Battery Energy Storage Systems Value Chain Analysis for the Identification of Opportunities for Enterprise Development

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SUMMARY

South Africa is confronted by the triple threat of inequality, poverty, and unemployment and has the highest inequality and unemployment rate in the world. The energy transition to a low carbon economy offers significant opportunity for the country to stimulate economic growth and overcome some of the social challenges faced by pursuing investments to reindustrialise the economy.

The country is expected to experience a significant investment in renewable energy as part of the energy transition. However, increased penetration of renewable energy demands other technologies to ensure that grid stability is maintained. Battery energy storage is seen as one such technology and according to the Integrated Resource Plan of 2019 and Eskom's latest Transmission Development Plan it is expected that a capacity between 2GW and 6.6GW will be required to be installed by 2032. This indicates the potential investment that will need to be made for battery storage thus highlighting the potential opportunity for localisation and industrialisation of such value chains.

Thus, this paper seeks to detail the activities, products and services required for lithium-ion and vanadium flow battery energy storage systems value chains with the inherent aim at unpacking potential enterprise development opportunities that exist. The paper will detail the upstream, midstream, and downstream activities within the value chains, key market competitors, barriers and possible solutions for reindustrialisation in the country.

KEYWORDS

Value chain analysis, localisation, reindustrialisation, enterprise development, battery energy storage systems (BESS), lithium-ion battery, vanadium flow battery, just energy transition (JET)

1 INTRODUCTION

South Africa is grappling with the triple challenge of inequality, poverty, and unemployment. The country is the most unequal country in the world and currently has a high unemployment rate of 32.7% [1, 2]. These underlying issues have been further exacerbated by the current electricity crisis. In response to these challenges, the government developed an Economic Reconstruction and Recovery plan aimed at stimulating equitable and inclusive sustainable growth with a large focus on the development of the green economy. This plan complements the National Development Plan (NDP) which spells out ambitions of the country to achieve its climate goals. These plans are underpinned by inclusivity and an objective to create sustainable growth for South Africans. In an energy context, there are various ways this can be achieved including the development of small, micro and medium enterprise (SMMEs) to participate in energy-related value chains through the localisation of key segments of those value chains.

The battery energy storage market in the country has been developing rapidly and is set to continue to do so as the country seeks to attain its climate commitments. The 2019 Integrated Resource Plan (IRP 2019) envisaged that 4GW of embedded generation and 2GW of energy storage should be added to the power system by 2030. The latest Eskom Transmission Development Plan (TDP) recommends a higher requirement of battery storage into the system, 6.6 GW by 2032, to ensure system stability [3]. These highlight the substantial opportunity to service the country's budding energy storage market and contribute towards economic growth and employment creation. The draft Just Energy Transition Investment Plan (JET-IP) details further investment opportunities and requirements for decarbonising the grid, green hydrogen development and new energy vehicles with a total of R1.5tn expected to be invested from 2023-2027. Additionally, the draft South African Renewable Energy Masterplan (SAREM) indicates that localising 70% of the components and 90% of balance of plant (BOP) and operations and maintenance (O&M) in the wind and solar PV value chains, combined with battery energy storage, could deliver 36,500 new direct jobs by 2030, with a total GDP contribution of R420 billion [4].

The South African embedded generation market has also grown significantly, with an increasing number of small-scale embedded generation installations driven by loadshedding, the desire to reduce energy bills and decrease reliance on the national grid [5]. Furthermore, the amendment to the Electricity Regulation Act (ERA) Schedule 2 granting exemption from obtaining a generation licence for embedded generation projects unlocks further opportunities for growth in the renewable energy sector as well as increases the demand for critical equipment within the value chain.

The development of a green economy in South Africa is envisaged to present significant opportunities and this paper seeks to unpack some of those enterprise development opportunities along the lithium-ion battery (lithium-ion battery) and vanadium flow battery (vanadium flow battery) value chains given that they are expected to be the main energy storage technologies proliferating the South African energy storage market.

2 LITHIIM-ION BATTERY ENERGY STORAGE SYSTEMS VALUE CHAIN

The lithium-ion battery value chain has various segments as depicted in Figure 1 and is comprised of upstream, midstream, and downstream activities. This section of the paper describes the activities associated with each segment of the value chain.

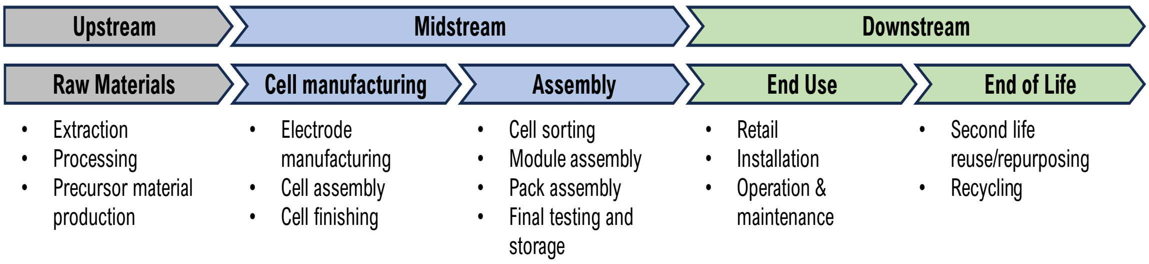

Figure 1: Lithium-ion battery value chain and associated activites. Adapted from [6].

2.1 Raw materials extraction

The minerals used to produce active lithium-ion battery materials are regarded as critical battery minerals and include lithium, graphite (main anode active material (AAM)), nickel, cobalt, manganese, iron and phosphate. The cathode active material (CAM) is made up of different types of minerals as shown in Figure 2. The cathode and anode form the larger portion of the material requirements in battery cells, with the cathode representing ~40% for NMC811[1] and ~43% for LFP[2], and anode representing ~27% for NMC811 and ~20% for LFP [7].

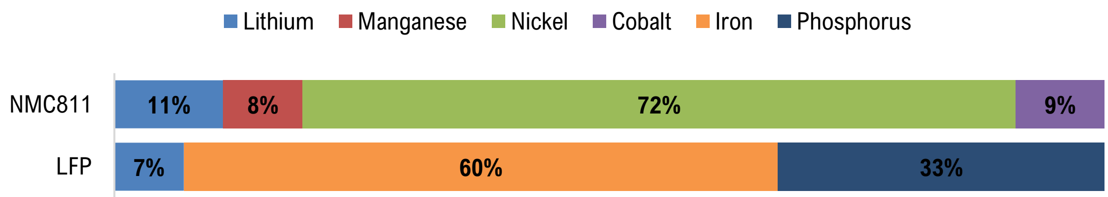

Figure 2: Metal composition of NMC811 and LFP cathode active materials. Adapted from [8].

Table 1 shows the top producers of critical battery minerals and highlights South Africa's contribution to global production. China is amongst the major producers for most of the minerals, this along with other factors such as skills and cheap labour has given the country an advantage in developing a vertically integrated lithium-ion battery manufacturing industry. South Africa is a major producer of manganese globally and produces other minerals such as iron, nickel, aluminium, etc., *albeit* at smaller quantities; furthermore, some of these minerals are key inputs to other industrial activities such as steel making.

[1] NMC – Nickel-Manganese-Cobalt
[2] LFP – Lithium-Iron-Phosphate

Table 1: lithium-ion battery critical minerals top producers and South Africa's contribution to global production, based on 2020 data from World Mining Data [9].

Mineral	Top 3 producers	Global contribution (%)	South African contribution (%)	Mineral	Top 3 producers	Global contribution (%)	South African contribution (%)
Lithium	Australia Chile China	48% 27% 15%	0%	Graphite	China Brazil Madagascar	71% 7% 5%	0
Manganese	South Africa Gabon Australia	31% 19% 17%	31%	Iron	Australia Brazil China	37% 16% 15%	2.38%
Nickel	Indonesia Philippines Russia	33% 13% 9%	1.39%	Copper	Chile Peru China	28% 10% 8%	0.14%
Cobalt	Congo, D.R. Russia Australia	66% 7% 4%	0.68%	Aluminium	China Russia India	57% 6% 6%	1.10%
Phosphorus	China Morocco United States	38% 17% 9%	0.76%				

2.2 Processing

Lithium-ion batteries require high purity materials and therefore high-grade sources; thus, significant refining capacity is required to reach sufficient quality battery chemical precursors. The refining activities of some of the critical battery minerals are discussed below.

a. Lithium

China, South Korea and Japan dominate lithium processing to produce battery precursors and have a combined market share of approximately 83.4%, followed by Chile (9%), USA (6%), and Canada (1%) [10]. South Africa has limited lithium resources with lithium pegmatites and spodumene-bearing pegmatites reported to occur in the Northern Cape and Kwa Zulu Natal (KZN) respectively. There is however limited exploration of these and hence no extraction nor processing of lithium in the country [11].

b. Manganese

The lithium-ion battery cathode precursors derived from manganese are manganese sulphate monohydrate (MSM) and electrolytic manganese metal (EMM). For optimal performance and safety of lithium-ion batteries, high-purity MSM and high-purity EMM are required [12]. Despite South Africa being the largest producer of manganese ore, 95% of this Mn is exported to be beneficiated in China, India, Norway, Malaysia and other markets. China currently accounts for about 90% of global production capacity of high-purity MSM [13]. Domestically, the Manganese Metal Company (MMC) refines manganese ore supplied by its partner South32 from the Hoatzel Manganese Mines located in the Kalahari Manganese Field into high-purity EMM. They supply the global battery market with the EMM for it to be further processed into a battery precursor [14].

c. Nickel

Nickel is mainly processed into high-purity class I products (nickel sulphate) and low-purity class II products (e.g., pig iron and ferronickel). Class II nickel can be processed into class I nickel, however, it requires significant additional processing and is more costly [13]. Nickel sulphate is a primary input for lithium-ion battery production, and along with other sulphates are used as precursors for manufacturing battery cathodes [15]. China and Russia dominate the production of class I nickel, accounting for a combined 40% of the global total [16].

2.3 Manufacturing

2.3.1 Cell and components manufacturing

The manufacturing process of lithium-ion battery cells consists of three stages: electrode manufacturing, cell assembly, and cell finishing, Figure 3. China currently dominates the lithium-ion cell manufacturing industry, accounting for 79% of the 2021 global manufacturing capacity, other countries that manufacture cells include the USA, Germany, South Korea, and Japan. However, to keep up with increasing demand for lithium-ion batteries from electric vehicles (EVs), energy storage system (ESS), and consumer electronics, global cell manufacturing capacity has also been increasing, it is estimated to have increased from 57 GWh/year in 2015 to 706 GWh/year in 2021 [17]. Projections indicate that it could reach 8,945 GWh/year by 2027 [18].

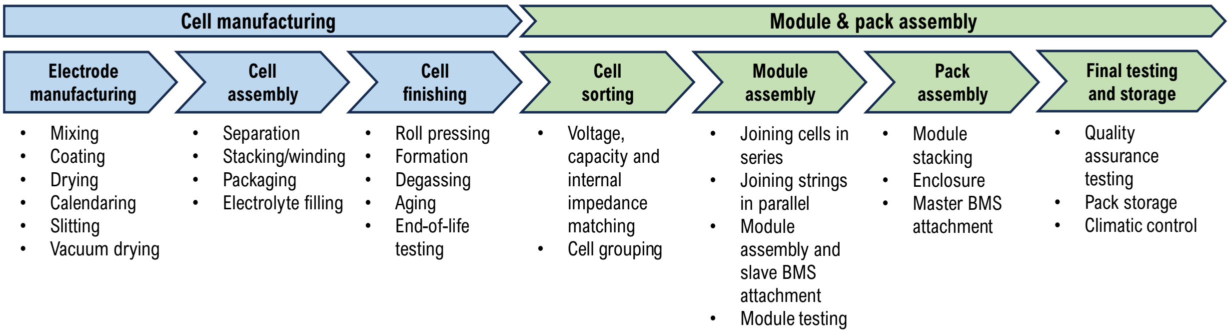

Figure 3: Lithium-ion battery manufacturing process steps from cells to pack assembly. Adapted from [17, 19].

2.3.2 Module and pack assembly

The assembly process involves four stages cell sorting, module assembly, pack assembly, and final testing and storage. The assembly market is very diversified and is driven by domestic demand in different countries. In its *South African Storage Technology and Market Assessment* report, Kritzinger *et al.,* [20], recommended that South Africa should consider focussing on the following activities pertaining to lithium-ion battery manufacturing:

- "Assembly of standardised commercial and industrial direct current (DC) BESS from cells and modules supplied by others", and
- "Assembly of standardised packaged alternating current (AC) BESS that include power conversion, power control, and ancillary systems"

Current battery production activities align with this recommendation where battery production in the country is primarily directed towards developing expertise in battery pack design and assembly for stationary, and industrial applications, with little being directed at the automotive industry [8]. Examples of South African companies involved in the module and pack assembly include BlueNova, SolarMD, FreedomWON, and Polarium.

2.4 End-of-life management

a. Second-life batteries

Multiple research indicates that when lithium-ion based EV batteries reach their end-of-life, they may still be used for stationary energy storage applications [8, 21, 22]. Generally, EV batteries should be replaced when they reach 70 – 80% of their original capacity, however they can still be used for less demanding applications such as grid storage [23].

A company that provides 2nd life batteries in South Africa is REVOV [24], they provide 2nd life batteries for the residential, light commercial and heavy industrial markets [8]. REVOV has a partnership with a Chinese firm that repurposes LFP batteries from EVs and then REVOV markets them and serves the warranty locally (i.e., repairs and replacement of faulty packs).

b. Recycling

Currently there are no lithium-ion battery recycling activities in South Africa. A study conducted by Mintek revealed that there is currently no viable business case for lithium-ion battery recycling in South Africa [25]. One of the key issues highlighted is that there are low collection rates by recyclers, the study posits that if potential recyclers could achieve a collection rate of 500 tons/year, then it would be viable to setup lithium-ion battery recycling facilities, however, the total lithium-ion battery waste collected in 2019 was between 6 and 10 tons/year [26].

3 VANADIUM FLOW BATTERY ENERGY STORAGE SYSTEMS VALUE CHAIN

The vanadium flow battery value chain has various segments as illustrated in Figure 4 and like the lithium-ion battery value chain, is comprised of upstream, midstream and downstream activities. This section of the paper describes the activities associated with each segment of the value chain. Due to a small number of manufacturers and the dominance of other more mature storage technologies, this value chain is still nascent. However, it presents opportunities for development and localisation, especially for long duration energy storage (LDES) applications which are expected to ramp up as more variable renewable energy is added to electricity networks and the technology costs decrease.

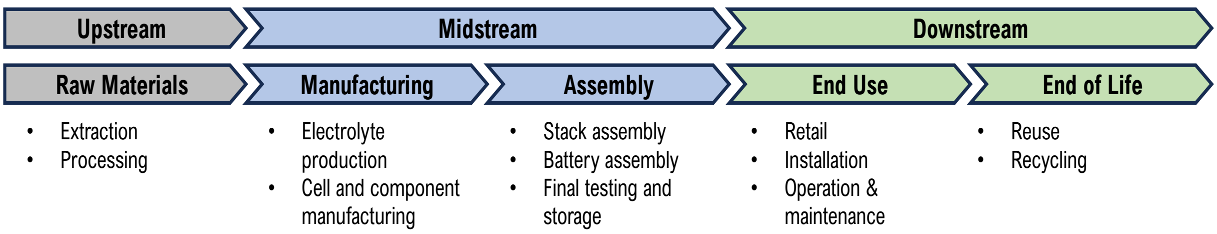

Figure 4: Vanadium flow battery value chain and associated activites

3.1 Raw material extraction

The main minerals required for vanadium flow batteries are vanadium, sulphur, graphite, iron, and copper; however, vanadium is the most critical as it is used to create the electrolyte solution. The electrolyte makes up around 85% of the total weight of a vanadium flow battery module [27]. Table 2 highlights the top producers of these minerals and South Africa's contribution. In 2020, China lead vanadium production, accounting for almost two-thirds of global production, followed by Russia (18%) and South Africa (8%).

3.2 Processing

High purity vanadium pentoxide (V_2O_5) is used as the electrolyte material for vanadium flow batteries. The processing of vanadium is still highly concentrated within the steel industry, especially in China; however South Africa does have expertise in vanadium processing [28]. In 2021, South Africa was amongst the leading exporters of vanadium oxides and hydroxides including V_2O_5 alongside Brazil, Russia, and China [29].

Table 2: vanadium flow battery critical minerals top producers and South Africa's contribution to global production, based on 2020 data from World Mining Data [9].

Mineral	Top 3 Producers	Global contribution (%)	South African contribution (%)
Vanadium	China Russia South Africa	66% 18% 8%	8%
Sulphur	China United States Russia	20% 10% 9%	0.74%

*Other critical minerals: Graphite, Iron, Copper. Refer to Table 1.

3.3 Manufacturing

Figure 5 illustrates the activities involved in the vanadium flow battery manufacturing process. Manufacturing of vanadium flow battery is distributed across the globe, with manufacturing in South America, North America, Europe, and Asia. In South Africa, Bushveld Energy is pursuing the development of a vertically integrated vanadium flow battery operation to supply the local, regional, and international ESS markets.

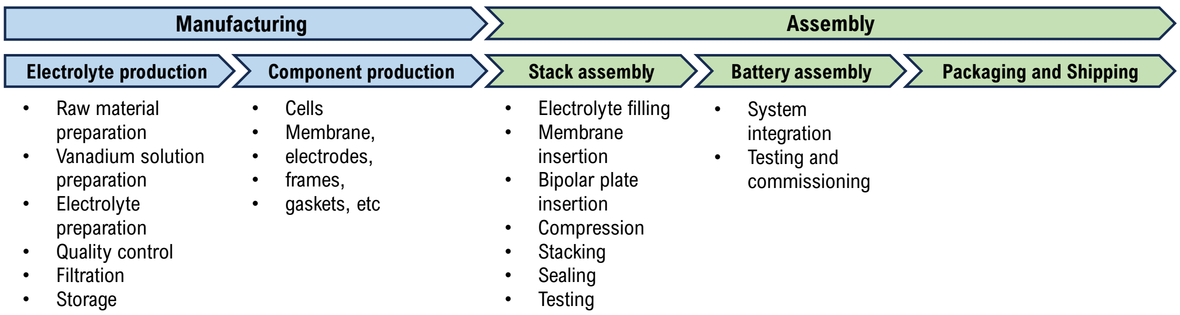

Figure 5: Vanadium flow battery manufacturing process steps

3.4 End-of-life management

Currently there are no vanadium flow battery recycling activities in South Africa. vanadium flow batteries have modular designs and most of the components are made from recyclable materials, thus at the end of a vanadium flow battery systems' operational life, most of the components can be disassembled and recycled. Additionally, the vanadium-based electrolyte is highly recyclable (>90% recyclability) and can be reused or repurposed to other valuable products [27]. The electrolyte's reusability and recyclability are the reason some electrolyte producers are developing business models to lease it, so that the end of the battery's operational life they can recover the electrolyte and re-lease it [30].

4 BATTERY ENERGY STORAGE COSTS

4.1 Lithium-ion batteries

Table 3 shows that the battery pack contributes a significant share towards the total system costs for residential & commercial and utility-scale lithium-ion battery systems, representing over 50% for both system scales. The cost drivers for the pack price can be attributed to the cost of manufacturing the lithium-ion cells, accounting for 74% of the total pack price Figure 6. The cell costs are largely driven by the cathode, anode, separator, and electrolyte costs which account for 51%, 12%, 7%, and 4% of the total cell cost respectively [31]. Figure 6 also shows that the battery management system (BMS) and assembly are the lowest cost components, representing 4% and 5% of the total pack costs, respectively.

Table 3: Cost breakdown of residential & commercial and utility-scale lithium-ion battery energy storage systems. Source(s): [32, 33].

Component	Residential & commercial (600 kW – 1MW)	Utility-scale (60 MW)
Battery pack	50.5%	58.6%
Electrical BOS	9.5%	10%
Structural BOS	2.7%	0.8%
Battery central inverter	4.3%	5.0%
EPC overhead	4.9%	2.9%
Installation labour and equipment	9.0%	4.5%
Soft costs (e.g. developer, sales, administrative)	18.5%	18.2%

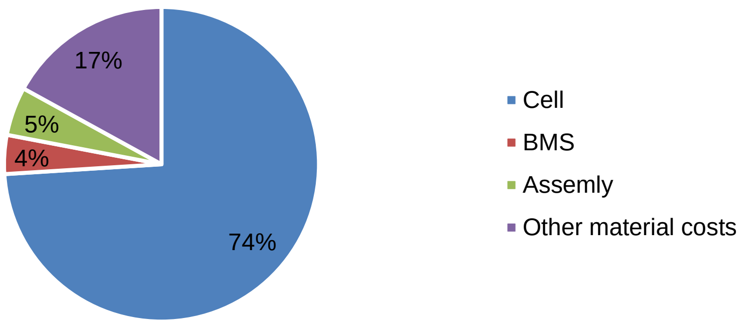

Figure 6: Percentage breakdown of lithium-ion battery pack cost. Adapted from [34].

4.2 Vanadium flow batteries

The total costs of vanadium flow battery energy storage systems are driven by the cell stack and vanadium electrolyte Table 4. Other system costs include stack assembly, BOP components, delivery and installation, and other costs. It should be noted that major drivers of the cost of cell stack are accessories such as current collectors, gasket, frames as well as bipolar plate and membrane Figure 7.

Table 4: Cost breakdown percentages for vanadium flow battery system. Source(s): [35, 36, 37].

Component	Cost contribution (%)
Electrolyte	26.2%
Cell stack	27%
Stack assembly	11%
BOP	19%
Delivery and installation	12.5
Other costs	6%

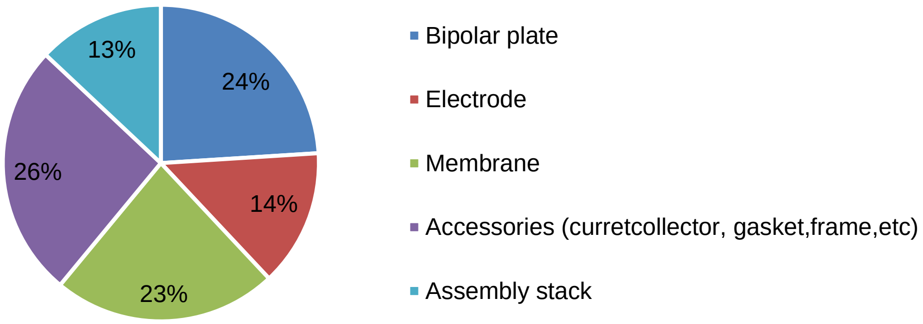

Figure 7: Percentage breakdown of the cost of vanadium flow battery cell stack. Adapted from [36, 38].

5 BARRIERS AND POSSIBLE OPTIONS FOR LOCALISATION

The global battery value chains present an opportunity for localisation, revenue generation, employment creation and economic growth. The revenue potential along the lithium-ion battery value chain is estimated to increase from ~USD85 billion in 2022 to ~USD400 billion in 2030, with the highest earnings being forecast for the active materials production, cell manufacturing, pack assembly segments of the value chain (see Figure 8) [39]. Other countries such as Rwanda, Kenya, Indonesia, Thailand, Australia, the USA and India and regions such as the EU are already implementing ambitious policies to develop domestic capabilities to support localisation.

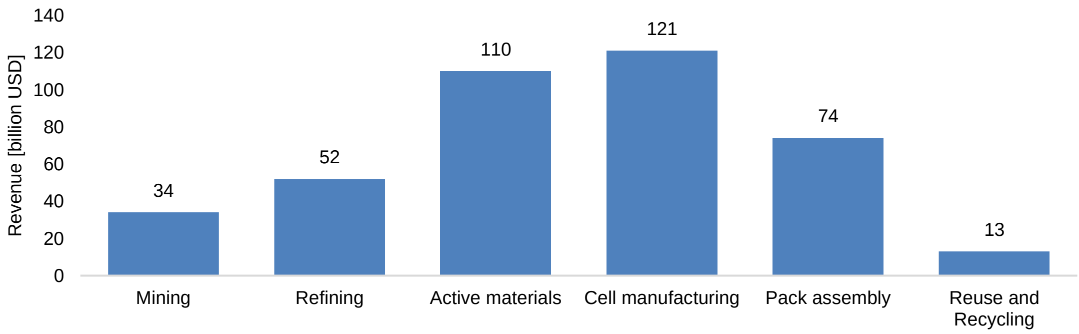

Figure 8: 2030 revenue potential across the different lithium-ion battery value chain segments. Adapted from [39].

South Africa has policies and initiatives that create demand for battery systems for behind-the-meter, front-of-the-meter and electric mobility applications, these are shown in Table 5.

Table 5: South African policies and initiatives creating domestic battery demand.

Storage application	Policy enablers
FTM	IRP2019, RMIPPPP
BTM	Distributed Generation Target 2030, Feed -in tariffs, mini-grids, rural electrification
e-Mobility	2021-2035 South African Automotive Masterplan (SAAM), Green Transport Strategy

However, the lithium-ion battery and vanadium flow battery value chains are still underdeveloped in South Africa and the country is currently heavily reliant of imported battery cells, particularly lithium-ion cells, from China and other leading countries. The main barriers for the development of battery value chain activities in the country include:

- Lack of policies and incentives that support local manufacturing and enterprise development in the lithium-ion battery and vanadium flow battery value chains.
- Limited domestic battery mineral processing and refining capacity,
- Limited access to capital and financing,
- Lack of skills and expertise in high-value activities.

In the short to medium term, it proposed that the country focuses on the value chain activities that it already has expertise in and develop policies that drive localisation in those segments of the value chains. These include:

- Refining and beneficiation of critical battery materials such as manganese, iron, phosphate, and vanadium,
- Development of novel battery module and pack designs and auxiliary systems,
- Innovation in module and pack assembly.

6 CONCLUSION

This paper provides an analysis of the global lithium-ion battery and vanadium flow battery value chains, highlighting the global dynamics in the value chains. Furthermore, the cost breakdown for the products and services in these value chains is also provided. The market demand for utility battery storage is at least 2GW (according to current plans). This equates to a potential investment of ~R24bn by 2030. This provides an indication of how significant the opportunities for localisation and sustainable growth can be if the country tries to maximise the proportion of local investment and value creation. Even though efforts by the government to promote local manufacturing exist through local content designation and establishment of special economic zones (SEZs), the challenge of cheaper imports cannot be ignored. Currently, lithium-ion battery manufacturing in SA is deemed to be unviable due to a lack of demand certainty, high capital costs to start operations, a lack of requisite knowledge and skills. Consequently, local companies resort to battery module and pack assembling. Due to the relative nascency of lithium-ion batteries usage in SA, end-of-life management of these batteries does not present any business opportunities, for example, lithium-ion battery recycling has no viable business case because the current lithium-ion battery waste is consumer electronics batteries and there are low collection rates. However, end-of-life for reuse in grid applications can become a business opportunity in the country.

It's a growing concern that as the pace of the global energy transition increases, the demand for these critical minerals is increasing drastically and might even exceed supply, due to supply being susceptible to rising geopolitical risks such as external shocks, resource nationalism, export restrictions, etc [40]. To circumvent this, the critical minerals supply chain needs to further diversify through increase exploration and the development of vertically integrated operations, especially in developing nations, to ensure that energy transition does not further exacerbate existing disparities in this segment of the value chain.

The largest contribution to the cost breakdown for the lithium-ion battery and vanadium flow battery emanates from the cell stacks and battery packs (at least 50%) providing a significant economic opportunity. South Africa actually houses many of the required raw materials and in some cases, is even the largest producer of such in the world i.e., iron and manganese albeit serving other local demand and industries. The country also produces other battery materials such as nickel, cobalt, and copper, aluminium, etc; however, it does not currently have enough refining/processing capacity to be able to produce battery precursors domestically. Furthermore, vanadium flow battery manufacturing is not concentrated in one region as lithium-ion battery manufacturing is, as such, there is still an opportunity for countries such as South Africa to enter the market, achieve economies of scale and a competitive advantage, more especially South Africa.

It is recommended that disintegrated funding streams for localisation and the above-mentioned opportunities be pursued. This can be justified using the socio- and macro-economic impact analysis for improving the triple challenge in the country. However, the major challenge of skills required for localisation and reindustrialisation must be solved as quickly as possible. Stricter requirements for skills transfer and proper monitoring and evaluation techniques for these large infrastructure projects should be adopted.

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