth	2022-2025
2	Introduce vanadium beneficiation support mechanisms in terms of section 26 of the Minerals and Petroleum Resources development Act		2022-2025
3	Develop a specific recycling/reuse regulatory regime aimed at reducing the impact of the vanadium value chain on the environment	Regulating environmental impact	2022-2025
4	Guidelines on the identification of appropriate locations for BESS solutions taking various factors into account		2022-2025
5	Guidelines for the dismantling of BESS equipment and the end of its service life, including specific BESS end-of-life provisions		2022-2025
6	Update IRP with increased renewable energy capacity provisions for wind and solar	Energy regulations for VRFB promotion	2022-2025
7	Introduce a set of regulations under section 19 of the National Energy Act, aimed at promoting deployment of VRFB		2022-2025
8	Introduce tax incentives in Section 12 of the income tax associated with the manufacturing, piloting, and deployment of VRFB	Industrial regulations for growth of VRFB	2022-2025
9	Introduce free trade zones—SEZs are duty-free areas offering storage and distribution facilities for value-adding activities within the Special Economic Zone for subsequent export		2022-2025

Note: Applies to the South African context

Notes

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