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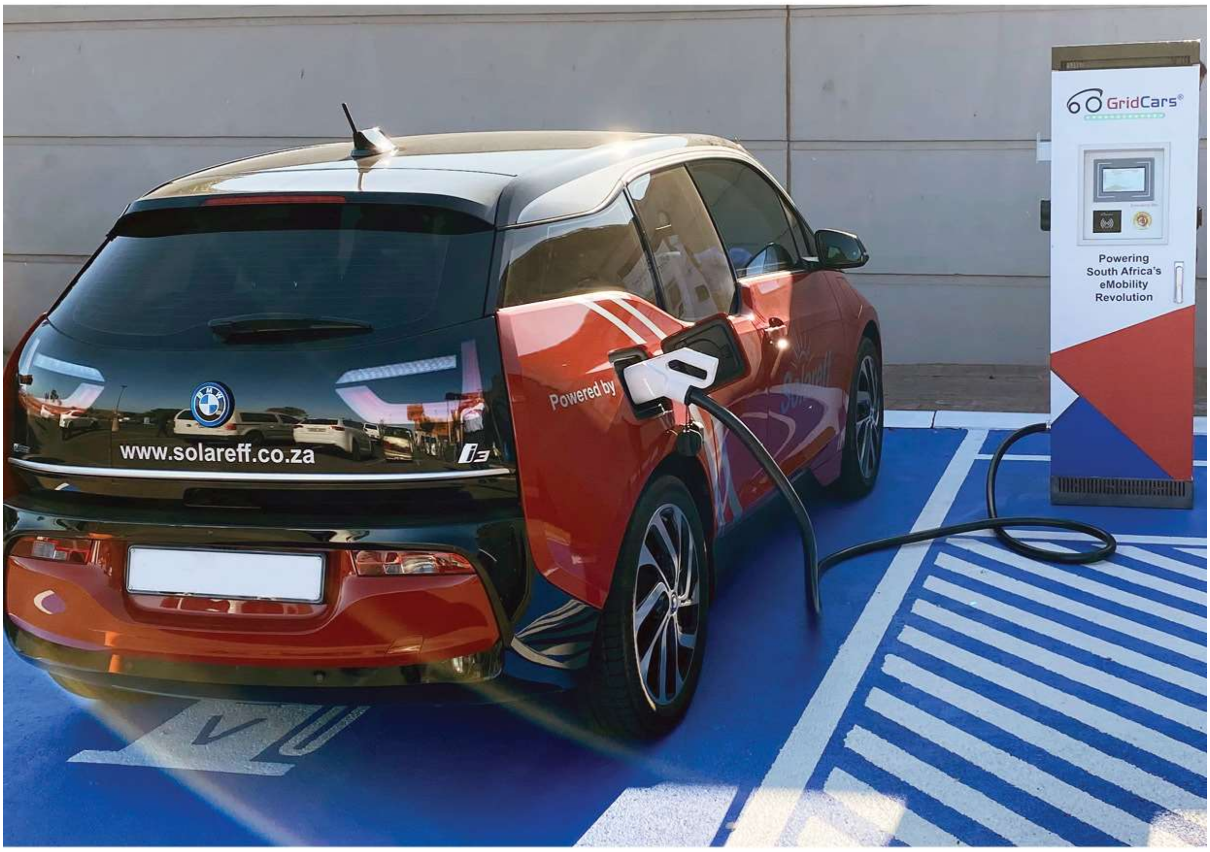
OPPORTUNITIES TO DEVELOP THE LITHIUM-ION BATTERY VALUE CHAIN IN SOUTH AFRICA



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EXECUTIVE SUMMARY

The world of mobility is rapidly changing. The market for electric vehicles (EVs), in all their forms, is growing exponentially. Combined with technological disruptions in the energy space, the rise of EVs puts battery technologies at the core of sustainable development. Multiple technologies and chemistries, with their respective advantages and shortcomings, are competing in a market currently dominated by lithium-ion batteries (LIBs).

Both South Africa's government and industry have indicated their intention to position the local value chain as a key player in the mobility of the future. This is critical to ensure a just transition to e-mobility which would notably preserve, if not increase, job creation. Indeed, South Africa hosts a vibrant automotive manufacturing value chain. Like in the rest of the world, the domestic industry, however, produces internal combustion engine vehicles and components. This raises the question of the positioning South Africa in the value chain.

Global dynamics

While economies of scale and improvements in battery technologies have led to battery prices falling dramatically over the past decade, batteries still make up between 40% and 50% of the total cost of an EV. Battery cells typically account for 70% of the total value of the battery pack, and cell costs are roughly composed of 50% raw materials and 50% manufacturing.

A LIB is formed from the assembly of modules connecting battery cells to management systems. Cells consists largely of four components: a cathode that determines capacity and the average voltage of a battery; an anode; an electrolyte solution; and a separator which determines the safety of a battery. There are six types of LIB chemistries. The most prominent chemistries for EVs are lithium nickel cobalt aluminium (NCA), lithium nickel manganese cobalt (NMC), lithium manganese oxide (LMO), lithium iron phosphate (LFP) and lithium titanate (LTO).

China is the dominant player in manufacturing LIBs, with three-quarters of production capacity. Panasonic and Contemporary Amperex Technology (CATL) are the leading manufacturers of LIBs, while the cell manufacturing market is dominated by LG Chem, BYD Auto and Panasonic. Similarly, the supply of cathodes, anodes, separators, electrolytes and electrolyte salts is concentrated in a few countries (China, Japan, South Korea, United States) and a limited number of firms. Correspondingly, looking at patents related to climate change mitigation in transport and LIBs in particular, the landscape is heavily dominated by a few countries (US, Japan, Germany, South Korea, France, China and the United Kingdom).

South African R&D capabilities

South Africa has committed to developing a LIB value chain, notably to feed into the automotive and energy storage sectors. As part of South Africa's Energy Storage Research, Development and Innovation Programme, a consortium was established in 2011 to work on developing the LIB value chain. Spearheaded by the Department of Science and Innovation, the consortium works on the whole value chain, from precursor and material development, to cell and battery manufacturing, to testing and validation, to recycling. It is composed of the Council for Scientific and Industrial Research, the University of Western Cape, the University of Limpopo, the University of the Witwatersrand, the Nuclear Energy Council of South Africa, the Nelson Mandela University, and Mintek.

The consortium, while limited in scale, has demonstrated the existence of domestic pockets of excellence. The initial ambition was to develop South African intellectual property (IP) and position the country at the cutting edge of research and development (R&D) in the space. While all institutions still pursue this mandate, the inability to compete with leading countries has led to a shift in function. The primary function of the consortium is effectively to build skills and expertise in the country.

South African mining and beneficiation capabilities

A wide array of minerals are used in the production of LIBs, including lithium, cobalt, manganese, nickel, graphite, bauxite, copper, iron, phosphate rock and titanium. South Africa is well endowed in such minerals (manganese, cobalt, iron ore, nickel, titanium). In the case of manganese, the country even benefits from a quasi-monopolistic position. The country also boasts longstanding experience and expertise in mineral beneficiation. However, to date, there is little beneficiation of minerals to battery grade in the country. Only manganese and aluminium are refined to battery grade at present, while nickel and lithium are in the pipeline.

Beyond South Africa, the African continent has incomparable reserves and mining capacity in key minerals supporting the LIB value chain. Bauxite (Guinea), copper (Democratic Republic of the Congo – DRC, Zambia), cobalt (the DRC, Madagascar, South Africa), graphite (Mozambique, Tanzania, Madagascar), iron ore (South Africa), lithium (Zimbabwe), manganese (South Africa, Gabon), nickel (South Africa, Zimbabwe, Botswana), phosphate rock (Morocco, Algeria, South Africa, Egypt) and titanium (South Africa, Mozambique, Madagascar) are widely available on the continent. However, Africa remains an extractive economy, as most minerals are refined and processed outside the continent. This opens for the door for regional integration. Importantly though, LIB costs depend less on raw material costs than on production volumes, putting the emphasis of economies of scale.

South African manufacturing capabilities

There is currently no commercial production of battery cells in South Africa and, despite some projects in development, it remains to be proven whether such an activity would be competitive domestically. Battery manufacturing based on imported cells is, however, a vibrant industry in the country. Numerous firms, in collaboration with academia, have developed IP and expertise in the manufacturing of specific components, parts and systems (most notably battery management systems) as well as the assembly of battery packs. In some cases, companies have further leveraged this expertise to develop additional offerings, such as specialised vehicles. A number of companies are also involved in marketing second-life batteries on the local (and regional) market.

At the end of life, there is currently no facility in South Africa in a position to effectively recycling LIB. Batteries are currently stockpiled and/or shipped to available facilities around the globe. All hazardous e-waste, including LIBs, will, however, be banned from being landfilled from August 2021. In line with the regulations on Extended Producer Responsibility (EPR), an effective waste management scheme for LIBs should be established in 2021-2022, including a pilot recycling facility.

Policy implications for the lithium-ion battery value chain in South Africa

Looking ahead, a number of key policy implications arise:

- First, the policy priorities should be to identify where in the entire LIB value chain South African industries are (or could be) competitive. Mining is a comparative advantage for the country. Battery manufacturing as well as mineral refining emerge as competitive areas. Others stages of the value chain (cell manufacturing, recycling) remain to be proven viable.
- Second, key components of an enabling policy framework should be formulated. Sending clear, positive signals in favour of the development of the industry would contribute to attracting

investments. Access to funding, particularly for commercialisation, remains a key hindering factor, along with testing and certification, and the provision of warranty.

- Third, accessing markets, both domestically and globally, is a challenge for firms operating in the LIB value chain from South Africa. On the domestic front, the lack of demand is a critical factor hindering development. Access to global markets is, moreover, extremely competitive and requires niche expertise. In the short term, a dual strategy aimed at growing local demand as well as local manufacturing (primarily on the back of global demand) would be required.
- Last, access to a pool of skilled and experienced people is a critical condition for the development of the innovation-heavy LIB value chain in South Africa. While access to skills has not been a key constraint to date, South Africa is far behind leading countries in LIB-related R&D and skills development. More resources are required to develop skills and IP in niches in which South Africa displays a competitive advantage.

Weighing options going forward

Four avenues emerge as possible pathways to support the development of the LIB value chain in South Africa. These are fostering: 1) mineral refining; 2) cell manufacturing; 3) battery manufacturing and assembly; and 4) battery recycling. Importantly, such options are not mutually exclusive but are rather complementary in nature. However, the viability of these pathways largely differs in the short term. Similarly, industrial development associated with these options is at different levels of maturity in the country. Indeed, only two pathways, namely developing battery manufacturing and mineral refining, are ready for scale-up. The other two avenues, i.e. developing commercially-viable cell manufacturing and recycling, are yet to be proven viable in the South African context.

First, fostering the growth of battery manufacturing (i.e. battery pack manufacturing) is the most viable option in the short to medium term. Programmes aimed at nurturing existing companies (for expansion, particularly to global markets) as well as assisting the emergence of new, additional businesses would be necessary:

- Financial assistance would go a long way in facilitating access to finance (particularly for commercialisation). This could be complemented by leveraging international development finance, innovative funding instruments, private finance and business development services;
- The domestic capacity to test and certify battery packs would need to be materially enhanced;
- An increased focus on R&D and skills development, in partnership with the Energy Storage Consortium, would contribute to improve access to human and intellectual capital. Making the existing R&D tax incentive more easily accessible for small, medium and micro enterprises (SMMEs) would also accelerate the development of innovative firms; and
- Improving the ease of doing business for SMMEs would strongly enhance their development and growth. This would range from reducing bottlenecks and hindering factors disproportionally impacting small businesses to improving the ecosystem of business facilitation services. Consideration could also be given to setting up local content requirements for the public procurement of LIBs.

A second avenue to enhance the involvement of South Africa's industry in the LIB value chain is to develop the beneficiation of local minerals to battery grade. South Africa can leverage its expertise and existing value chains to develop battery-grade products.

This hinges on a set of measures:

- Access to modern infrastructure would be required, particularly reliable, affordable and clean energy and transport services;
- Investment support could be enhanced through both financial (such as development finance) and non-financial assistance (such as special economic zones and industrial parks). This could also extend to R&D and skills development support; and
- A mineral beneficiation policy could be enacted to further improve the competitiveness of the industry. A bottom-up approach, through an export tax or a development pricing policy, would represent the most viable option. A top-down approach, though the Automotive Production and Development Programme (APDP) and localisation requirements, would also be supportive.

A third avenue to expand the LIB value chain in South Africa is to explore the possibility of building cell manufacturing capacity domestically. Effectively, it remains to be proven whether a South Africa-based company could be competitive on this market segment. Attracting investors to set a giga-factory in South Africa would require to confirm the business case. On the supply side, this would call for a partnership with an existing manufacturer and a leading research institution, as well as favourable investment conditions. On the demand side, a sizeable market, which remains to materialise, would need to be serviced from such a giga-factory.

A fourth avenue to consider in the development of South Africa's LIB value chain is battery recycling.

South Africa does not at present have such a recycling facility. While the country has expertise in mineral processing and recovery, the economic viability of a possible plant is unknown at this point. The ongoing process of establishing an EPR scheme for batteries sold in the country could provide the impetus for the establishment of a recycling facility in the medium term.

Conclusion

Looking ahead, the possibility of developing the domestic LIB value chain should not be overestimated: South Africa displays key pockets of excellence but not all activities in the value chain are likely viable domestically. At the same time, the importance of developing the LIB value chain should not be underestimated: an established LIB industry is instrumental in the local development of both the (renewable) energy and (electric) transport industries. In fact, provided the emphasis is put on the country's evidenced strengths, rather than unsubstantiated aspirations, an electrifying opportunity lies ahead for South Africa. Eureka?

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ACRONYMS AND ABBREVIATIONS

AfCFTA	African Continental Free Trade Area
APDP	Automotive Production Development Programme
BEV	Battery Electric Vehicle
BESS	Battery Energy Storage Systems
BMS	Battery Management System
BNEF	Bloomberg New Energy Finance
CATL	Contemporary Amperex Technology
CHIETA	Chemical Industries Education and Training Authority
COMESA	Common Market for Eastern and Southern Africa
CPUT	Cape Peninsula University of Technology
CSIR	Council for Scientific and Industrial Research
DEFF	Department of Environment, Forestry and Fisheries
DoT	Department of Transport
DRC	Democratic Republic of Congo
DSI	Department of Science and Innovation
DST	Department of Science & Technology
dtic (the)	Department of Trade, Industry and Competition
EAC	East African Community
EMD	Electrolytic Manganese Dioxide
EMM	Electrolytic Manganese Metal
EMS	Energy Management Systems
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric vehicle
FCEV	Fuel Cell Electric Vehicle
eWASA	e-Waste Association of South Africa
EWSETA	Energy & Water Sector Education Training Authority
GHG	Greenhouse gas
GW	Gigawatt
GWh	Gigawatt hours
HEV	Hybrid Electric Vehicle
iESS	intelligent Energy Storage System
IP	Intellectual Property
ICE	Internal Combustion Engine
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IDC	Industrial Development Corporation
IFC	International Finance Corporation
IoT	Internet of Things
IPP	Independent Power Producer
IRP	Integrated Resource Plan
ISO	International Organisation for Standardisation
ITC	Information and Communications Technology
kg	Kilogram
kt	Kiloton
kWh	Kilowatt-Hour
LCO	Lithium Cobalt Oxide
LFP	Lithium Iron Phosphate
LIB	Lithium-ion Battery
$LiPF_6$	Lithium Hexafluorophosphate

LMO	Lithium Manganese Dioxide
LTO	Lithium Titanate
MerSETA	Manufacturing, Engineering and Related Services Sector Education and Training Authority
MFN	Most Favoured Nation
MSM	Manganese Sulphate Monohydrate
MMC	Manganese Metal Company
MW	Megawatts
MWh	Megawatt-hour
MVA	Manufacturing Value Added
NAAMSA	National Association of Automobile Manufacturers of South Africa
NCA	Nickel Cobalt Aluminium Oxide
NECSA	Nuclear Energy Council of South Africa
NERSA	National Energy Regulator of South Africa
NMC	Nickel Manganese Cobalt
NMU	Nelson Mandela University
NTB	Non-tariff barrier
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicle
PGM	Platinum Group Metal
PRO	Producer Responsibility Organisation
PV	Photovoltaic
R&D	Research and Development
RBM	Richards Bay Minerals
RIDMP	Regional Infrastructure Development Master Plan
RDI	Research, Development and Innovation
SADC	Southern African Development Community
SANAS	South African National Accreditation System
SANEDI	South African National Energy Development Institute
SEDA	Small Enterprise Development Agency
SEFA	Small Enterprise Finance Agency
SETA	Services Sector Education and Training Authority
SEZ	Special Economic Zone
SMMEs	Small, Medium and Micro Enterprises
t	Tonne
TIPS	Trade & Industrial Policy Strategies
UET	UniEnergy Technologies
UK	United Kingdom
UL	University of Limpopo
UNIDO	United Nations Industrial Development Organisation
US	United States
USGS	United States Geological Survey
UWC	University of Western Cape
V	Volt
VRFB	Vanadium Redox Flow Battery
WTO	World Trade Organization
Wh	Watt-hours
Wits	University of the Witwatersrand

1. INTRODUCTION

The world of mobility is rapidly changing. The market for electric vehicles (EVs), in all their forms, is growing exponentially. Combined with technological disruptions in the energy space, the rise of EVs puts battery technologies at the core of sustainable development.

Electric batteries date back to 1800 and the first electrochemical battery by Alessandro Volta. Since then, the technology has dramatically evolved to power a large range of electrical products. The use of rechargeable batteries in the automotive sector is also not new. Rechargeable batteries have been used to support the ignition of internal combustion engine (ICE) vehicles, as well as auxiliary functions since the 1920s. The first electric cars were produced around the 1880s. Progress in developing ICE, however, relegated batteries to a subaltern role in the automotive industry for more than a century.

More recently, growing concerns around the impacts of the air pollution and greenhouse gas (GHG) emissions generated by ICE vehicles have propelled efforts to improve the environmental performance of vehicles. Despite notable improvements of the ICE, rechargeable batteries, along with fuel cells, have emerged as the only avenue to design vehicles with zero tailpipe emissions. Decarbonising transport is at the core of the transition to sustainable development, particularly to combat climate change. Globally, transportation accounted for 18% of GHG emissions in 2016, with the lion’s share coming from passenger cars.

After a period of maturation, decreasing production costs and supportive policy frameworks have set EVs on an exponential growth trajectory. As the demand for EVs grows, so is the demand for batteries. Both full-electric vehicles, also known as Battery Electric Vehicles (BEVs), and Plug-in Hybrid Electric Vehicles (PHEVs), rely on battery technology for their propulsion and operation. Among other developments (in the energy and Information and Communications Technology (ITC) sectors notably), this has put once again the spotlight on batteries.

As such, material improvements have already been achieved in the development of batteries. The technological development of battery remains, moreover, far from mature. Batteries are still becoming more powerful, more durable in time, smaller in size, safer to operate and cheaper to produce, without the technological frontier being yet in sight.

Such trends are, however, highly disruptive and reshuffling the cards in the automotive value chains. Traditional automotive manufacturers, which have dominated the sector for centuries, are being forced to rethink their business models and technological development. New players are also emerging, coming as well from the ICT and mining value chains, with the aim of disrupting the status quo in the automotive sector. Much emphasis is put on the battery technology. Multiple technologies and chemistries, all with their respective advantages and shortcomings, are currently competing in a market currently dominated by the lithium-ion battery (LIB). New technologies, such as solid-state batteries, are also on the horizon. Like the engine, the battery accounts for the lion’s share of production costs and is the key to competitiveness in the sector.

South Africa hosts a vibrant automotive manufacturing value chain. As in the rest of the world, the domestic industry, however, produces ICE vehicles and components. Both government and the industry have indicated their intention to position the local value chain as a key player in the mobility of the future. This is critical to ensure a just transition to e-mobility, which would notably preserve (if not increase) job creation in the value chain. A key component of this strategy is the development of capabilities in the EV battery value chain. This raises the question of the positioning of the country in the value chain. Well-endowed with the minerals required for the production of batteries, does South Africa and other African countries have the potential to build on their natural resources to support mining and beneficiation? Leveraging on the existing automotive value chain, can the country develop new capabilities relevant in the battery value chain? Should the country focus on specific segments of the value chain or work to build a complete value chain domestically?

This report contributes to answering these questions. Effectively, it builds on a previous study[1] conducted by TIPS on behalf the dtic and the National Association of Automobile Manufacturers of South Africa (NAAMSA) (Montmasson-Clair et al., 2020), which explored policy options to develop the EV value chain in South Africa, both from a market and industrial development perspective, but focuses on the development of the battery value chain.

Given the domination of LIBs in the market to date, the report focuses on this technology. Section 2 reviews global developments in the LIB field. Section 3 discusses South African capabilities in the LIB value chain. Section 4 discusses policy implications while Section 5 reviews the possible options for the development of the local industry in the value chain, including costs and benefits. Section 6 concludes.

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[1] The study is available on the TIPS website: Harnessing electric vehicles for industrial development in South Africa.

2. GLOBAL DYNAMICS IN LITHIUM-ION BATTERY

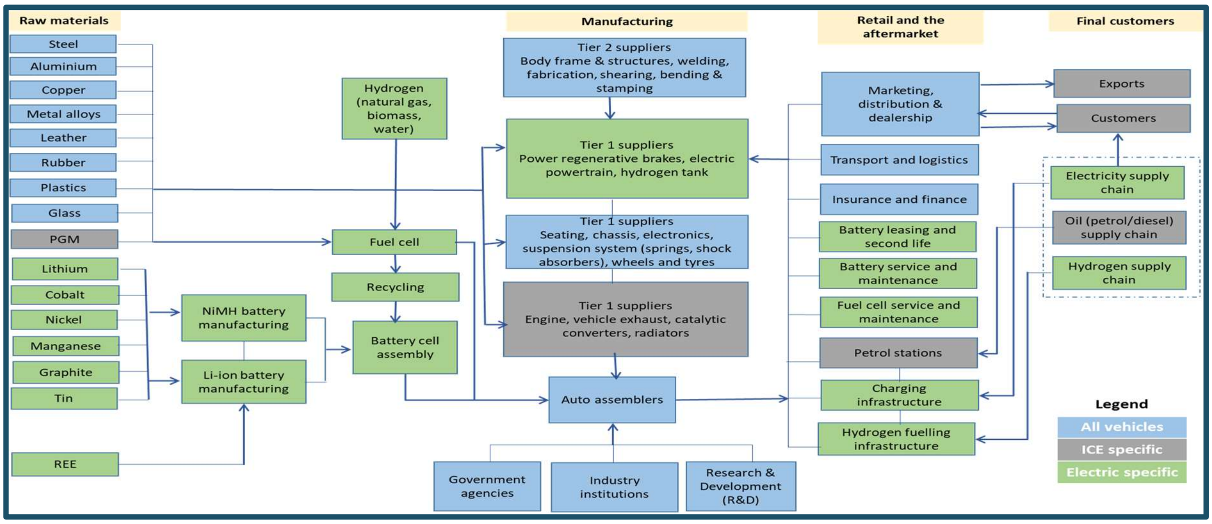
This section discusses key global dynamics related to LIBs. After an introduction of the entire EV value chain, the LIB value chain is discussed, highlighting the variety of LIB chemistries. The interplay between various LIBs and the use in EVs is then unpacked. Last, global dynamics around the production of LIB, including manufacturing capacity and patents, are reviewed.

2.1. The automotive value chains – electric vs combustion

LIBs are a predominant part of the EV value chain. Figure 1 compares the automotive value chains based on ICE and electric drivetrains. In the value chain, LIBs constitute one of the major differences (with the electric drivetrain) with the value chain of ICE vehicles.

Overall, the production of electric motors, batteries, wiring harnesses and inverters will be positively impacted by the shift to EVs. By contrast, ICE-specific components, such as engine parts, radiators and catalytic converters, will be hindered. Importantly, while full-electric vehicles, i.e. BEVs and Fuel Cell Electrician Vehicles (FCEVs), run solely on a battery or fuel cell, Hybrid Electric Vehicles (HEVs) have both an ICE and a battery. Furthermore, PHEVs use the battery as the primary energy sources, while HEVs (known also as mild hybrids) only utilised the battery to improve the efficiency of the ICE.

Figure 1: The automotive value chain: EV and ICE vehicles



Source : Montmasson-Clair et al., 2020

2.2. The lithium-ion value chain – multiple chemistries

The use of LIBs has grown significantly in recent years. LIBs offer distinct advantages and improvements over other battery technologies. They have higher energy density, a longer cycle life, and can charge and discharge faster than other alternatives. They can deliver large amounts of current for high-power applications (such as power tools and EVs), require less maintenance, and can be mass-produced leveraging existing technology. While other storage solutions exist commercially, such as lead-acid batteries, nickel-metal hydride batteries and vanadium redox flow batteries (VRFBs), none of the alternatives have the versatility of a LIB (Commonwealth of Australia, 2018). Furthermore, drawbacks of the LIB, such as safety[2] and cost, are being rapidly

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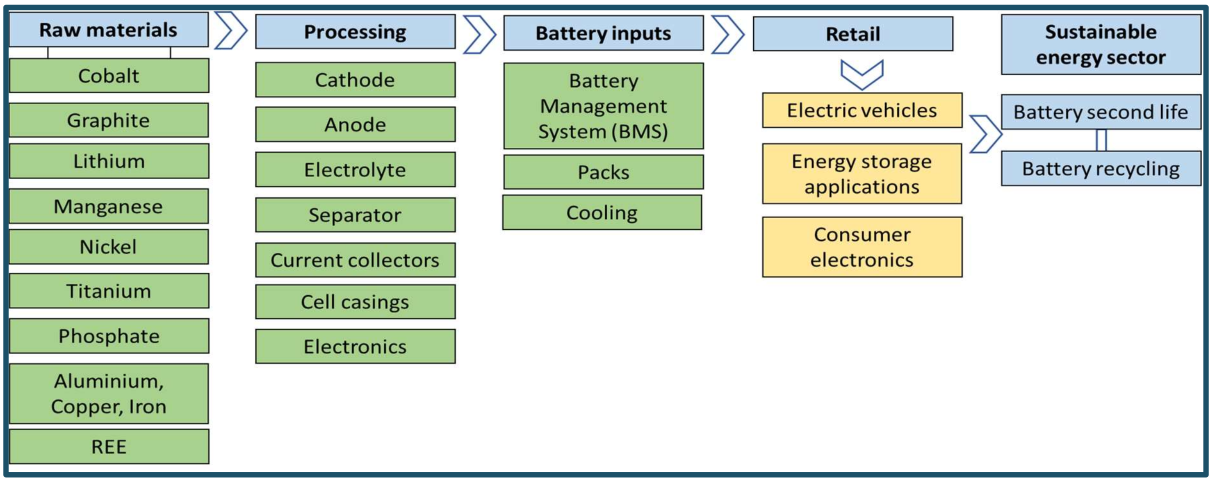
[2] LIBs are sensitive to high temperatures and require a protection circuit to maintain safety by limiting peak voltage, and also prevent cell voltage from dropping too low on discharge (Battery University, 2020b).

addressed as the overall technology improves. Figure 2 depicts the LIB value chain, highlighting the main components and raw materials featuring in the manufacturing of a battery.

Figure 2: The lithium-ion battery value chain



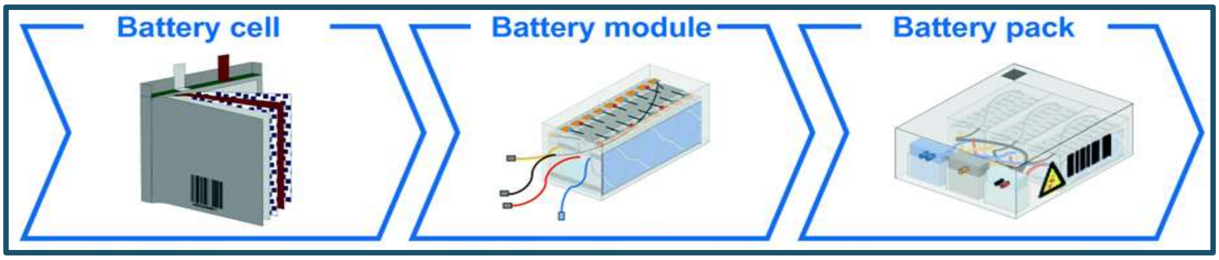
Source: Authors

A LIB or battery pack is formed from the assembly of modules connecting battery cells to management systems monitoring and controlling temperature. LIB cells consists largely of four components:

- A cathode (positive electrode) that determines capacity and the average voltage of a battery;
- An anode (negative electrode);
- An electrolyte solution; and
- A separator which determines the safety of a battery and prevents the battery from short-circuiting and overheating[3] (Commonwealth of Australia, 2018).

LIB components are then processed into cylindrical, prismatic or a pouch shape and encased in a shell, aluminium or plastic casing (Weber, 2019; Pettinger et al., 2018). In addition, a LIB cell also contains cell casings, electronics and other cell components. LIB production facilities typically manufacture battery cells and modules, while others are also involved in the design and assembly of the battery pack. The battery cells are assembled into a module (usually 12 cells per module) containing electronic management components. The LIB pack is then built from multiple battery modules integrated into a metal or carbon-fibre enclosure (Weber, 2019). In addition, key components in a battery pack include the battery management system (BMS), cooling systems, fuses and a pre-charge circuit, safety vents and a current interrupt device. Figure 3 shows the battery pack manufacturing process from cell production to module and pack assembly.

Figure 3: Lithium-ion cell and battery manufacturing



Source: Pettinger et al., 2018

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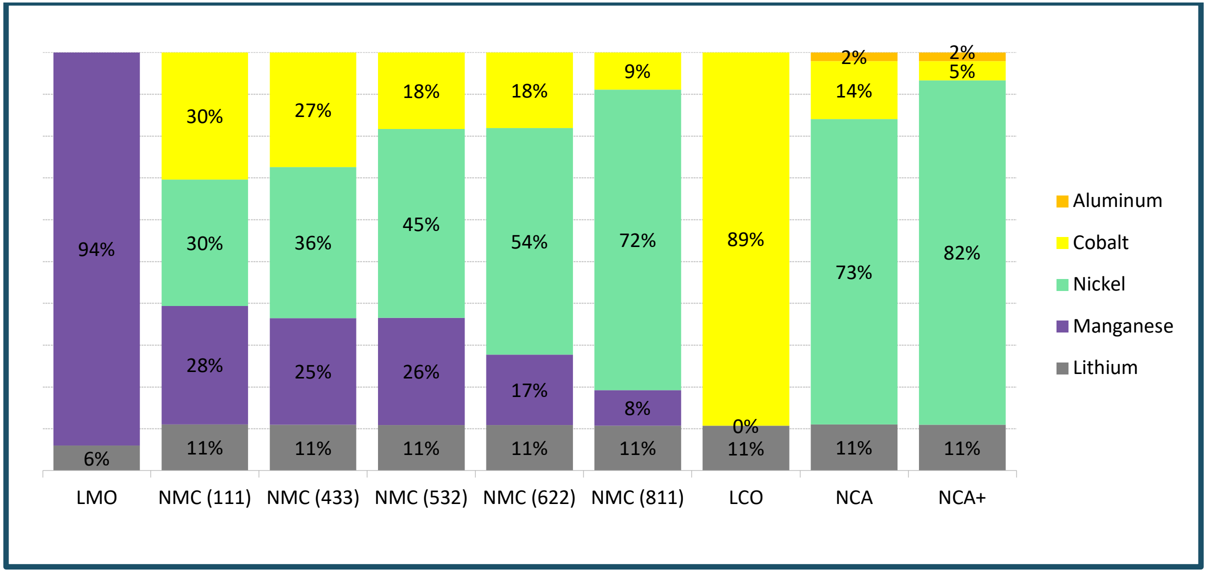
[3] Commercialised separators are synthetic resin (plastic), such as polyethylene and polypropylene.

The cathode is made from a lithium-based compound using mixed metal oxides and phosphates, while the anode is commonly made from graphite, a form of carbon coated in copper foil. The composition of the electrolyte[4] varies from one type of battery to another. Aluminium foil is used as the current collector for the cathode electrode across each of the LIB chemistry applications.

In a lithium-ion cell, the cathode represents approximately 25% of battery costs and is essential for determining battery performance. Building a better cathode is therefore a key driver for advancing lithium-ion technology. Most cathodes for LIBs use combinations of phosphates and metal ions, such as lithium, cobalt, manganese, nickel, aluminium, titanium and iron. Each battery type has considerably different properties. The type of cathode chosen for a LIB can affect the energy density, power density, safety, cycle life, and cost of the overall battery.

There are six types of LIB chemistries. The most prominent chemistries for vehicle batteries are lithium nickel cobalt aluminium (NCA), lithium nickel manganese cobalt (NMC), lithium manganese oxide (LMO), lithium iron phosphate (LFP) and lithium titanate (LTO) (Coffin and Horowitz, 2018). Lithium cobalt oxide (LCO) batteries are not used in vehicles because they are more expensive than other LIBs and not as safe. Figure 4 details the metal content of various cathode chemistries, highlighted the key role of lithium, manganese, nickel, cobalt and aluminium. As such, this paper considers all LIB cathode chemistries, excluding LCO.

Figure 4: Metal content of lithium-ion battery cathodes, by weight



Source: Bloomberg New Energy Finance (BNEF), 2020, Dataset on 2018 Lithium-ion Battery Price Survey

Applications of LIBs in EVs need to ensure that batteries are safe and have high energy and power density, in addition to a high cycle life, fast discharge-charge rate and lower cost. As detailed in Table 1, competing LIB technologies can be compared across four aspects: specific energy, voltage, thermal runaway/safety and cycle life. Economically, battery cost is one of the major barriers because a high price impedes the commercial scalability and widespread adoption of EVs.

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[4] LIBs generally use gel electrolyte composed of electrolyte with an added gel precursor. Materials used for making electrolyte salts are lithium hexafluorophosphate ($LiPF_6$), lithium perchlorate (LiClO4), and lithium hexafluoroarsenate (LiAsF6) mixed in an organic solvent.

Table 1: Lithium-ion battery chemistries

CATHODE CHEMISTRY	ANODE	SPECIFIC ENERGY DENSITY (WH/KG[5])	VOLTAGES (V[6])	DANGER OF THERMAL RUNAWAY[7] AND FIRE (I.E. SAFETY)	TOXIC ELEMENTS	CYCLE LIFE[8]	MAIN APPLICATIONS	COMMENTS
LITHIUM IRON PHOSPHATE LFP (LIFEPO$_4$)	Graphite	90-125	3.4	No	No	2000-3000 cycles	EVs and stationary applications	LFP is known for its stability, safety and improved discharge compared to other cathode chemistries. The addition of iron in a LFP battery improves safety and reduces heat output, meaning that LFP batteries do not require the same level of cooling as NMC batteries. LFP cathodes tend to have a longer cycle life than most other LIBs. In addition, LFP batteries are often the most cost-effective option as well when their long cycle life is taken into consideration. However, the lower voltage of the LFP battery means that it has less energy than other types of LIBs. EV application example: Tesla Model 3.
LITHIUM NICKEL MANGANESE COBALT OXIDE NMC (LINIMNCOO$_2$)	Graphite	150-220	3.7	Yes	Yes	1000-2000 cycles	EVs, medical devices and stationary applications	NMC batteries have a relatively high-energy density when compared to other LIB chemistries. Additionally, the presence of cobalt makes NMC batteries safe and reduces the risk of thermal runaway. Compared to other chemistries, production costs for NMC batteries are relatively low.

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[5] A battery's specific energy is closely related to its total capacity – it is a measure of the amount of electricity in watt-hours (Wh) contained in a battery relative to its weight in kilograms (kg).

[6] Higher cell voltages in LIBs are desirable as they increase battery capacity, however, they can also compromise safety leading to a reaction that damages cell components resulting in reduced cycle life or a fire outbreak.

[7] In thermal runaway, batteries initiate an unstoppable chemical reaction causing battery cell temperature to rise, causing a fire to erupt.

[8] The reported cycle life is the cycle life of the individual cathode, and not of the whole battery cell with the anode and cathode combined. The cycle life is number of charge-discharge cycles that a battery can go through while it retains 80% or more of its initial capacity.

								EV application example: BMW i3, Audi e-tron, Hyundai Kona, Jaguar i-Pace, Chevrolet Bolt.
LITHIUM COBALT OXIDE LCO ($LICOO_2$)	Graphite	150-200	3.0	Yes	Yes	500-1000 cycles	Mobile phones, laptops and cameras	LCO cathodes are limited by low thermal stability (which reduces its safety) and high cost. These cathodes are not used in EV batteries because they are more expensive than and not as safe as other LIB options.
LITHIUM MANGANESE OXIDE LMO ($LIMN_2O_4$)	Graphite	100-150	3.8	Yes	Yes	500-1000 cycles	Power tools, medical devices and EVs	LMO generally have higher power than other cathodes but have a shorter lifespan. LMO batteries are known for their increased thermal stability (resulting from the absence of cobalt) and their ability to charge relatively quickly. As such, LMO batteries are commonly found in medical devices and power tools. EV application example: Nissan Leaf first-generation.
LITHIUM TITANATE OXIDE LTO ($LI_4TI_5O_{12}$)	Lithium titanate	50-80	2.4	No	No		Solar street lighting, storing wind and solar energy, EVs	LTO batteries are very safe, high performing, and long-lasting, however their high upfront cost has prevented them from mass commercialisation. The main advantage of the LTO battery is its fast recharge time, due to its advanced nanotechnology. However, these cathodes have lower voltage, or lower energy density than other LIB chemistries, which can present issues with powering vehicles efficiently. EV application example: Mitsubishi i-MiEV.
LITHIUM NICKEL COBALT ALUMINIUM OXIDE NCA ($LINICOALO_2$)	Graphite	155-260	3.6	Yes	Yes	500 cycles	EVs and stationary applications	NCA is similar to NMC chemistries. The NCA composition is more expensive and less safe, which makes it less attractive to the wider EV market. It has high capacity, high voltage, and well-established performance, which makes it a promising alternative cathode material in LIBs, but they are not as safe and can be quite costly. EV application example: Tesla Model S.

Source: Commonwealth of Australia, 2018; Barrera, 2020; Battery University, 2020a; BNEF, 2020, Dataset on Electric Vehicle Outlook 2020 – Data

2.3. Lithium-ion batteries and electric vehicles

NMC, NCA, LFP and LMO battery technologies have been successfully adopted by the automotive industry for BEVs and PHEVs. These cathodes have become the most prominent battery chemistries for EVs owing to their good structural stability, abundant resources and relative low cost, therefore showing large application potential for EVs. With the ever-increasing demand of EVs, the production volume of the major four battery cathode technologies has correspondingly increased. Each has its own advantages and disadvantages; however, given that these are relatively mature battery technologies, they should remain dominant in the EV market for the foreseeable future.

According to GreenCape (2019), NMC cathodes currently account for about 28% of global EV sales, which is expected to grow to 53% by 2027. The most commercially viable battery chemistry is the NMC, blended with graphite and tin to improve the specific energy of the battery pack and prolong its life (Coffin and Horowitz, 2018). An increasing number of automotive producers use the NMC chemistry due to its high energy density, low internal resistance, high reliability and therefore relatively long distances per charge in BEVs and PHEVs (Darton Commodities, 2016).

NMC batteries can be differentiated according to the share of NMC in their structure. Current NMC cathodes employ mixed ratios of 60% nickel, 20% manganese and 20% cobalt (6:2:2) and of 50% nickel, 30% manganese and 20% cobalt (5:3:2). However, there is significant rise of NMC 8:1:1 in the Chinese market, a mix requiring less cobalt and more nickel, which is easier and cheaper to source. NMC 8:1:1 is, however, less stable and safe (reducing cobalt content compromises the electrochemical performance of the battery), therefore NMC 6:2:2 and NMC 5:3:2 are still dominant in the EV industry, despite concerns relating to the price and sustainable sourcing of cobalt.

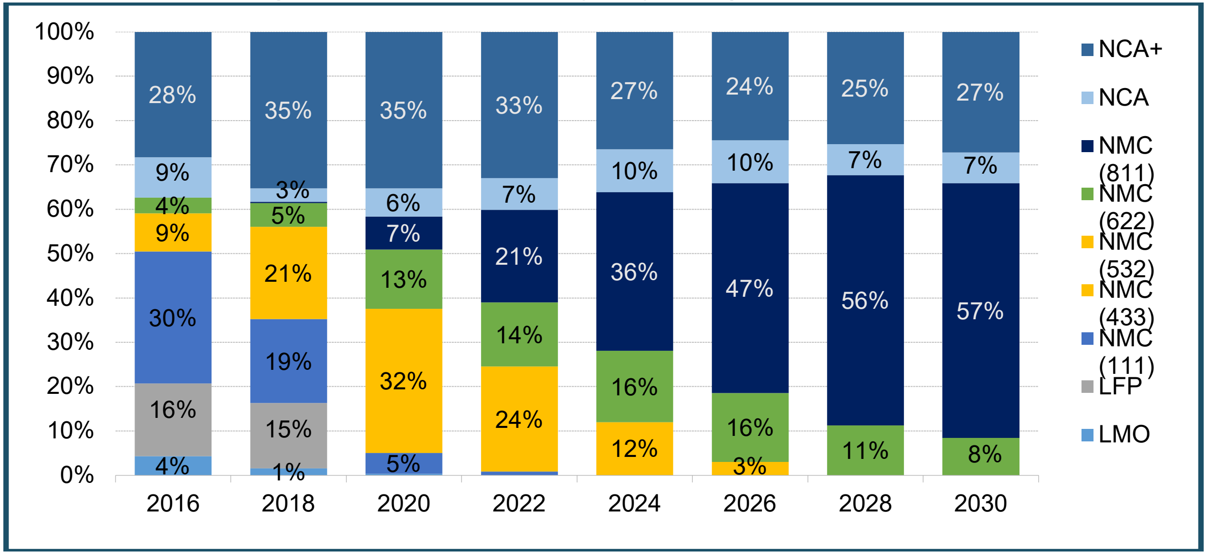
The first generation of the Nissan Leaf, BMW i3 and Chevy Volt had a LMO battery technology with a NMC blend. This combination is said to improve the specific energy capacity and life span required for EV application (Ding et al., 2019). The LMO in the LMO/NMC battery generally constitutes 30%, and "provides high current boost on acceleration while the remaining NMC gives the long driving range" (Ding et al., 2019).

NCA and LFP technologies are mainly used by Tesla (Model X, Model S, Model 3). The NCA battery used to power the Tesla Model S in 2012 had only 15% of cobalt content. Panasonic and Tesla achieved the lowest EV battery pack costs of US$110/kWh through its reduction of cobalt content in NCA cathodes. Since June 2020, Tesla has been exploring the use of LFP batteries in its Model 3 vehicles. LFP batteries are not typically used in EVs because of their low-energy density, a disadvantage the Tesla batteries are expected to face as well. However, LFP batteries have the advantage of being extremely safe, and cheaper to produce as they do not use cobalt, which is expensive and highly controversial (Lambert, 2020). LFP batteries are also widely used in energy storage and industrial applications.

LTO batteries, replacing the graphite anode, are widely accepted as one of the best batteries for the future of LIBs in EV applications. The main advantages of the LTO batteries are their high level of safety and quick-charge capabilities. The LTO battery is used in the Mitsubishi i-MiEV and the Honda Fit. The batteries are also used in the TOSA concept electric bus developed in Geneva, Switzerland.

Figure 5Figure 5 highlights the spilt between cathode chemistries as well as BNEF's forecast to 2030, clearly depicting the expected growth in the NMC 8:1:1 chemistry.

Figure 5: Cathode chemistry for passenger electric vehicles



Source: BNEF, 2020, Dataset on Electric Vehicle Outlook 2020 – Data

2.4. Global trends in lithium-ion battery production

Figure 6 and Figure 7 show the cost breakdown of a LIB pack with a NMC cathode. The battery cell accounts for the largest share in a lithium-ion battery pack cost, while components represent the second-largest cost item. Manufacturing, logistics and marketing account for the smaller shares. Other major cost components for LIB cells are material (supply and logistics), labour, depreciation and R&D.

Figure 6: Cost breakdown a 100 kWh NMC LIB pack

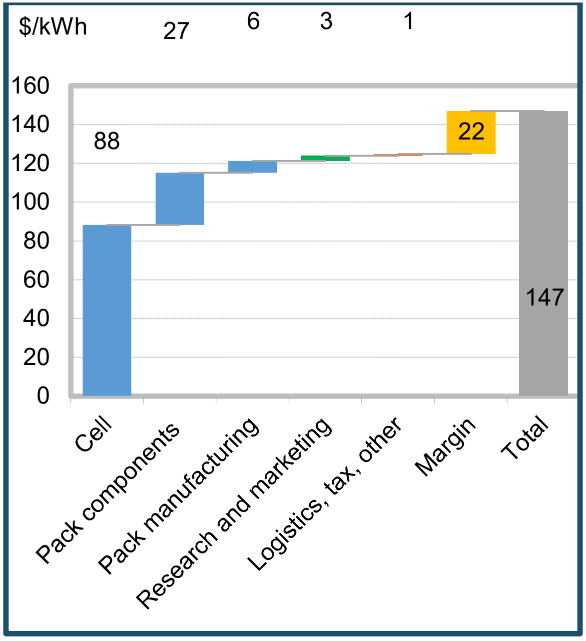
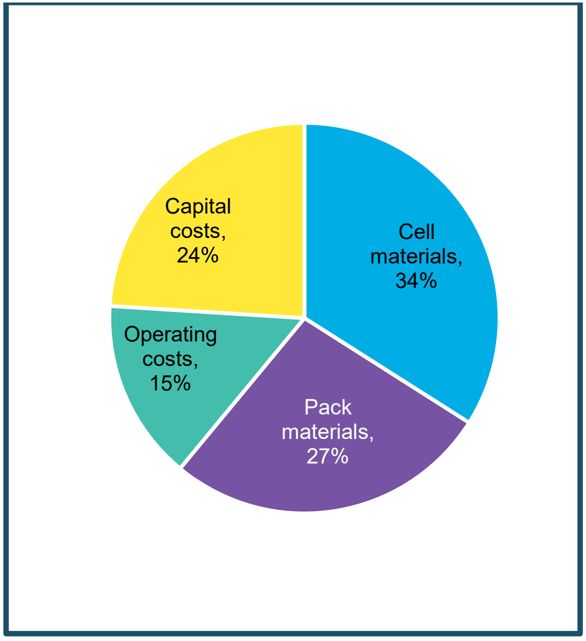


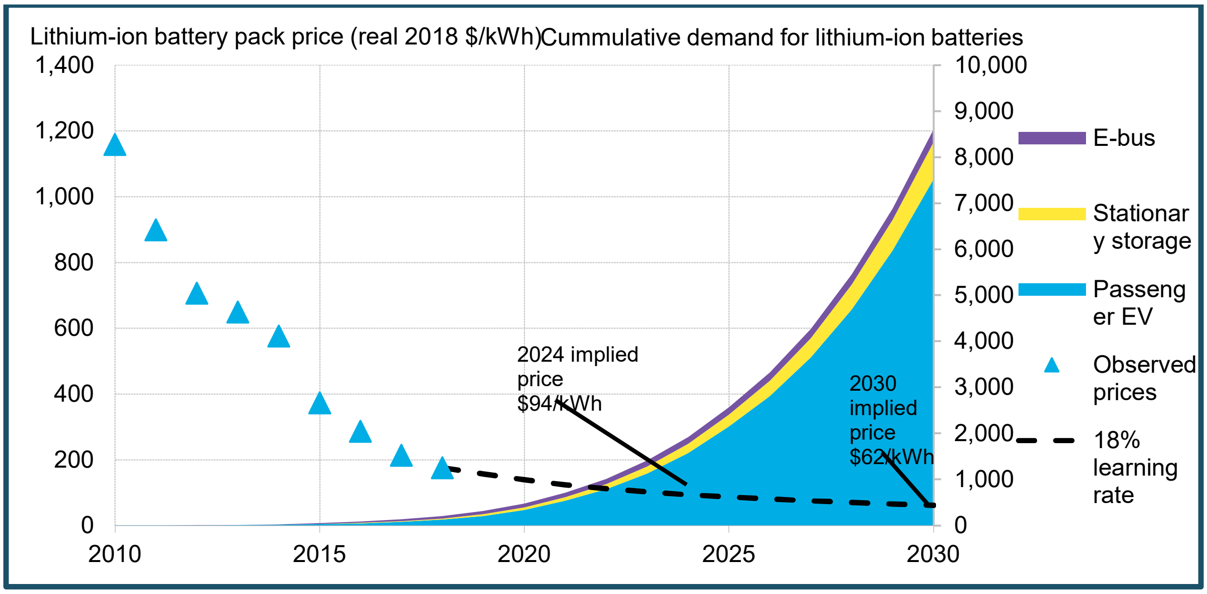
Figure 7: Cost breakdown of a lithium-ion battery pack



Source: BNEF, 2018, Dataset on 2018 Lithium-ion Battery Price Survey

Currently, batteries make up between 40% and 50% of the total cost of an EV. Economies of scale and improvements in battery technologies have seen battery prices fall by more than 70% since 2010 (see Figure 8). A battery cell represents the large majority of a LIB pack cost. Battery cells typically account for 70% of the total value of the battery pack, and cell costs are roughly composed of 50% raw materials and 50% manufacturing (BNEF, 2019).

Figure 8: Lithium-ion battery price and demand outlook

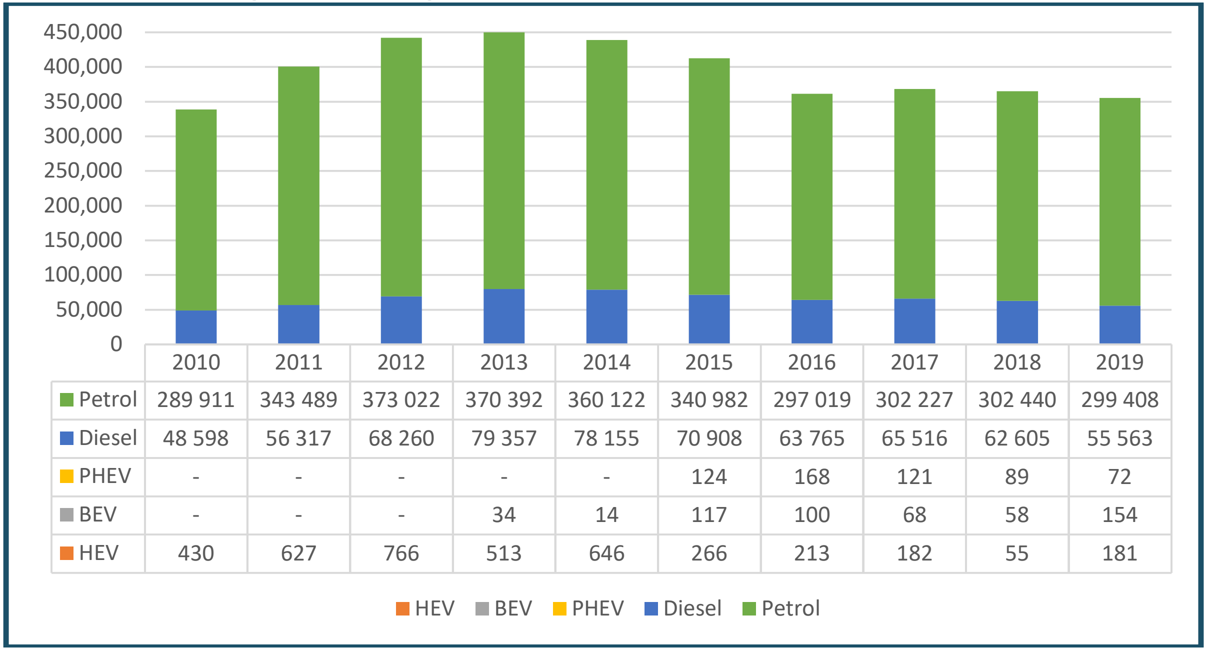


Source: BNEF, 2018, Dataset on 2018 Lithium-ion Battery Price Survey

LIB manufacturers and original equipment manufacturers (OEMs) around the world are investing in "giga-factories" with huge capacities, anticipating growth in LIB demand for application in EVs, e-buses and e-trucks. LIB prices are forecasted to decline to US$131/kWh by 2020 and below US$100/kWh by 2025 (Figure 8). The electrification of commercial vehicles and stationary storage is expected to become increasingly attractive by 2030.

The forecast in demand is due mostly to the rapid expansion of EVs, from about 2% of global market share in 2018, to 25%-35% by 2030 (BNEF, 2020). In South Africa, the sales of EVs remains extremely marginal with 6 043 EVs sold over the 2010-2019 period, corresponding to less than 0.1% of new car sales in the country (see Figure 9). A significant growth potential is therefore discernible on the local market (Montmasson-Clair et al., 2020).

Figure 9: Passenger car sales in South Africa from 2010 to 2019



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
🟩 Petrol	289 911	343 489	373 022	370 392	360 122	340 982	297 019	302 227	302 440	299 408
🟦 Diesel	48 598	56 317	68 260	79 357	78 155	70 908	63 765	65 516	62 605	55 563
🟨 PHEV	-	-	-	-	-	124	168	121	89	72
⬜ BEV	-	-	-	34	14	117	100	68	58	154
🟧 HEV	430	627	766	513	646	266	213	182	55	181

Source: Montmasson-Clair et al., 2020, based on data from Lightstone Auto

Importantly, LIB costs depend much less on raw material costs than on the production volume of the batteries, hence steadily improving economies of scale for LIB production would lead to expected cost reductions. Continued cost declines for LIB pack prices could also be achieved through reduced manufacturing capital expenditures, new pack designs and changing supply chains. Low battery prices remain the most critical goal to lowering the high cost of EVs.

Figure 10 shows the sensitivity of a LIB battery (NMC 8:1:1) to lithium, nickel, cobalt and manganese prices. The sensitivity of the LIB price to commodity prices is shown to be quite low. For example, a 50% increase in lithium prices would increase the price of a LIB battery pack by less than 5% (see Figure 10). Manganese price sensitivity is by far the lowest compared to other raw material inputs. At a price of US$2 694 per metric ton, any increase in the price of manganese would have a negligible impact on the battery pack. For nickel, doubling its prices would result in an increase of over 8% in the overall price of the battery pack. Despite this low price sensitivity, forecasted increases in the demand and prices of LIB materials would favour African mining and beneficiation prospects. This would provide strong underpinning to consider strengthening regional value chains in the mining industry, as discussed in Box 3.

Figure 10: NMC 8:1:1 battery pack price sensitivity

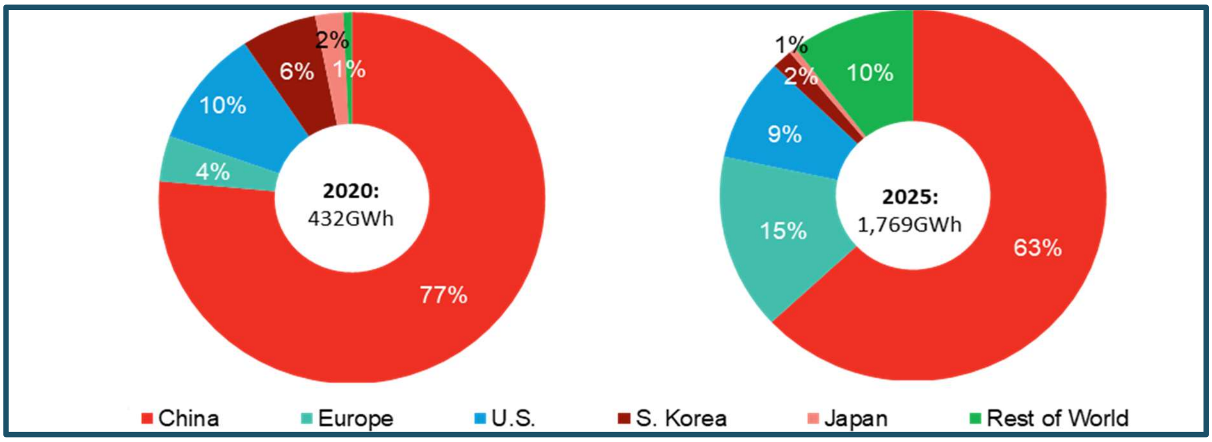
Source: BNEF, 2018, Dataset on 2018 Lithium-ion Battery Price Survey

2.5. Global manufacturing dynamics

China is a dominant player in manufacturing LIBs, with a 77% global share of production capacity in 2020 (Figure 11). BNEF (2020) forecasts that, by 2025, China’s manufacturing capacity would be in excess of 1 100 GWh (63%). China’s leading EV battery manufacturers, BYD and CATL, have plans to exponentially increase their battery production to boost capacity. These two Chinese firms are aiming to become leading automotive battery suppliers worldwide.

According to InsideEVs (Kane, 2019), China, along with Japan, the US and South Korea, accounted for 97% of total LIB production. Nevertheless, BNEF’s projections imply material opportunities for LIB manufacturers outside of these leading countries. According to BNEF, by 2023, Europe, Middle East and Africa would collectively account for almost 228 GWh of lithium-ion cell manufacturing capacity per year, compared to the 345 GWh accounted for by the Asia-Pacific region (excluding China).

Figure 11: Global manufacturing capacity of lithium-ion batteries



Source: BNEF, 2020, Dataset on Electric Vehicle Outlook 2020 – Data

Panasonic was the leading manufacturer of LIBs in 2019 with a market share of 26% (Table 2). CATL was the second largest LIB producer with a share of 23%, primarily suppling LIBs to BMW, Volkswagen and Daimler. LG Chem and BYD are ranked in third and fourth place, respectively. Both companies have announced plans to increase their production capacity for LIBs by 2020.

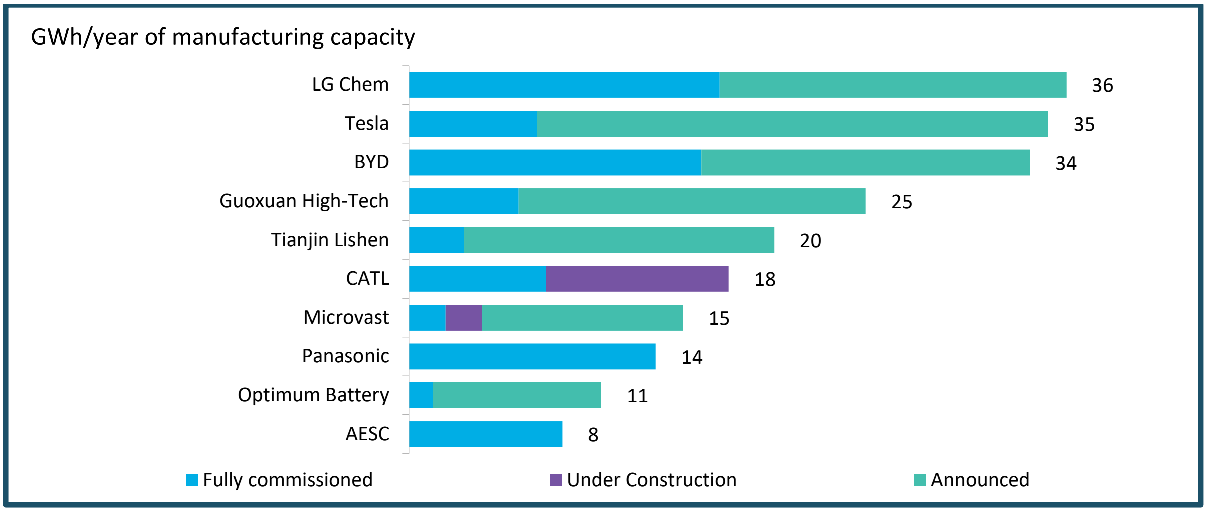
Table 2: Global market share for passenger EV lithium-ion batteries in 2019

COMPANY	MARKET SHARE
Panasonic	26%
CATL	23%
LG Chem	12%
BYD	9%
Samsung SDI	8%
AESC	4%
SK Innovation	1%
Other	18%

Source: BNEF, 2020, Dataset on Electric Vehicle Outlook 2020 – Data

In terms of lithium-ion cell manufacturers, the market was in 2019 dominated by LG Chem, BYD and Panasonic. As shown in Figure 12, most leading manufacturers are moreover currently expanding their production capacity.

Figure 12: Top 10 lithium-ion cell manufacturers globally (in GWh/year)



Source: BNEF, 2020, Dataset on Electric Vehicle Outlook 2020 – Data

Figure 13 to Figure 22 provide a more disaggregated view of the market for key LIB components, namely the cathode, the anode, the separator, the electrolyte and the electrolyte salt. They highlight the various degrees of concentration of the various markets. Cathode manufacturing is fairly disaggregated with the top 10 firms hosting about half (48%) of the plant capacity. Most of the productive capacity is, however, concentrated in China (53%), Japan (29%) and South Korea (12%). Anode manufacturing is much more concentrated. The top 10 firms accounted for 86% of manufacturing capacity in 2016. Again, China (75%), Japan (22%) and South Korea (3%) controlled the market. The separator market displayed a similar pattern, with the top 10 firms representing 72% of global manufacturing capacity. China (39%), Japan (34%), South Korea (19%) and the US (9%) hosted the plants. The electrolyte and electrolyte salt production capacity was located in China (68%), Japan (14%), South Korea (10%) and the US (8%). At a firm level, production was fairly concentrated for electrolyte solutions (top 10 firms accounting for 69% of productive capacity) and very concentrated for electrolyte salt (95% of manufacturing capacity in the hands of top 10 firms).

Figure 13: Cathode manufacturers in 2016 (in tonnes/year; fully commissioned capacity)

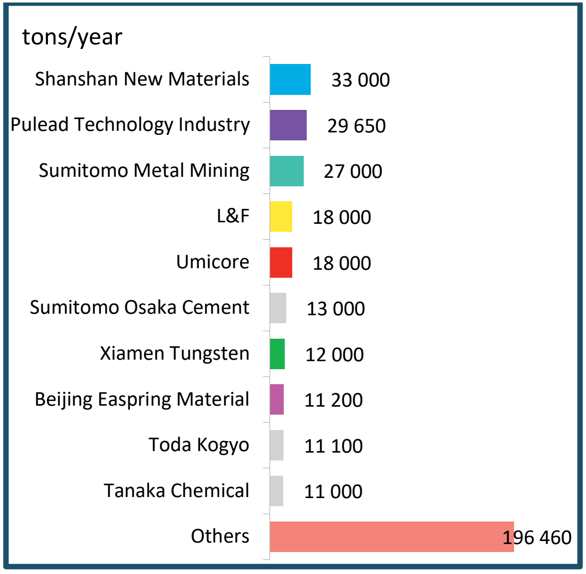


Figure 14: Cathode suppliers in 2016 (in tonnes/year)

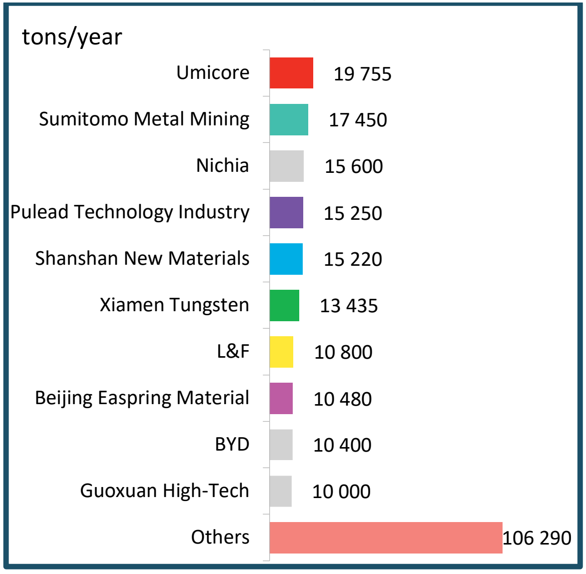


Figure 15: Anode manufacturers in 2016 (in tonnes/year; fully commissioned capacity)

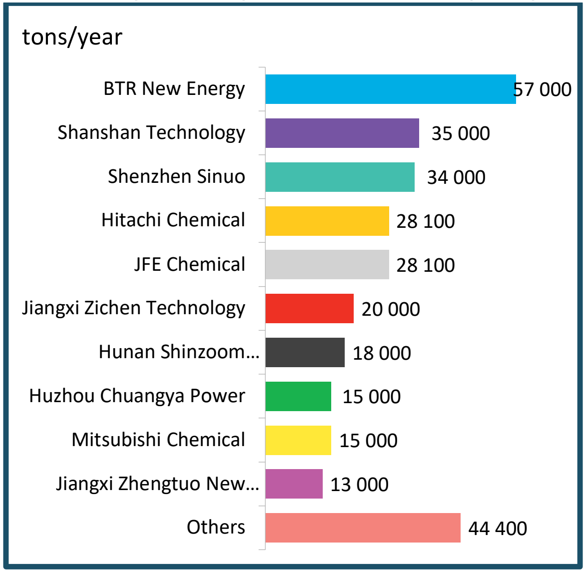


Figure 16: Anode suppliers in 2016 (in tonnes/year)

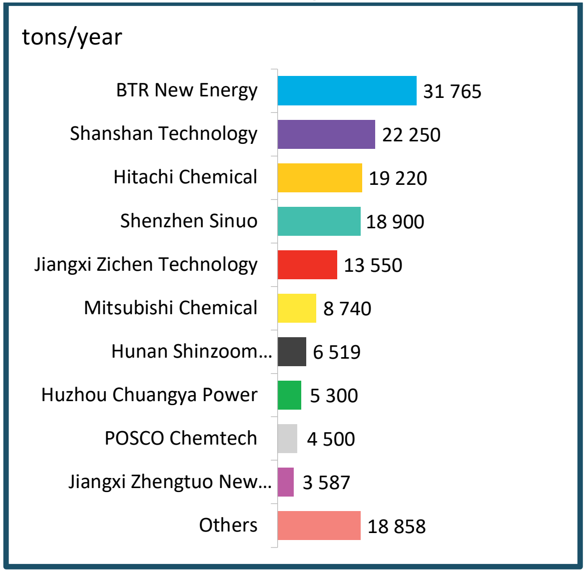


Figure 17: Separator manufacturers in 2016 (in million m^2/year; fully commissioned capacity)

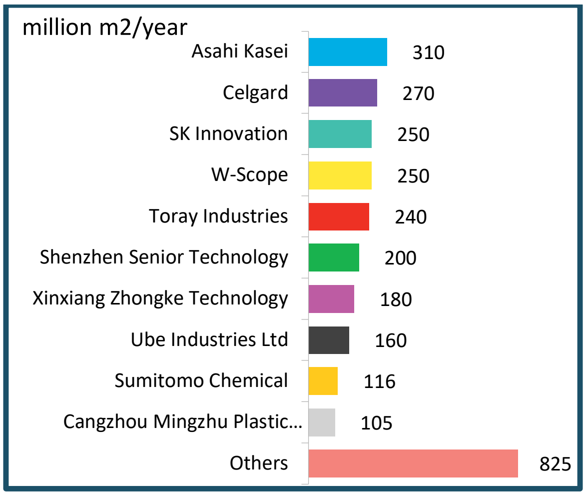


Figure 18: Separator suppliers in 2016 (in million m^2/year)

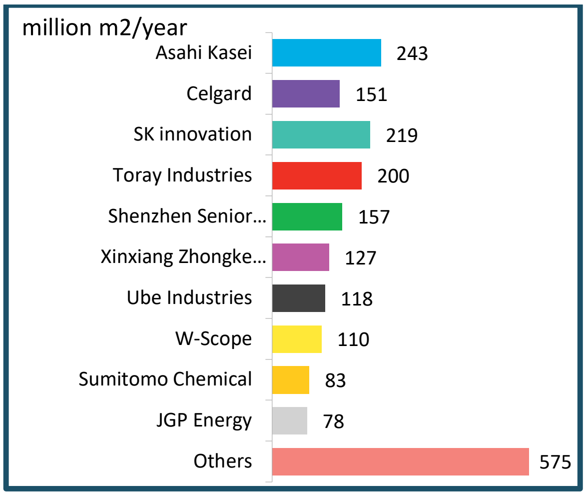


Figure 19: Electrolyte solution manufacturers in 2016 (in tonnes/year; fully commissioned capacity)

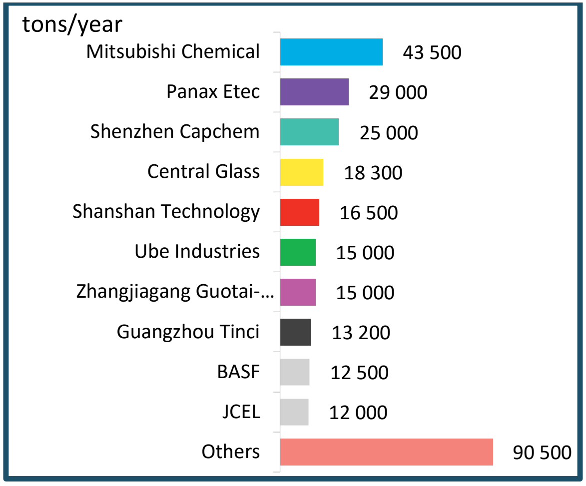


Figure 20: Electrolyte solution suppliers in 2016 (in tonnes/year)

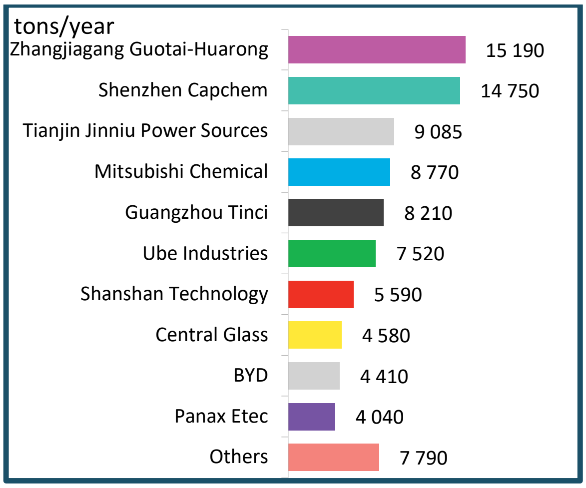


Figure 21: Electrolyte salt manufacturers in 2016 (in tonnes/year; fully commissioned capacity)

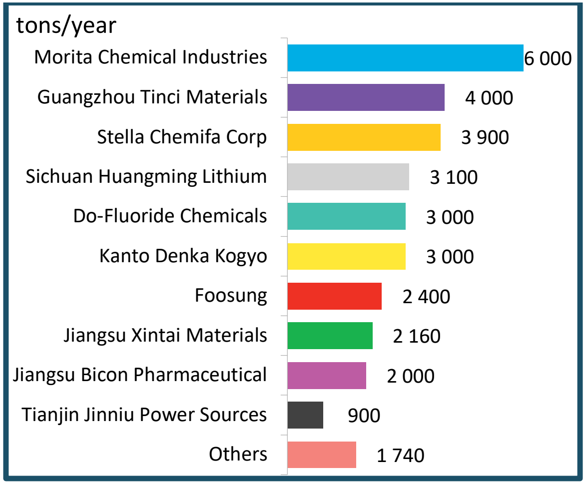
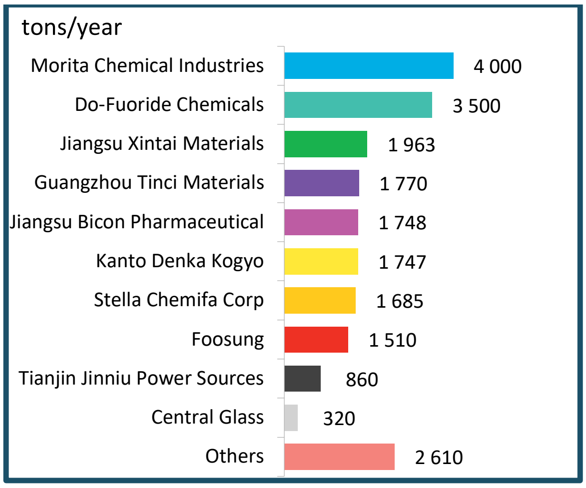


Figure 22: Electrolyte salt suppliers in 2016 (in tonnes/year)



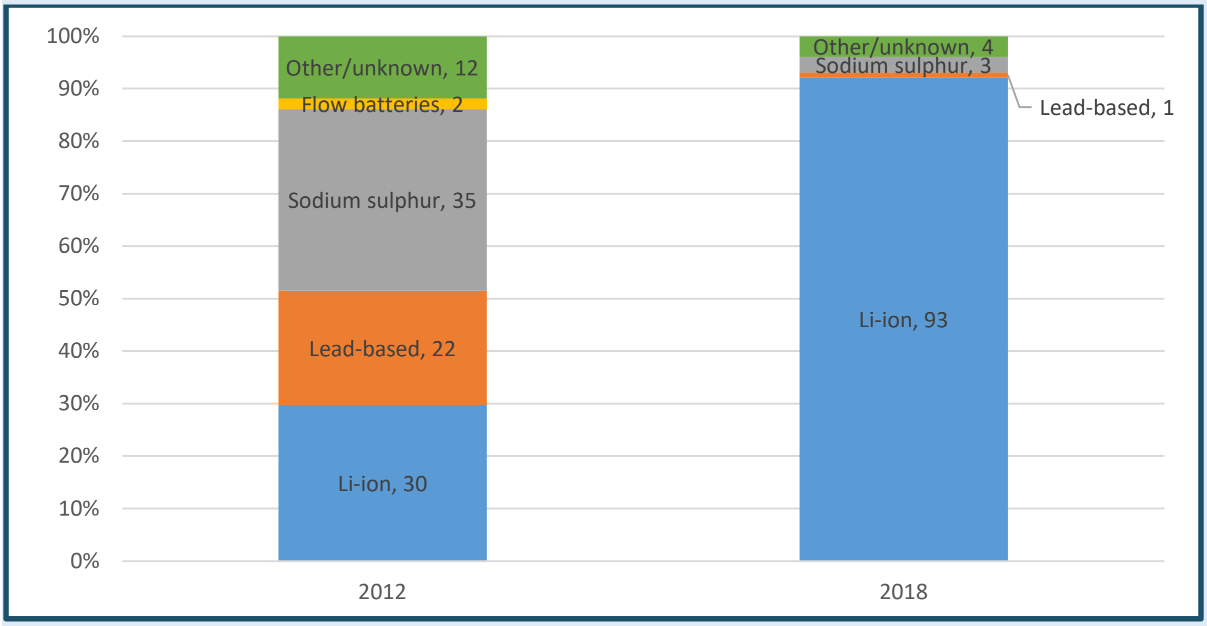
Source: BNEF, 2017, Dataset on Battery Components: Capacity, Shipment and Supply Chain

Box 1: Global dynamics in lithium-ion batteries for storage

Global Battery Energy Storage Systems (BESS), like EVs, are dominated by LIBs. This is primarily due to the high energy density and the steady decrease in LIB prices. LIB technology in energy storage has, however, grown at a slower rate than e-mobility applications. Global total storage capacity is approximately 200 GWh (IEA, 2020).

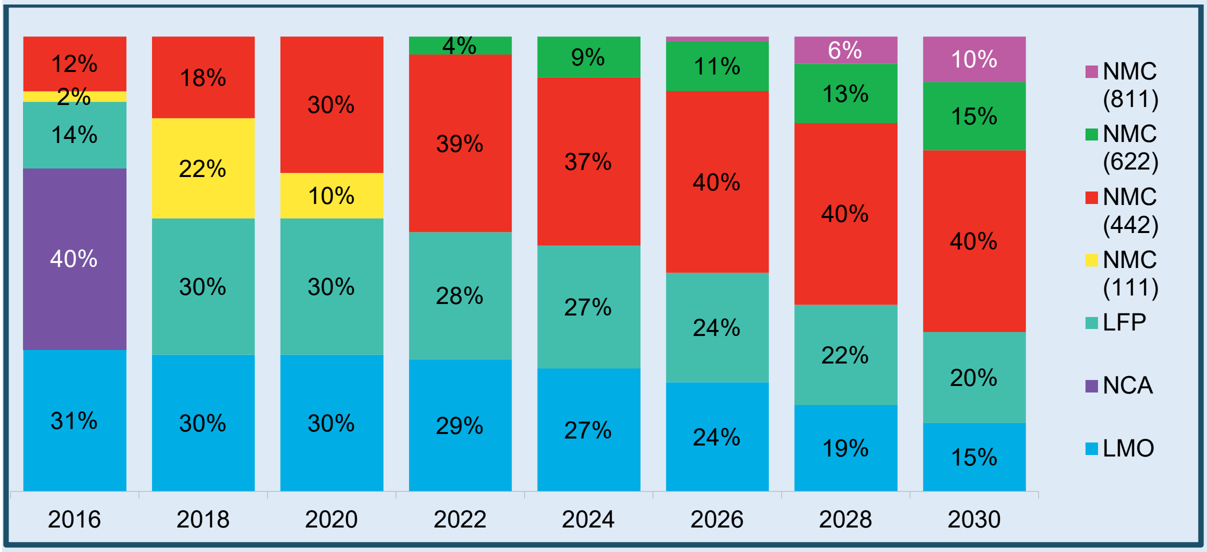
To date, 90% of the global energy storage capacity is attributable to pumped storage hydropower, while batteries account for less than 3%. Batteries in energy storage are, however, expected to increase exponentially. Of the 3% battery storage capacity, lithium-ion technology is the dominant battery. LIBs have increased exponentially and are currently being installed at a rate on par with all other storage technologies combined, as shown in Figure 23. LIBs account for over 90% of new energy storage installations, the remaining batteries account for less than 10% (IEA, 2020). Figure 24 details the breakdown between chemistries.

Figure 23: Energy storage technology mix excluding pumped hydropower storage, 2012-2018



Source: Authors, adapted from IEA, 2020

Figure 24: Mix of cathode chemistries 2016-2030, for stationary storage applications



Source: BNEF, 2020, Dataset on Electric Vehicle Outlook 2020 – Data

The battery energy storage market is concentrated in Asia, Europe and the US. Key players include:

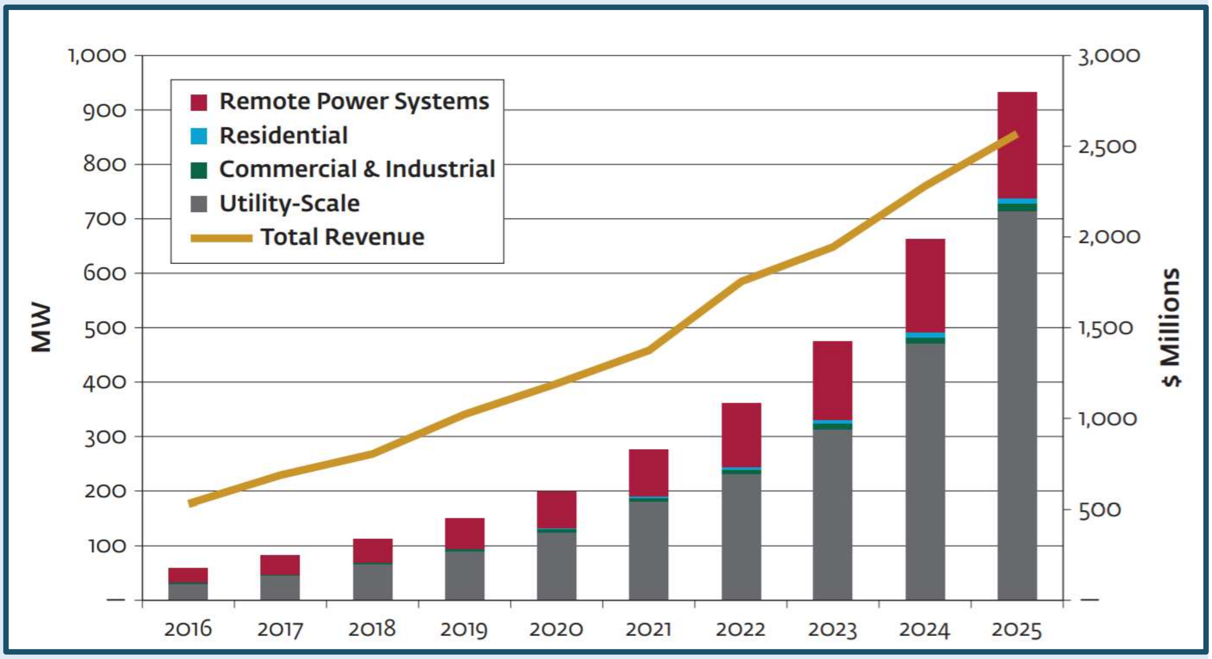
- Japanese companies: Panasonic, NEC Corporation, Toshiba and Hitachi;
- Chinese companies: TrinaBESS and BYD;
- South Korean companies: Samsung SDI and LG Chem;
- US companies: General Electric, Tesla, Trimus Power, Johnson Controls and AES Corporation;
- European firms: ABB (Switzerland), Siemens AG (Germany) and AEG Power Solutions (Netherlands);
- And a few others: Delta Electronics (Taiwan).

Business Wire projects that the global market size for battery energy storage system will grow at a compound annual growth rate of 32.8% from 2020 to 2025, rising from US$ 2.9 billion in 2020 to US$ 12.1 billion in 2025. The projection is based on further declining LIB prices and the efforts of the private sector to further improve the performance of LIB for stationary usages (Business Wire, 2020).

Large-scale battery storage is projected to grow in Africa due to growing climate change mitigation policies, Africa's underdeveloped power distribution, and the fall in renewable energy prices. In 2017, the International Finance Corporation (IFC) estimated that the energy storage market for Africa would reach US$4 billion-US$5 billion by 2025 and that over 70% of the forecasted storage projects would be from utility-scale opportunities (IFC, 2017).

As shown in Figure 25, in the Sub-Saharan African region, the IFC estimated in 2017 that over 900 MW storage capacity would be deployed by 2025 and that about 70% would be from remote power systems as the region has an underdeveloped grid connectivity. The majority of remote power systems would include energy storage technology as prices fall and would rely heavily on renewable energy technologies. The IFC forecast that South Africa would be the largest market in the region (IFC, 2017).

Figure 25: Projected annual stationary energy storage deployments, power capacity and revenue by market segment in Sub-Saharan Africa



Source: IFC, 2017

Looking at the battery energy storage market in South Africa, the 2019 Integrated Resource Plan (IRP) for Electricity provisions for an increased rollout of renewable energy-based generation, along with 2 GW of new energy storage capacity by 2030.

This notably follows from a 2010 loan agreement between Eskom, the World Bank and other funders with the aim “to enhance power supply and energy security in an efficient and sustainable manner” (World Bank, 2010). As part of the funding conditions, Eskom was required to facilitate the development of large-scale, renewable-based energy capacity in support of South Africa’s long-term strategy to undertake mitigation actions to reduce GHG emissions. The IRP notes that one of Eskom’s roles is to pilot an energy storage-technology programme based on batteries.

2018 saw the launch of Eskom’s tender for 1.4 GWh of BESS. The programme follows a technology-agnostic approach that can include solid-state and flow-battery systems. The BESS programme is being implemented in two phases, with the initial phase starting with 800 MWh capacity of distributed battery storage by December 2020. Phase 1 will see the implementation of BESSs at multiple sites in various units built in close proximity to the existing grid to facilitate the integration of renewable energy into the national grid (Eskom, 2018; Chutel, 2018; Scotto and Fontana, 2019). Phase 2 of the programme includes 640 MWh capacity of distributed battery storage, in addition to 60 MW of solar photovoltaic (PV) due for completion by December 2021.

The tender expects a minimum 20% of local content requirement in the first phase of procurement. This includes subcontracting to local suppliers and the inclusion of skill development programmes for local workers (Scotto and Fontana, 2019).

2.6. Global dynamics in intellectual property rights/patents

The number of patents filed is an important measure that can be used to determine the international competitiveness in LIB manufacturing. Patents and licensing agreements are increasing due to the growing number of companies operating in LIBs, particularly focused on NMC technology. LIB-related patent filings have increased significantly in the past decade. The LIB patent landscape is dominated by companies developing battery technology and companies using batteries within different applications, such as automotive, electronic devices and storage applications.

According to Nanowerk (Kuyate and Patel, 2011), in 2015, 60% of patent applications were filed for raw materials used in LIBs, while a further 26% of the patents included research on materials and the manufacturing of LIBs. For example, Panasonic, formerly Matsushita Electric Industrial Co, focused its activities mainly on expanding its production capacity in LIBs whereas BASF, BYD and Hon Hai Precision have focused on pursuing R&D activity to develop LIBs.

Most R&D activities in LIB technology has been taking place in Japan, South Korea and the US. The first patents for NMC battery technology were filed in the late 1990s by Japanese and Korean companies, including Sony, Samsung, Mitsubishi Chemical and LG Chem. Since then, patent publications have increased, owing to intense patenting activity in LIBs by Japanese, US, Chinese and Korean battery and material manufacturers, and the emergence of EV manufacturers including Nissan, Toyota and BMW (Element Energy, 2012).

Looking at patents related to climate change mitigation in the transport sector (Figure 26), the landscape is heavily dominated by a few countries, namely the US, Japan, Germany, South Korea, France, China and the United Kingdom (UK). Focusing on patents related to the propulsion of electrically-propelled vehicles (Figure 27), Japan, Germany, the US and South Korea overshadows all other countries. For patents related to processes or means for the direct conversion of chemical energy into electrical energy (Figure 28), Japan and South Korea clearly dominate, followed by the US, Germany and China. For the conversion of electric current, Japan, the US, China and Germany are in the lead (Figure 29). Overall, the domination of Japan remains strong in the field, although South Korea, Germany, the US and China are playing an increasing role.

Figure 26: Patents related to climate change mitigation in the transport sector

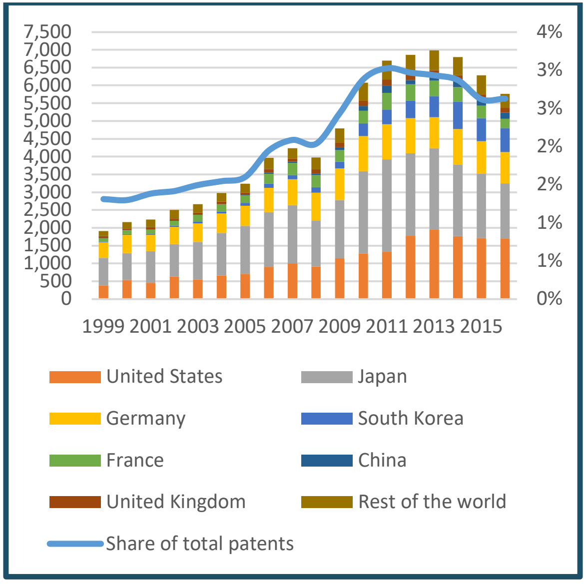


Figure 27: Patents related to the propulsion of electrically-propelled vehicles (B60L)

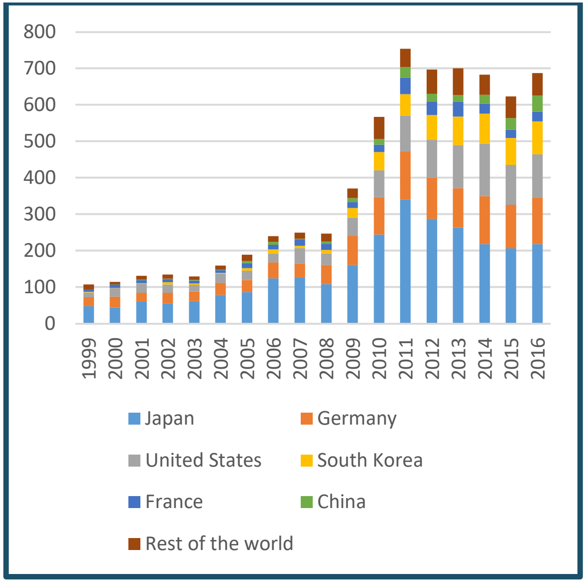


Figure 28: Patent related to processes or means for the direct conversion of chemical energy into electrical energy (H01M)

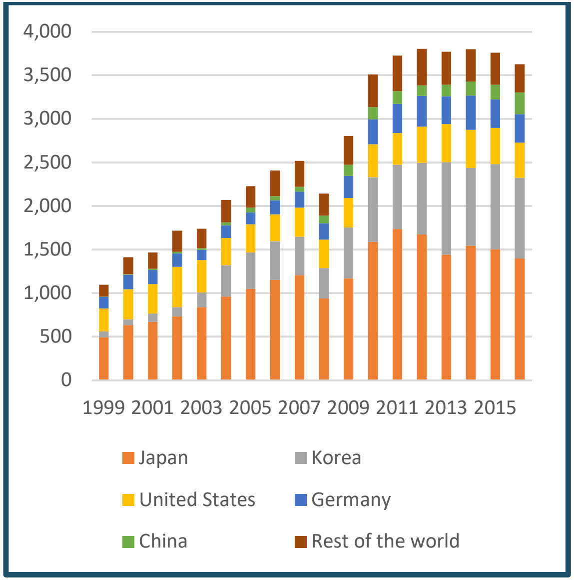
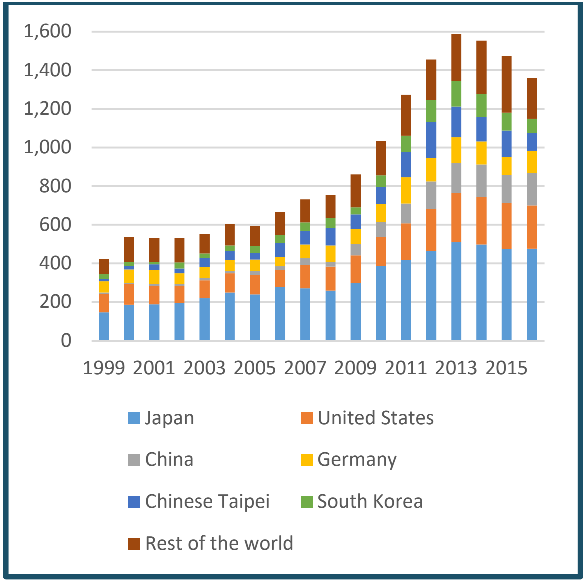


Figure 29: Patent related to apparatus for the conversion between AC and AC, AC and DC, DC and DC and for use with mains or similar power supply systems (H02M)



Source: Authors, based on data from the OECD, Series on IP5 Patent Families, based on applicant(s)'s country(ies) of residence and Priority Date, downloaded from https://stats.oecd.org in July 2020

Further analysis shows that South Korea, once the global leading producer of LIB patents, lost its market leadership to China in 2017 (Kyung-eun and Kim, 2020; Rauscher, 2019).

China has made fast ascension as a worldwide leader in patent grants, based on data from the World Intellectual Property Organisation. China has invested heavily in LIBs to groom the power for EVs, smartphones and energy storage systems as future mainstay growth for the economy.

Box 2: Dynamics around vanadium-based batteries

Although LIBs currently dominate the market for mobility and energy storage applications, alternatives exists. In South Africa, the development of VRFBs has particularly attracted attention in recent years.

This battery technology recharges using an electrolyte exchange consisting primarily of water and chemical additive acids, such as sulphuric acid or hydrochloric acid (Bushveld Energy, 2018). VRFBs have several advantages over LIBs and other battery technologies used for industrial applications, particularly in large-scale energy storage applications. VRFBs have high energy efficiency, a long life, are non-flammable and reusable (Conca, 2019). In addition, VRFBs provide the most cost-effective means to store energy, with low maintenance costs, and can be deep charged without affecting the battery's life (Shripad and Revankar, 2019; Bushveld Energy, 2018). Additionally, according to Bushveld Minerals, VRFBs are about 30% less carbon intensive than LFP or NMC batteries of the same size. Furthermore, the vanadium from a VRFB can be easily recovered at a fraction of its market value, enabling circularity. That said, the competitiveness and rate of commercialisation of flow batteries remains hindered by the high capital costs associated with the sourcing and extraction of vanadium and the low solubility of the vanadium salts that the battery employs (Kear et al., 2011; Conca, 2019).

VRFBs are the most market-ready redox-flow batteries. Other examples of redox flow batteries include polysulfide bromide batteries and zinc-bromine batteries. Global reserves of vanadium in 2018 stood at 22 million tonnes. China accounts for the world's largest vanadium reserves, with 43%, while South Africa represents 16% of the world's vanadium reserves. Brazil and the US also host marginal volumes of vanadium reserves. From Figure 31, in 2018, China, Russia, South Africa and Brazil were the top four vanadium producing countries. South Africa is the third-largest producer of vanadium, with most of its vanadium production supplied by Bushveld Minerals' Vamteco and Vanchem operations and Glencore's Rhovan facility. On average, South Africa produces 8% of the world's vanadium feedstock (Bushveld Energy, 2018). South Africa's production of vanadium has fallen by more than half since 2016, from 21 397 tonnes in 2013 to 8 163 tonnes in 2016 as a result of the closure of Evraz Highveld's Mapochs mine, together with the suspension of operations at Vantra vanadium mine (Vanchem). The Vantra mine previously had the capacity to produce 5 000 tonnes of vanadium a year.

Despite their uncertainty and VRFBs' limited share in current battery markets, the demand for VRFBs is expected to increase to over 18 000 MWh (20%) by 2027. According to the World Bank (2020), by 2050, vanadium demand for energy storage alone would be 173% of the entire current market demand. However, for this to happen, current production of vanadium would need to be doubled (Chen, 2017; Bushveld Energy, 2018).

In South Africa, Bushveld is focused on developing and growing vanadium for the global energy storage market and on advancing the battery technology (Bushveld Energy, 2018). Bushveld Energy and the IDC entered into a co-operation agreement in 2016 to assess the feasibility of manufacturing VRFBs in South Africa. This included evaluating Africa's VRFB market potential, conducting techno-economic studies for the local manufacturing of vanadium electrolyte and VRFB system manufacturing in South Africa, deploying a test system with Eskom as well as identifying potential local and foreign partnerships (James, 2018; the dtic, 2017). Most recently, Bushveld Energy and the IDC approved the start of construction for an eight million litre and 200 MWh vanadium electrolyte manufacturing plant in East London. The plant also has the support of the dtic and is located inside the East London Industrial Development Zone.

The company aims to be involved in the whole vanadium value chain, from the exploration, mining and processing of vanadium, electrolyte and VRFB manufacturing to assembling the batteries locally using locally sourced components. In 2019, Bushveld Energy received its first VRFB from UniEnergy

Technologies to South Africa.[9] Bushveld Energy has also advanced partnerships with other VRFB manufacturers, including minority equity stakes in Invinity Energy Systems (UK) and Enerox GMBH (Austria). This has significantly assisted in building the company's capability to develop and deliver energy storage solutions across Africa.

Figure 30: Global reserves of vanadium (in metric tonnes of contained vanadium)

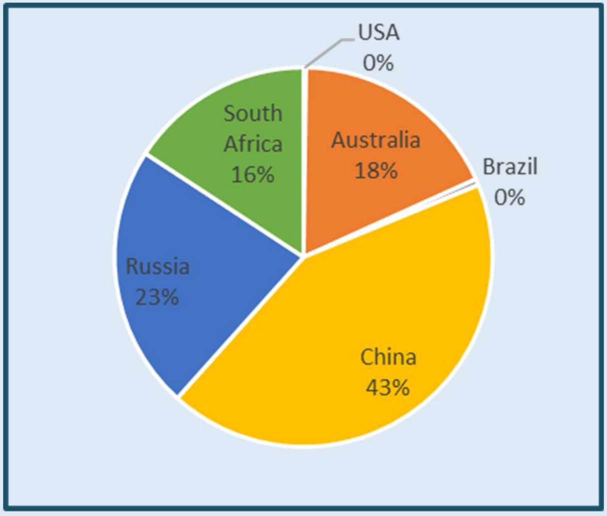
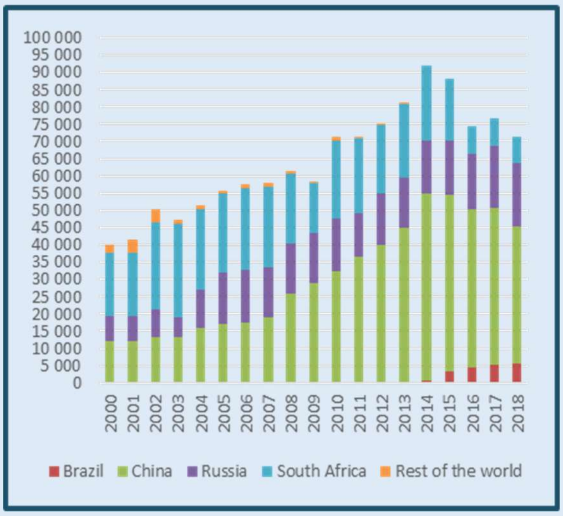


Figure 31: Global production of vanadium (in metric tonnes of contained vanadium



Source: Authors, based on data from the US Geological Survey Minerals Yearbook, Series on vanadium, downloaded in October 2020 at https:www.usgs.gov

Bushveld Energy announced in 2020 that it has made significant progress with the construction of its hybrid mini-grid project at Vemetco. Bushveld, together with Spanish-company Abengoa[10] and Enerox,[11] plans to commission Africa's first commercial and megawatt-scale hybrid power plant composed of VRFBs. The project would have a generation capacity of 3.5 MW solar photovoltaic (PV), with the PV units supplied and installed by Abengoa and 4 MWh of VRBF storage, provided by Enerox. In addition, Bushveld has signed a Memorandum of Understanding with Thebe Investment Corporation as a strategic equity partner in the development and funding of the project. Once the financial closure of the project is reached, Bushveld will apply for an electricity generation licence with the National Energy Regulator of South Africa (NERSA), before it proceeds to the construction phase. Commercially, the project is said to be structured as a separately funded Independent Power Producer that would sell its electricity directly to Eskom (Arnoldi, 2020).

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[9] VRFBs are being manufactured by Bushveld Energy's US-based technology partner, UniEnergy Technologies (UET). The trial should take 18 months, after which the system would be redeployed locally to a commercial site (James, 2018).

[10] In addition to supplying PV units at the Vametco mine, Abengoa will also provide maintenance for the facility post-commissioning (Arnoldi, 2020).

[11] Enerox is a global company that develops, manufactures and installs energy storage infrastructure storage. To date, the company has over 130 VRFBs installed globally. Enerox is considered as a key strategic investment with other investors in the commercialisation of the hybrid power plant.

3. SOUTH AFRICAN CAPABILITIES RELATED TO LITHIUM-ION BATTERIES

While not a leader in the field, South Africa displays an array of capabilities in the development of LIBs. This section reviews domestic capabilities at various stages of the value chain, from skills development and R&D, to mining and beneficiation, to manufacturing, to waste management.

3.1. Developing local capabilities in the lithium-ion battery value chain

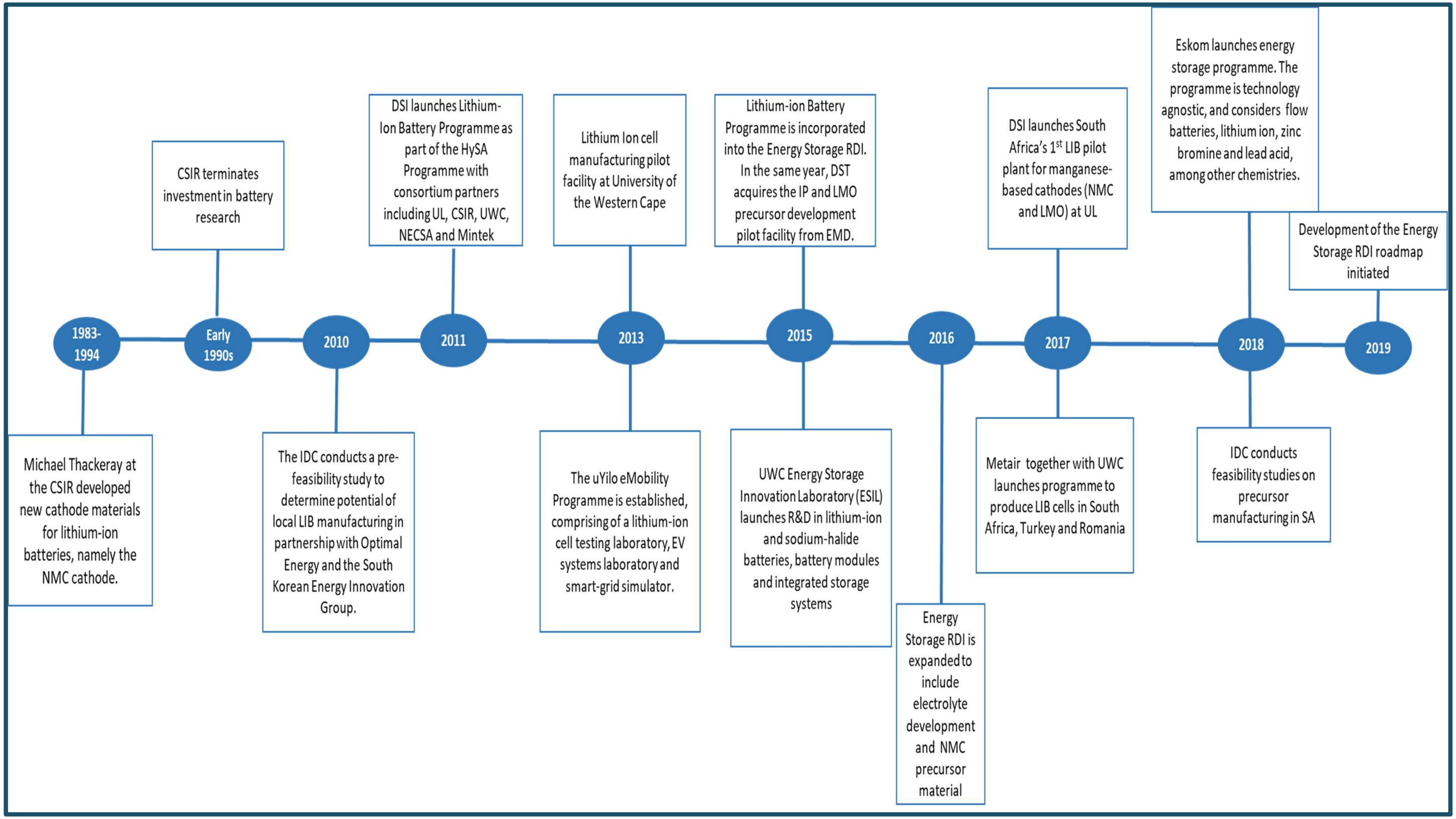
South Africa is heavily reliant at present on imported LIB cells and battery modules from China and other leading countries. Through various government and industry-led initiatives, the country has committed to developing a LIB manufacturing industry, notably to feed into the automotive value chain and the rollout of energy storage systems. Figure 32 provides a timeline of key initiatives in the country.

As part of South Africa's Energy Storage Research, Development and Innovation (RDI) Programme, led by DSI, a consortium was established in 2011 to work on developing the LIB value chain, with the ambition of feeding into the energy storage and EV value chains. The consortium is composed of the Council for Scientific and Industrial Research (CSIR), the University of Western Cape (UWC), the University of Limpopo, the University of the Witwatersrand (Wits), the Nuclear Energy Council of South Africa (NESCA), Nelson Mandela University (NMU) and Mintek.

The consortium's initial ambition was explicitly to develop South African IP and position the country at the cutting edge of R&D in the LIB space. While all institutions still pursue this R&D mandate, the inability to compete with leading countries in this space (see Section 2.6 on patents for more details on this) has led to a shift in function. The primary function of the consortium is effectively to build skills and expertise in the country by training skilled Masters and PhD graduates. Albeit different from the initial idea, this function is critical for the development of a South African LIB value chain.

As raised later in Section 4.3, most local entrepreneurs active in the LIB value chain in South Africa have emerged from academia, and the growth is conditioned *inter alia* on access to skills.

Figure 32: Timeline of the development of lithium-ion battery value chain in South Africa



Michael Thackeray at the CSIR developed new cathode materials for lithium-ion batteries, namely the NMC cathode.

CSIR terminates investment in battery research

The IDC conducts a pre-feasibility study to determine potential of local LIB manufacturing in partnership with Optimal Energy and the South Korean Energy Innovation Group.

DSI launches Lithium-Ion Battery Programme as part of the HySA Programme with consortium partners including UL, CSIR, UWC, NECSA and Mintek

Lithium Ion cell manufacturing pilot facility at University of the Western Cape

The uYilo eMobility Programme is established, comprising of a lithium-ion cell testing laboratory, EV systems laboratory and smart-grid simulator.

Lithium-ion Battery Programme is incorporated into the Energy Storage RDI. In the same year, DST acquires the IP and LMO precursor development pilot facility from EMD.

UWC Energy Storage Innovation Laboratory (ESIL) launches R&D in lithium-ion and sodium-halide batteries, battery modules and integrated storage systems

Energy Storage RDI is expanded to include electrolyte development and NMC precursor material

DSI launches South Africa's 1st LIB pilot plant for manganese-based cathodes (NMC and LMO) at UL

Metair together with UWC launches programme to produce LIB cells in South Africa, Turkey and Romania

Eskom launches energy storage programme. The programme is technology agnostic, and considers flow batteries, lithium ion, zinc bromine and lead acid, among other chemistries.

IDC conducts feasibility studies on precursor manufacturing in SA

Development of the Energy Storage RDI roadmap initiated

Source: Authors

The Energy Storage consortium is structured to cover the whole value chain, with each institution playing a specific role:

- The CSIR leads on the development of high-performance electrode materials for both cathodes and anodes. The council has developed IP for lithium manganese nickel oxide, lithium manganese oxide (used in Nissan Leaf), LMO as well as titanate anode (for grid storage system and e-bikes). The CSIR has an IP portfolio covering 56 territories. The portfolio is driven by the commercialisation potential of products as well as the availability of other LIB components.
- The UL spearheads the development of manganese-based precursor materials, particularly for the manufacturing of LMO-based cathode. The university developed high-quality precursor materials for cathode (for LMO and NMC chemistries) and has an operational pilot plant. The UL is also involved in material modelling, using large-scale simulations to predict vital properties of electrode materials and their interactions.
- NECSA is responsible for working on the electrolyte, notably the fluorination of precursor materials and the development of liquid electrolytes. It has developed a process to produce the electrolyte component lithium hexafluorophosphate ($LiPF_6$) based on the technology platform of fluorspar for LIBs at a relatively low cost (Campbell, 2015).
- NMU established uYilo, the national electric vehicle programme that included a battery testing and validation facility in 2013. The programme built on its expertise of more than 20 years in the lead-acid batteries to develop competencies in LIBs. The university's research group does some fundamental research on the chemistries of LIB. This includes their formation processes and how to improve their thermal processes to reduce their cost. Currently, its main function in the field of LIBs is to establish accredited test procedures of cells and batteries to ensure that they comply with international standards and the information provided by manufacturers. The NMU battery testing laboratory is accredited to SANAS 17025 (ISO/IEC 17025:2005)[12] for automotive lead-acid and LIBs for stationary applications. The facility has equipment to test at the cell level up to 5V and battery modules and packs up to 100V. Effectively, the battery testing facility at the university can only conduct performance testing and would like to expand its services to include safety and abuse testing that is typically required for LIBs that are going to be transported or shipped internationally. These would be according to the UN 38.3 specifications for the transporting of dangerous goods. Setting up such a facility would cost about R10 million, allowing local cell as well as module developers and manufacturers to certify their products for local as well as international safe transporting. The chemistry facilities at the NMU can also test and validate the raw and intermediate materials that are developed by companies that do mineral beneficiation (such as lithium manganese oxide, lithium titanate oxide). These testing facilities have specialist scientists and fall within the SANAS good laboratory practices, even though the methods as such are not accredited. The vision is to set up a comprehensive testing facility for all LIBs up to 300V, including the support and validation of the raw materials manufactured by the local industry. The university also focuses on the skills development of science and engineering students for the new emerging battery energy sector. While opportunities exist for developing IP on the cathode and anode material development, funding for infrastructure development and incentives for student and researchers in this field has been limited.
- The UWC is responsible for cell and module production. It assembles LIBs mostly from imported cell components since the local LIB materials supply chain is still at the beginning of its

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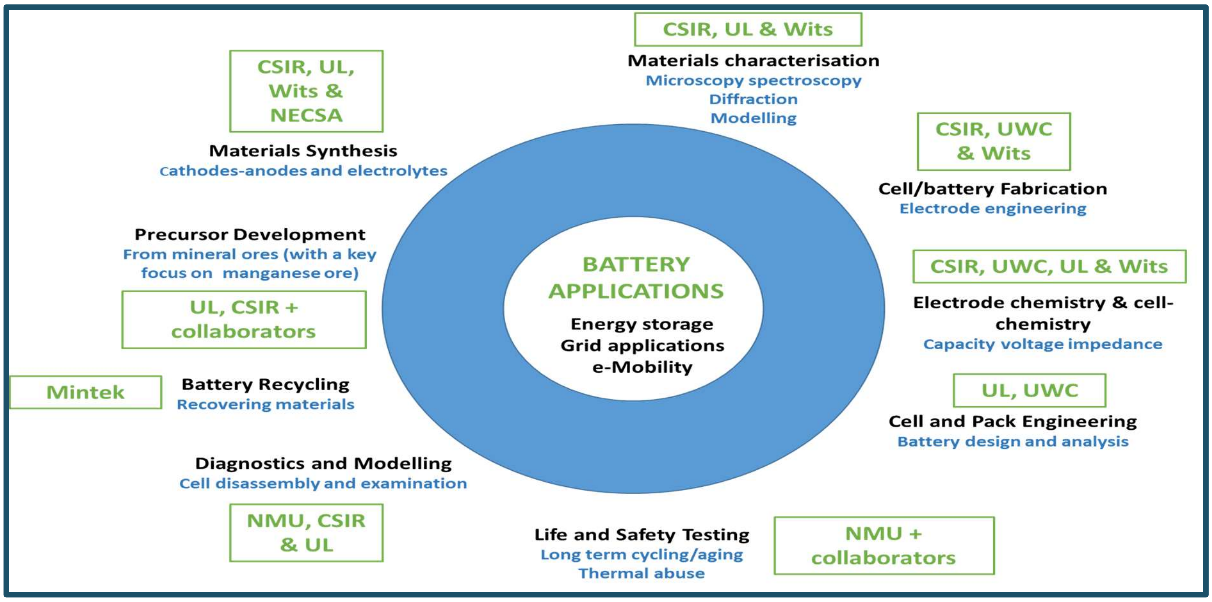
[12] SANAS is the South African National Accreditation System; ISO is the International Organisation for Standardisation and IEC is the International Electrotechnical Commission.

development. The university can assemble high-quality cells comparable to leading commercial technologies but cannot compete on price and consistency. The work at UWC focuses on understanding cell assembly process parameters and the validation of various battery components, as a production facility, it is not deemed a commercial opportunity at this point. In addition to cell assembly and component validation, the UWC is working on battery pack design. The university also developed a BMS a few years ago, but due to the fast pace at which the LIB industry is moving, that BMS may be technologically outdated by now. The UWC supports industry with supplying skills required for manufacturing of LIBs and engages in student exchange programmes with the Argonne Laboratory in the US and has an internship programme with students from the Cape Peninsula University of Technology (CPUT), through which students develop skills in battery assembly and testing.

- Mintek looks at developing technology for precursor manufacturing and the recycling of LIBs, notably to recover valuable mineral components. Mintek is also looking at the business case for a LIB recycling facility in South Africa. The institution has developed a process to refine nickel obtained from platinum group metal (PGM) mining into nickel sulphate. The technology has been commercialised by Thakadu Group. Mintek has also developed patented IP for the direct plating of nickel (and cobalt) as well as some cutting-edge knowledge in the leaching process (including bio-leaching). Mintek has developed a new low-carbon process to produce high purity manganese sulphate monohydrate. The process bypasses electrowinning through an evaporation crystallisation process using solar energy. Mintek is also experienced in process flow sheet simulation (to get the optimal flow sheet).
- Wits works on the research, development and innovation of advanced battery chemistries as well as solid-state electrolytes. The university is collaborating with the local start-up Indabuko Institute to develop manganese-based cathode materials for LIBs. Testing of the lithium-ion cells is carried out with a Bio-Logic BCS-X testing facility at the university. In addition, Wits is involved in developing the LTO anode material for a standard LIB. The key research focus is to curb the undesirable gas generation observed with LTO-based cells when operated at a high temperature. Similar to the UWC and the UL, Wits is benefitting in the DSI-funded student exchange programme with the Argonne National Laboratory in the US.

Figure 33: Structure of South Africa's Energy Storage Consortium



Source: Authors, updated from DSI, 2020

The consortium maintains a number of partnerships with industry (Metair, Hulamin, Zello, MegaMilion, Manganese Metals Company), international institutions (Argonne National Laboratory in the US), training institutions (Energy & Water Sector Education Training Authority – EWSETA, Chemical Industries Education and Training Authority – CHIETA) as well as other academic institutions in the country (CPUT, Stellenbosch University). These initiatives highlight the key role of long-term partnerships between universities, industry and government in advancing new technologies in energy storage solutions and vehicle manufacturing.

The Energy Storage Consortium, while limited in scale compared to leading countries, has demonstrated the existence of domestic pockets of excellence. Investment by the DSI and the dtic to develop a commercialisation plan for the LIB value chain requires engagement with potential commercial partners in industry and relevant agencies, including the Department of Mineral Resources and Energy, to ensure mineral supply as well as the establishment of strong public-private partnerships and collaborations that extend beyond South Africa. The competitiveness of the LIB industry in South Africa and the associated benefits depend on the ability of the industry to secure significant funding and investment, from both local and global partners.

3.2. Mining and mineral beneficiation

A wide array of minerals is used in the production of LIBs, including lithium, cobalt, manganese, nickel, graphite, bauxite, copper, iron, phosphate rock and titanium. Annexure A unpacks the global dynamics for each key mineral required for the production of LIBs. Table 3 lists South Africa's reserves and production of key LIB-related minerals present in the country. Importantly, South Africa does not produce lithium[13] or graphite.

South Africa disposes of large amounts of manganese and is part of a small oligopoly of countries. The country hosts about 80% of known resources of manganese and 30% of reserves. Similarly, it accounts for about a third of global manganese mining. Manganese mines are primarily located in the Northern Cape. South Africa's manganese mines are operated by a few large producers, such as Assmang, Samancor Holdings and Tshipi e Ntle Manganese Mining, and a number of smaller companies. Assmang, a joint venture between African Rainbow Minerals and Assore, owns the Nchwaning and Gloria mines (collectively Black Rock Mine) in the Northern Cape and the Cato Ridge Works ferromanganese smelter in KwaZulu-Natal. Samancor Holdings, a joint venture between South32 and Anglo American, owns 74% of Hotazel Manganese Mines, which operates the Mamatwan and Wessels mines in the Northern Cape, and 100% of the Metalloys ferromanganese smelter in Gauteng. Tshipi e Ntle Manganese Mining owns the Tshipi Borwa mine in the Northern Cape. African Rainbow Minerals owns the Machadodorp ferrochrome and ferromanganese works in Mpumalanga, which are used to investigate alternative technologies for the smelting of manganese and chrome ore.

Over 80% of South Africa's manganese ore is exported and beneficiated out of the country. Of the ore beneficiated locally, beneficiation primarily consists of ferromanganese alloys, silico-manganese alloys and refined manganese alloys. In fact, despite South African manganese beneficiation experiencing a 15-year decline, largely due to disruptions in electricity supply and rising electricity costs, steel and alloy production remains the primary consumer of manganese. About 90% of manganese ore in South Africa is an input into steel and alloy making. There are four main players in South African manganese alloy production: Metalloys and Assmang (producers of ferro-manganese), Transalloys and Mogale

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[13] The country has a number of mines which produce lithium as a marginal by-product.

Alloys (producers of silico-manganese). Other (marginal) manganese products include electrolytic manganese dioxides (EMD), electrolytic manganese metal (EMM), manganese oxide and manganese sulphate (DMR, 2013).

Manganese alloy production is radically different from the production of manganese for LIB. Manganese alloys are primarily produced through a smelting process, while manganese base materials for battery making are produced through a leach and filtration process or from manganese metal produced through electro-winning, depending on the cathode chemistry (DMR, 2013; Euro Manganese Inc, n.d.). For instance, Transalloys, a manganese alloy smelter located in Mpumalanga, is looking to enter the LIB value chain. Transalloys, in partnership with a Russian R&D partner, is investigating the possibility of producing battery grade manganese, however, the company would need a "business case" to justify investments in producing manganese products for LIB cathodes.

NMC cathodes require high purity manganese sulphate monohydrate (MSM), which can be produced either from manganese ore or from EMM. One company in South Africa, the Manganese Metal Company (MMC), beneficiates manganese ore for various applications, including LIB batteries. MMC is a first-stage beneficiation company located in Nelspruit, Mpumalanga. MMC produces manganese metal, the starting material for NMC cathodes through the electro-winning process. MMC is the world's largest producer of 99.9% manganese, which is the selenium-free EMM grade. The firm is the only supplier of EMM outside of China, where the 99.7% manganese grade is produced, using selenium as process additive. In 2019, MMC captured only 1.8% of the 1.56 million ton market for manganese metal but dominated the selenium-free segment. While the production of LIBs does not appear to be sensitive to selenium specifically, MMC's positioning as a non-Chinese company of an inherently higher purity product provides a key differentiating factor.

The company has more than 45 years of industry experience, a technically differentiated premium product, a strong customer base and strong logistics channels. MMC operates at full production capacity of 28 000 tons per annum, beneficiating about 80 000 tons of high-grade South African ore per annum. Its major customers are in the LIB battery, steel, aluminium and chemicals industries. MMC exports over 90% of its products to its customer base located in 23 different countries.

MMC sees strategic value in producing manganese for the LIB industry and intends to grow its sales into that market. MMC projects that by 2025 half of its production capacity would be in producing for the LIB industry. Currently, 30% of existing sales are to the LIB industry in Asian countries, and MMC intends to follow the growth of LIB production as it migrates to Europe and North America.

Electro-winning is a highly energy-intensive process. Electricity makes up about 40% of MMC's production cost base. As a result of rising electricity prices and the forecasted growth of demand for MSM, MMC is busy with a project to install MSM capacity via an alternative production route directly from ore, bypassing the electro-winning process. MMC aims to offer both EMM and MSM to LIB industry customers, depending on their preference. The MSM production process envisaged by MMC is a low-carbon approach and should be scalable depending on the demand growth of various NMC cathode formulations. The firm's expansion into MSM production would offer NMC cathode producers a very compelling alternative to the current China-dominated supply.

In addition, South Africa is a key player in the production of titanium. Mines are found in KwaZulu-Natal, Limpopo and Western Cape. Main companies include Richards Bay Minerals (owned by Rio Tinto at 74%) and Tronox Mineral Sands in KwaZulu-Natal. In addition, a controversial new titanium mine is being pursued in Xolobeni, in the Wild Coast region of the Eastern Cape of South Africa by Transworld Energy and Minerals, owned by Australian corporation Mineral Commodities.[14]

There are two main beneficiated products of titanium, synthetic rutile and titanium slag. South Africa beneficiates ilmenite (titanium iron oxide) into titanium slag and exports most of it as titanium dioxide or slag. The small amount of titanium sold domestically is used in several value added sectors including plastics, pigment industry, medical applications and sporting equipment (DMR, 2008).

South Africa does not currently have private manufacturers producing battery grade titanium. The CSIR-hosted Titanium Centre of Competence plant beneficiates titanium in a continuous process to produce high-grade titanium powder (used in LTO batteries). The plant became operational in 2018 and produces high-quality titanium metal in powder form through a patented high-temperature, alkali-metal reduction process, at a production capacity of two kg an hour (Ozoemena, 2015). At the 2020 South African Investment Conference, Anglo African Metals pledged that they would invest R280 million in titanium beneficiation in the Gauteng province (Creamer, 2020).

The country also produces nickel, iron ore, phosphate rock, cobalt and copper.

Nickel mining is dominated by African Rainbow Minerals's Nkomati mine, in Mpumalanga. Two new nickel mining projects are also spearheaded by mining company Uru Metals, namely the Zebediela nickel sulphide project, in Limpopo, and the Burgersfort nickel project, in Mpumalanga.

In 2018, exports accounted of 82% of South Africa's nickel sales. Local nickel demand is driven by the stainless steel production. Other nickel applications include the production of fertilisers, pesticides, coinage, magnets and non-steel allot production (DMR, 2009). Nickel sulphates are used in LIB. In 2018, construction began for a nickel sulphate purification plant by Lonmin, a PGM mining firm, and Thakadu Group, a metals and energy materials company. Thakadu is developing the plant to beneficiate Lonmin's nickel output by-product. The plant is located in the North West province at the Lonmin base metals refinery. The plant is expected to produce class-one battery grade nickel sulphate at a production capacity of 25 000 tons per annum (Solomons, 2018).

Iron ore mining is primarily located in Northern Cape. It is dominated by Kumba Iron Ore, part of global conglomerate Anglo American (owned at 13% by the Public Investment Corporation), and Assmang, part of Assore. Chinese International Resources Limited, which acquired Evraz Highveld Steel and Vanadium's Mapochs mine, and Anglo-Australian conglomerate Rio Tinto also have local operations.

South Africa exports 88% of its iron ore, with the remaining 12% supplying the domestic market. Most iron ore producers sell their iron directly to steel producers. The iron ore that is not sold to the steel sector is beneficiated through capital-intensive dense medium separation or jigging by miners.

Phosphate rock is quarried in multiple locations, in the Western Cape, Limpopo, KwaZulu-Natal, and North West. The mining of phosphate rock is carried out by one large company, Foskor, and one smaller producer, Gecko Fert, while Kropz is developing a new mine. Foskor's acid division produces fertilisers and phosphoric acid from the phosphate rock supplied by the company's mining division.

South Africa does not yet have the domestic capability to refine and manufacture the battery grade copper required for the anode current collector. South Africa's copper beneficiation is centred primarily on pipes and cables. In 2017, 50% of South Africa's copper was exported. Of the exports,

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[14] Local communities are opposing the development of the mine on the basis of severe environmental, social and cultural impacts.

28% were semi-manufactured exports. In 2015, South African copper production was estimated to be R9 billion (Makgetla and Levin, 2019).

Palabora smelter is one of the largest copper producers in South Africa. Located in Limpopo, the smelter refines copper found in the Palabora mine. The smelter has two anode refining furnaces, a holding/scrap melting furnace and an anode casting wheel, with a production capacity of 60 000 tonnes of refined copper a year. Copalcor is the second largest secondary copper smelter in the country. It manufactures copper, brass and alloy solutions. Copalcor's facilities have a production capacity of five kt per annum (Jones, 2015).

While South Africa does not have bauxite, South32, in Richards Bay, produces aluminium based on imported ore from Australia. South32[15] produces primary aluminium for the fabrication sector. South32 does not have any downstream aluminium processing facilities and provides aluminium to fabricators and semi fabricators, such as Hulamin.

Hulamin is another key player in South Africa's aluminium industry. Hulamin is an aluminium semi-fabricator based in Pietermaritzburg, KwaZulu-Natal. The firm sources virgin aluminium from South32 and scrap aluminium from a range of sources, including used beverage cans. Hulamin's largest division is rolled products. The firm produces a range of high-specification, complex, tight tolerance products. Its rolled products operations include slab cast house and recycling facilities.

Hulamin has extensive experience in supplying aluminium for the automotive sector and sees future growth potential in this sector from the push to reduce the weight of motor vehicles. In the LIB space, Hulamin is engaged in the following:

- The firm currently supplies aluminium battery base plate material for a leading US EV producer and is exploring additional opportunities to grow its sales of plate into the EV sector.
- It is exploring the production of battery-grade current collector aluminium foil (referred to as "battery foil"). Hulamin is the only foil manufacturer in South Africa to consider the technology needed to develop high-strength aluminium foil optimised for LIBs. Hulamin commenced its product development activities on battery foil in 2019 and has so far been successful in producing aluminium battery foil samples for testing in Europe and the US. The company is involved in strategic discussions with several potential partners and battery manufacturers in Europe, the US and Asia to explore opportunities to develop and supply battery foil. The project is, however, complex as the product is highly specialised and technically demanding. It would require relatively significant capital investments to get to market (in the region of R50 million to establish the required manufacturing capabilities).
- Hulamin is investigating the production of rolled aluminium covers and aluminium extrusions for structural support in the battery pack frame/body.

Last, while South Africa does not mine lithium, Lithium Lion plans to establish a lithium hydroxide pilot plant in the Musina-Makhado Special Economic Zone (SEZ) in the Limpopo province within the next two years. The pilot plant would convert spodumene, processed from lithium hard rock, into battery-grade lithium hydroxide (for cathode production). Lithium Lion is looking to source the spodumene from hard rock deposits in Zimbabwe, provided supply is up and running within the next

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[15] South32 has serval business operations in South Africa, in manganese, coal and aluminum.

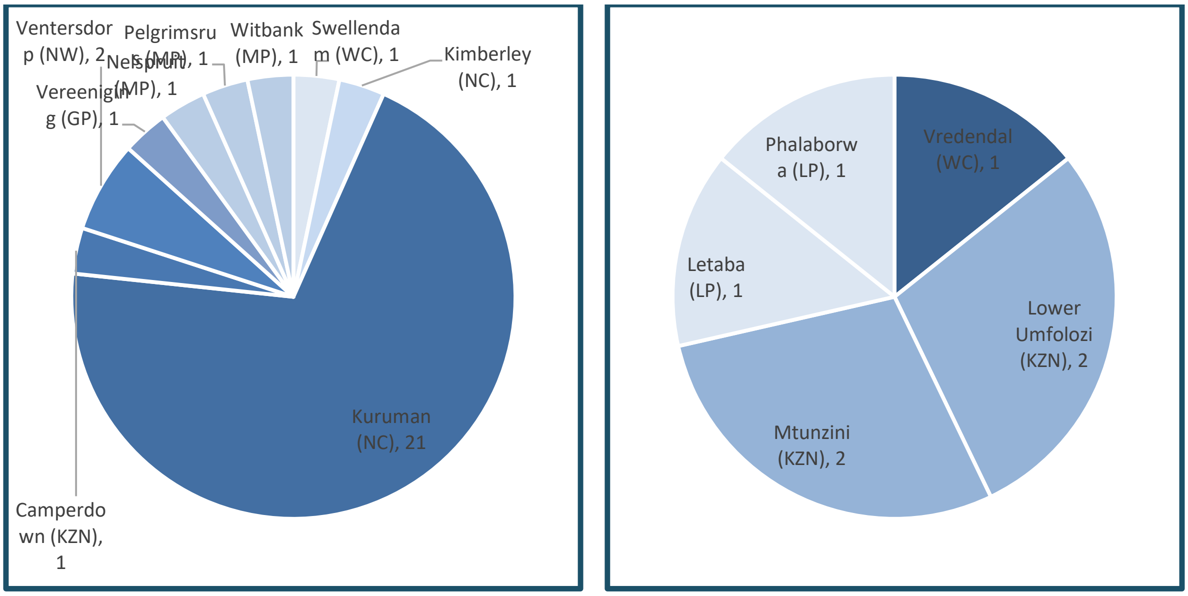
18 months. The pilot plant, estimated to cost about US$2.5 million, would produce 1 000 tons of lithium hydroxide to prove commercial viability. In the long run, Lithium Lion aims to establish a 10 GW factory, which would produce 10 000 tons of lithium hydroxide. To the extent possible, the company aims to use solar thermal energy instead of grid-tied electricity and coking coal to power the production process. However, the technology, developed by Mintek, is still at the laboratory and conceptual stage, and remains to be proven viable technologically and economically.

Table 3: South Africa's reserves and production of key minerals in 2017/2018

MINERALS	RESERVES	SHARE OF GLOBAL RESERVES	PRODUCTION	SHARE OF GLOBAL PRODUCTION
Manganese	230 000 kt	30%	5500 kt	31%
Titanium mineral concentrate	71 300 kt	8%	600 kt	5%
Nickel	3 700 000 t	4%	44 000 t	2%
Iron ore (content)	770 000 kt	1%	52 000 kt	3%
Phosphate rock (gross weight)	1 400 000 kt	2%	2 078 kt	<1%
Cobalt	24 000 t	0,3%	2200 t	2%
Copper	n/d	n/d	65 kt	<1%

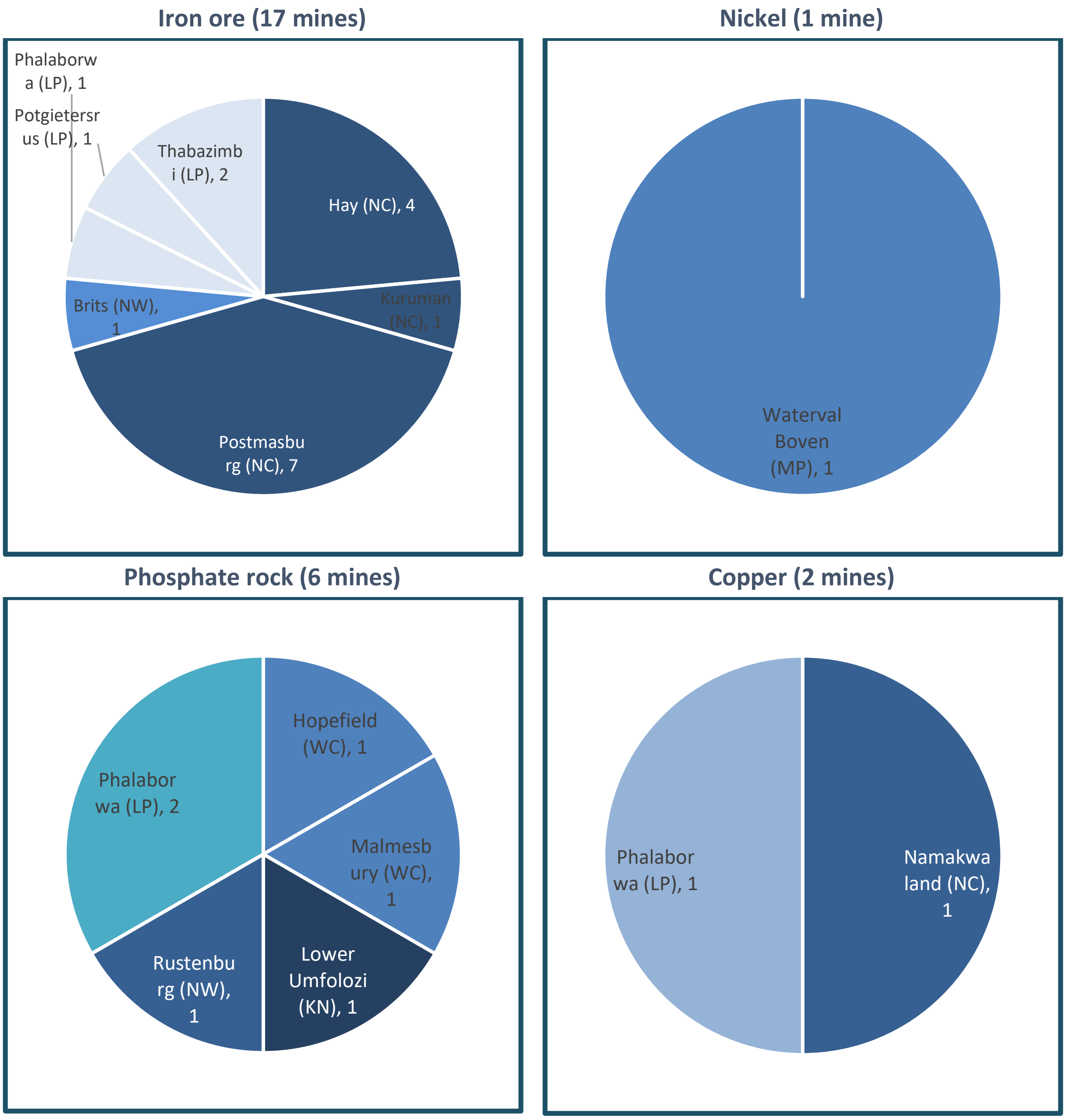
Source: Authors, based on data from the DMR, Series on Mineral Statistics: National Production & Sales (Monthly), downloaded from Quantec in October 2020; and from the US Geological Survey, Minerals Yearbook

Figure 34: Geographical location of South Africa's mines for key metallic minerals (primary production only)



Manganese (30 mines)

Titanium (7 mines)


Iron ore (17 mines)

Nickel (1 mine)

Phosphate rock (6 mines)

Copper (2 mines)

Source: Authors, based on data from Quantec. EasyData. Interactive database. DMR data on Operating Mines by Type of Mine and Commodities at District Leve, accessed at www.quantec.co.za in September 2019

In sum, South Africa is well endowed in minerals relevant to the production of LIBs. In the case of manganese, the country even benefits from a quasi-monopolistic position. The country also boasts longstanding experience and expertise in mineral beneficiation. However, to date, there is little beneficiation of minerals to battery grade in the country.

Beyond South Africa, the African continent has, in one way or the other, all LIB-relevant mineral, as detailed Table 4. The African continent has incomparable reserves and mining capacity in key minerals supporting the LIB value chain. A third of the world's manganese, three-quarters of its phosphate and over half of the world's cobalt are supplied from counties on the continent.

In addition, Zimbabwe, for example, is set to play a major role in lithium production, while Mozambique and Tanzania have made considerable investments in graphite production. Nickel, however, is relatively less concentrated in Africa. Notwithstanding, the region mines every material required to produce LFP, NCA, LTO, LMO and NCA LIB anodes and cathodes.

Table 4: Africa's main reserves and production of key minerals related to lithium-ion batteries

MINERALS	COUNTRY	RESERVES	SHARE OF GLOBAL RESERVES	PRODUCTION	SHARE OF GLOBAL PRODUCTION
Bauxite (thousand metric tons)	Guinea	7 400 000	24%	46 160	15%
Copper (metric tons of copper content)	DRC	19 000 000	2%	1 020 000	5%
	Zambia	19 000 000	2%	712 000	4%
Cobalt (metric tons, cobalt content)	DRC	3 600 000	51%	64 000	57%
	Madagascar	120 000	2%	3800	3%
	South Africa	50 000	<1%	2300	2%
Graphite (metric tons)	Mozambique	25 000 000	8%	300	<1%
	Tanzania	18 000 000	6%	n/d	n/d
	Madagascar	1 600 000	<1%	9000	1%
Iron ore content (metric tons)	South Africa	770 000 000	1%	52 000 000	3%
Lithium (metric tons)	Zimbabwe	230 000 (lithium content)	1%	40 000 (gross weight)	2%
Manganese (metric tons gross weight)	South Africa	230 000 000	30%	5 500 000	31%
	Gabon	61 000 000	8%	1 929 000	11%
Nickel (metric tons, contained nickel)	South Africa	3 700 000	4%	44 000	2%
	Zimbabwe	n/d	<1%	17 743	<1%
	Botswana	n/d	<1%	16 878	<1%
Phosphate rock (thousand metric tons)	Morocco	50 000 000	72%	9400	12%
	Algeria	2 200 000	3%	390 (P_2O_5 content)	<1%
	South Africa	1 400 000	2%	772 (P_2O_5 content)	<1%
	Egypt	1 300 000	2%	1300 (P_2O_5 content)	2%
Titanium (metric tons)	South Africa	71 300 000 (TiO_2 content)	8%	600 000 (gross weight)	5%
	Mozambique	14 880 000 (TiO_2 content)	2%	1 347 780 (gross weight)	17%
	Madagascar	8 600 000 (TiO_2 content)	1%	244 800 (gross weight)	3%

Source: Authors, based on data from the DMR, Series on Mineral Statistics: National Production & Sales (Monthly), downloaded from Quantec in October 2020; and from the US Geological Survey, Minerals Yearbook

Although many minerals are available, they are widely exported to China, Japan, the US and Europe. While China produces 74% of the world's LIBs and continues to expand its production capacity in LIB manufacturing, it is heavily reliant on raw materials from Africa.

Africa remains an extractive economy, as most of its (battery-related) minerals are refined and processed outside of the continent. While the raw material abundance emphasises Africa's vital role in the battery market, the manufacturing of LIBs requires manufacturing expertise, economies of scale and significant investment in beneficiation and value-chain infrastructure to compete. This opens the door for regional integration, as discussed in Box 3.

Box 3: Regional trade and lithium-ion batteries

The majority of the minerals essential for LIB manufacturing are sourced within the Southern African region. Investigating the potential for developing a LIB value chain in the region involves assessing the potential for regional integration and collaboration. From a South African perspective, this includes considering the ease of accessing mineral inputs which are not found in South Africa. As mentioned in Section 3, South Africa does not have sufficient lithium and cobalt minerals.

South Africa's mineral trade has been liberalised in all respects. South Africa extends a Most Favoured Nation (MFN) import tariff of 0% on most minerals relevant for EVs, with the exception of titanium which has an MFN tariff of 10% and rare-earth elements with an MFN tariff of 1.6% (Market Access Map, n.d.).

Within the Southern Africa region, the DRC, Zambia, and Zimbabwe host significant cobalt and lithium reserves. These counties have export taxes on these and other minerals as measures to support their beneficiation policies. The DRC has export duties of 10% on mineral products, Zambia has 10% export duties on mineral ores and concentrates, and Zimbabwe has 5% export taxes on lithium (WTO, 2020, 2016a, 2016b).

Global tariffs on LIBs are particularly liberalised too. The tariffs from the top 10 importers of LIB (in volume terms) range from the lowest MFN tariff of 1.9% from Spain and Slovakia to 10% from China and Thailand. African countries levy the highest tariffs on LIB imports, with MFN tariffs ranging from 10% to 30%. From the top 10 African importers of LIBs, South Africa, Botswana and Mauritius are the most liberalised, with MFN tariffs of 0%. The highest MFN tariffs come from Morocco and Nigeria with 30% and 20% respectively (Market Access Map, n.d.; Trade Map, n.d.).

South African LIB exports are tariff-free to countries within the Southern African Development Community (SADC) region due to the free trade area. However, exports to countries outside of the SADC region face MFN tariffs as high as 30%. Once the SADC-EAC-COMESA Tripartite Agreement[16] and the African Continental Free Trade Area (AfCFTA) are fully operational, LIB tariffs could decrease.

Indeed, South Africa is a member of the SADC Free Trade Area, the SADC-EAC-COMESA Tripartite Free Trade Area and AfCFTA. The primary objective of these agreements is to facilitate the elimination of tariffs and to increase inter-African trade.

These agreements could ease trade in minerals by lowering the cost of trade through trade facilitation. Trade facilitation refers to the broad range of measures that serve to streamline and simplify the technical and legal procedures in the trade of goods. It covers the full spectrum of border processes, ranging from the electronic exchange of data about a shipment, to the simplification and harmonisation of trade documents, and includes the possibility of appeals of administrative decisions by border agencies (Moïsé, 2014).

Southern African Development Community (SADC)

As part of its long-term regional integration goals, SADC established a Free Trade Agreement in 2008. The agreement allows duty-free trade among member states (excluding Angola and the DRC), on 85% of intra-regional imports. Within the Free Trade Area, quota restrictions are prohibited and

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[16] The Tripartite is made up of the regional economic communities: the Southern African Development Community (SADC), the Common Market for Eastern and Southern Africa (COMESA) and the East Africa Community (EAC).

member states have agreed to eliminate all non-tariff barriers (NTBs). Establishing a SADC Customs Union was intended to address NTBs through member states harmonising their customs policies to reduce the costs and delays at border crossings. The SADC Customs Union was, however, not realised in 2010 as intended and, at the 2015 Heads of State and Government Summit, SADC announced that there would be negotiations for a new target date for the Customs Union (tralac, 2019).

The SADC Industrialization Strategy and Roadmap 2015-2063 was adopted in 2015. The strategy is anchored on three interdependent and mutually supportive pillars: industrialisation as a champion of economic transformation; enhancing competitiveness; and deeper regional integration (SADC, 2015). The Industrialisation Strategy and Roadmap sets ambitious goals, namely: 6% annual growth in per capita income; doubling the share of manufacturing value added (MVA) to 30% by 2030 and then increasing MVA to 40% by 2050; increasing the share of medium-and-high-technology production in total MVA by 30% in 2030 and 40% by 2050; increasing manufactured exports to at least 50% of total exports by 2030; increasing the share of industrial employment in total employment to 40%; and increasing the global market share for the export of intermediate products to around 60% of total manufactured exports (SADC, 2015).

To achieve these goals, the strategy provides strategic interventions for addressing the three key binding constraints to industrialisation, namely: 1) inadequate and poor quality infrastructure; 2) industrial development skills deficit; and 3) insufficient finance.

To tackle inadequate infrastructure, the strategy aims to fast-track the implementation of the Regional Infrastructure Development Master Plan (RIDMP). The RIDMP could play as a catalyst for industrial development, by reducing the cost of doing business, including in relation to NTBs and local procurement of inputs for infrastructure development. Infrastructure support programme for industrialisation, extending beyond the medium term, would also be beneficial (SADC, 2015).

The strategy advocates for additional resources to be directed to vocational training of all kinds, especially for skills required in medium- and high-technology industries and occupations. It also calls for a flexible education system, which retrains people to meet the demand of businesses and industry, with a focus on science and technology, innovation and mathematical disciplines. Increased collaboration between institutions of higher education and business and industrial communities and the undertaking of a skills audit at the regional level are also put forward in the Industrialisation Strategy (SADC, 2015).

To address insufficient financing, the strategy recommends that governments reorder their public expenditure programmes, giving priority to public and private investment in human capital development and physical infrastructure.

The strategy also sets out three potential growth paths: agro-processing; mineral beneficiation and downstream processing, and industry- and service-driven value chains. The paths are mutually supporting and inclusive, encompassing the combination of downstream value addition and backward integration of the upstream provision of inputs, intermediate items and capital goods (SADC, 2015).

For mineral beneficiation, the strategy has identified energy minerals (including polymers), ferrous minerals (iron and steel), base-metals mineral (copper, aluminium, nickel, cobalt), fertilisers, diamonds, platinum, and soda ash as strategic minerals. The strategy recommends that Sovereign Wealth Funds play a role in beneficiation investments, the promotion of interlinkages and ploughing back natural resources rents. SADC should, according to the strategy, facilitate cross-border infrastructure investment to ease the flow of minerals, negotiate with destination markets to promote "beneficiation at source" within the region, facilitate regional co-operation in technology and skills sharing, and assess the landscape on contracts in the minerals sector to evaluate the scope and visibility of mineral beneficiation and value addition (SADC, 2015).

SADC-EAC-COMESA Tripartite Free Trade Area

Expanding the free trade areas in Africa, the SADC-EAC-COMESA Tripartite Agreement was launched in 2015. The agreement is a conglomeration of the three free trade areas. It allows for tariff-free, exemption-free, and quota-free trade across 26 countries (tralac, 2016). As of February 2020, the agreement was signed by 22 members but ratified only by eight countries. A total of 14 ratifications is required for the agreement to enter into force.

African Continental Free Trade Area (AfCFTA)

In 2019, the African Union launched the AfCFTA. The AfCFTA is aimed at creating a single continental market, allowing the free movement of people and investments and the removal of tariffs on 90% of tradable goods and services. All African countries, except Eritrea, have signed the agreement (EY Tax Insights, 2020).

Phase 1 of the AfCFTA negotiations, which included the Protocol on Trade in Goods and the Protocol on Trade in Services, have been concluded. Phase 2 includes the protocols on competition, investment and IP (AU, 2019). Trading under the AfCFTA Agreement was set to commence in July 2020. This date was postponed to January 2021, due to the COVID-19 global pandemic (EY Tax Insights, 2020).

The specific objectives for the AfCFTA are that state parties:

- Progressively eliminate tariffs and NTBs to trade in goods;
- Progressively liberalise trade in services;
- Co-operate on investment, intellectual property rights and competition policy;
- Co-operate on all trade-related areas;
- Co-operate on customs matters and the implementation of trade facilitation measures;
- Establish a mechanism for the settlement of disputes concerning their rights and obligations; and
- Establish and maintain an institutional framework for the implementation and administration of the AfCFTA.

The AfCFTA recognises the importance of infrastructure development in enabling inter-Africa trade. A key goal of the agreement is to promote investment in quality infrastructure to increase cross-border trade and competitiveness. The emphasis on infrastructure investment encompasses infrastructure in all spheres, from communication and digital infrastructure to strategic facilities, such as harbours and special economic zones (Albert, 2019).

According to the African Development Bank, Africa needs to invest US$170 billion every year in infrastructure. Although investment will be negotiated in the next phase of the agreement, it provides for investment through national investment plans; investment promotion agencies and partnerships; trade facilitation measures (such as standards certification and harmonisation); and a programme for infrastructure development and strategic logistics management (AU, 2019; Albert, 2019). Investment strategies for infrastructure from the AfCFTA aim to encourage investment by agencies linking international and domestic investors and firms, attracting foreign investment and strategic use of national investment funds (Albert, 2019).

3.3. Battery manufacturers and importers

In addition to the mining and beneficiation of key LIB materials, a number of South African firms are involved in manufacturing and assembling LIBs. South Africa has developed expertise from industry and academia to support the development of precursors and material, cell manufacturing, as well as activities related to cell module and pack assembly using imported cells. Outside of the Energy Storage consortium, interest by local industries to produce cells and battery packs locally has increased. A few companies, including Maxwell and Spark, BlueNova, EV Dynamics and FreedomWon, have started importing lithium-ion cells from East Asia and assembling batteries locally for both domestic and international markets. Metair, AutoX and Megamillion are exploring the potential to manufacture LIB cells locally with the support of local universities. Other players are working towards developing other battery components and parts. Some companies, such as Revov, are also developing the market for second-life batteries. In addition, wide array of battery importers are reselling imported batteries on the local market.

Manufacturing of cells and batteries

In 2017, local automotive specialist, distributor and retailer of energy solutions and automotive components, Metair Investments, launched a programme together with the UWC for the production and certification of LIBs across its operations in South Africa, Romania and Turkey. Metair's agreement with the UWC led to the company investing R3 million over three years to pilot a prototype lithium production project from 2018. From Metair's perspective, the partnership with the UWC aims to improve the company's understanding of the complexity of the manufacturing process. According to GreenCape (2019) and Metair (Venter, 2017), the facility houses the only pilot-scale lithium-ion cell assembly facility in Africa. The production focuses on mining cap lamp cells, 12V lithium-ion automotive batteries, 48V LIBs for energy storage applications using efficient chemistry mixes based on widely available local minerals, such as manganese and nickel (Venter, 2017).

Metair began its production for LIBs in its plant in Turkey in 2019, and while in Romania, the company acquired a 35% holding in Primemotors through its wholly-owned subsidiary Rombat, in an effort to accelerate its production of LIBs for the growing European market as the global production of EVs accelerates (Venter, 2017). Metair's European (Romania and Turkey) operation started with the conversion of buses and ferries in Europe (such as in Germany).[17]

Through its Romanian activities, the company has developed intellectual property at multiple levels:

- Manufacturing: developed its own modular, multi-level manufacturing line, which can be set up for about €15 million (compared to €30-€35 million traditionally).
- Chemistry: works on separators as well as the electrolyte.
- Cells: develops cells, from LFP to NMC, particularly for low-temperature LIB (-30 ˚C to -35˚C)
- Subcomponent: develops machine and the electronic control (BMS).

While Metair[18] currently services the South African market by importing products through its local subsidiary, First National Battery, the company is working on establishing an assembly line domestically. It aims to target first the industrial segment (telecommunications, forklift, food transportation and handling, mining and data centres) before moving into the EV space.

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[17] Access to affordable, clean electricity was also an important factor in the location of the plant.

[18] Metair recently announced at the Third Investment Conference its plans to invest R1.1 billion in the automotive industry for components manufacturing in KwaZulu-Natal, the Eastern Cape and Gauteng (Business Insider, 2020). However, there is no mention of which components the investment plans to target.

Compared to other local players, Metair is a key components supplier with a global footprint, thus the company has the advantage of existing relationships and partnerships with leading OEMs in the global automotive value chain. The company believes that sustained R&D initiatives to support local production with locally available commodities will drive down the cost for LIBs, which might be cheaper when compared with Chinese counterparts. However, as previously highlighted, production scale is a key factor in reducing battery prices (Venter, 2019).

AutoX and Megamillion have also announced their plans to build their own battery manufacturing facilities for the manufacturing of lithium-ion battery cells.

AutoX, as one of South Africa's largest battery manufacturing company in after-market and sales, works closely with OEMs to supply lead-acid batteries, particularly for the local industry. The company has an in-house R&D facility and collaborates with industry and industrial research organisations to develop innovative technologies in battery production (Who Owns Whom, 2019). According to Who Owns Whom (2019), AutoX has built strong working relationships with NMU and has sponsored post-graduate students to conduct research in LIB manufacturing with the aim of promoting cell development and the manufacturing of cells for telecommunication, back-up storage and forklift applications, specifically developed for the African market. In addition to producing battery cells, in the long run, the company considers expanding into battery pack assembly as this is a "relatively" easy process given the company's expertise in lead-acid battery manufacturing and assembly. The company announced that it has acquired new cathode technology IP for LIBs, however, it was unable to disclose the cathode technology, although it did mention that the technology is not NMC. Unfortunately, being an existing lead-acid battery manufacturer does not provide significant advantages to enter the LIB value chain because LIB manufacturing is an entirely different process to lead-acid battery manufacturing, and would require investment in new facilities and production processes.

The Megamillion Energy Company, in partnership with LIB technology experts from Asia, aims to be Africa's first large-scale producer of LIBs, primarily for the energy storage market and EVs. The estimated total investment in the local LIB manufacturing plant is around US$1.5 billion, with funding from a mix of local and global private equity investors. The plant's final annual LIB production output is expected to be 32 GWh cells by 2028. Venter (2020) reports that a sample of LIBs produced by the company's technical partner in Asia have successfully undergone tests at NMU. Due to delays caused by COVID-19 in 2020, the company hopes that operations can commence in 2021. Initially, the plant will produce batteries primarily for energy storage applications and later for e-mobility applications, specifically for locally made EVs, e-bikes and e-buses. Discussions are also being held with authorities in Zambia, Ghana and Ethiopia for similar LIB manufacturing operations to be installed in those countries.

Ultimately, with the support of government, international technology partners, and local technology institutions, Megamillion aims at contributing to the entire LIB value chain, from the manufacturing of cathode materials to single cells, from battery pack assembly to LIB end-products. LionESS, a subsidiary of Megamillion, is already supplying a locally designed and manufactured energy storage system for residential homes and small businesses.

In 2017, Pyxis Energy had proposed to build an integrated, cell/battery production and recycling facility in the Saldanha Bay Industrial Development Zone in the Western Cape Province. The proposed factory was meant to produce LIBs or similar batteries with an annual production estimated at up to 200 GWh. However, discussions about the factory have been "shelved" and it is unlikely that the proposed development will go ahead. Although an Environmental Impact Assessment study was conducted by Africa Geo-Environmental Engineering and Science (AGES) for a battery factory in Saldanha Bay with an added recycling component, the challenge in accessing key base materials required for LIB manufacturing was identified as a major risk to the project, consequently causing it to cease. The company had targeted the Bakita mine in Zimbabwe as a possible source of lithium, however, there were concerns by various investors over Zimbabwe's political instability, deteriorating economic environment and the high risks inherent in doing business in the country. This discouraged investors intending to invest in Zimbabwe to explore new business opportunities in the country's domestic lithium industry.

Battery component manufacturing and assembly

A LIB cannot be assembled without a BMS and every battery has a BMS. Multiple local battery companies are involved in offering BMS hardware, technologies and software for various applications in the local market.

Currently, battery production in South Africa is mainly targeted at developing expertise in battery pack design and assembly, especially for industrial, energy and storage applications but not the automotive industry, where the main volume of demand can be expected in the long run. The assembly of packs, however, relies on cell and module imports, particularly in LFP and NMC battery technologies. China is the primary exporter of lithium-ion cells into South Africa. Imported cells are assembled locally in different configurations and specifications. LIB designs require different equipment from cell to module assembly, but rely on similar processes and equipment from module to pack assembly. As such, there exists a huge market for battery pack manufacturers to target a variety of market segments with reliable and affordable LIB technology, from industrial and commercial usages, to stationary storage, renewable energy-based grid services and EVs.

In South Africa, battery pack production is still in an evolutionary phase, yet dynamic, with companies that have all invested in partnerships to produce battery packs locally for both local and international markets. Most of these companies have their in-house master BMS while others import the system from Chinese manufacturers.

Local battery industry technology company Balancell offers BMS and LIB electronics for mobile battery applications, such as forklift batteries and for stationary battery applications. Balancell employs about 40-50 employees. It focuses on the industrial battery market, producing about 100 batteries a month at its Cape Town plant.[19] Given that the company sources all components apart from the cells locally, it is supporting about 200 jobs in downstream industries. Balancell currently holds IP in BMS design, thus enabling the company to play a key role in increasing its value add in LIB technology. The firm's BMS is an Internet-of-Things solution and notably allows for remote control of the battery. Leveraging its unique intellectual property in the BMS and battery design, the company produces LFP battery packs,[20] using imported cells from China. According to the company, Balancell's unique intellectual property and design results in its batteries being significantly cheaper than Chinese equivalent batteries. While the company favours LFP cells (for their low cost, high safety and heavy weight), its BMS would be compatible with any chemistry. All other components (casing, electronics, counterweight for forklift) are produced domestically in South Africa. Balancell is also the sole supplier to Toyota Industrial Equipment, which is offering forklifts and reach trucks in South Africa and Sub-

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[19] Balancell initially received a grant of R10 million from the Technology Innovation Agency. Over the years, the company has struggled to secure funding for R&D and productive expansion. The company currently benefits from an IDC facility.

[20] The firm focused on LFP batteries because they are cheaper, safer and heavier than their counterpart (in the case of forklift, weight matters – they need counterweight to match the weight of the lead acid battery they replace).

Saharan Africa. The company has the opportunity to access Toyota distribution channels and supply large motive industrial batteries globally.

Mellowcabs, based in the Western Cape, develops and builds light electric delivery vehicles for application in last mile delivery. The company has just achieved ISO status in its manufacturing facility, and is enjoying strong growth in the e-commerce and home-delivery sectors. It is also pursuing European homologation early in 2021, with European Union (EU) sales following soon after. It plans on producing around 500 vehicles annually in the Western Cape. Mellowcabs proudly boasts a South African content of above 60%. As part of uYilo's e-mobility programme and expanding the LIB value chain locally, uYilo co-funded the development of an intelligent BMS for LFP battery packs. MellowCabs was the industry partner, in conjunction with Stellenbosch University as the academic partner.

Durban-based battery manufacturer Maxwell and Spark designs and assembles batteries and associated mobile systems, as well as conducting independent lithium-ion cell testing. Maxwell and Spark went to market with the Fridge.Li system – the first-ever commercial electric truck refrigeration system powered LIBs for the logistics and transport industry, in early 2020. According to the company, the Fridge.Li electric truck fridge system is over 90% more energy cost-efficient than a standard diesel truck fridge, resulting in an average saving of R1.5 million a vehicle in the long run. Currently, the company supplies its Fridge.Li system domestically to the SPAR group and multiple large transporters and retail supermarkets across the country. In addition, the firm exports to Australia and is looking at other export opportunities (Europe, North America). Maxwell and Spark also supplies LFP battery packs for the forklift, telecommunication and golf cart market, and have subsequently established a strong relationship with South Africa's largest electric materials handling equipment supplier, which now uses Maxwell and Spark as its LIB supplier (Maxwell and Spark, n.d.). The firm uses primarily LFP batteries (for their cost and safety). It also uses NMC and LTO chemistries to a lesser extent. The company's Tier 1 LFP cells are imported from China, while making use of NMC cells imported from Japan. Maxwell and Spark has designed and developed the BMS, Internet of Things (IoT) telematics system and other electronic and mechanical components in-house. More than 25% of the company's staff are engineers, and seven of those are postgraduate. The company holds two patents, however, only one is in use.

Local battery company BlueNova Energy, in partnership with the Reunert Group, launched a new facility in Cape Town in 2015 to produce LIB packs based on the LFP cathode for residential, commercial, industrial and utility scale sectors in the local market, as well as for the export market (the dtic, 2017; Who Owns Who, 2019). According to Who Owns Whom (2019), BlueNova imports its lithium iron phosphate prismatic cells from Chinese manufactures and then assembles these cells into battery packs. The company has since developed its own BMS as well as its own patented Energy Management Systems (EMS). Additionally, all the control electronics, displays and software in the battery pack are developed by BlueNova engineers using local component suppliers. Although BlueNova is currently focused on the assembly of LFP battery packs, the company aims in the long run, to assemble LTO battery packs. BlueNova has achieved a significant milestone in the energy sector with its exports of intelligent Energy Storage System (iESS) and battery packs to Namibia, Botswana and Mozambique. The company sees great potential in the African market and has developed market opportunities for the application of battery solutions for the region, particularly in agricultural and mining sectors.

FreedomWon offers LIB packs using imported LFP prismatic and $LiFePO_4$ cells from Chinese manufacturers. The company produces LIBs targeted at storage applications, utility vehicles including golf carts and towing vehicles, forklifts as well as mining locomotives, primarily across Southern and Western Africa, but also with a focus on Europe, Australia and New Zealand. LIB components, such as the casings, harnesses and copper bar used by the company for their packs, are manufactured locally either in-house by FreedomWon or sourced from its associated partners. The FreedomWon battery packs contain an advanced BMS imported from the United States and circuit breakers imported from Italian manufacturers.

EV Dynamics manufacturers electric drivetrains for EVs and e-busses. EV Dynamics’ core business is in converting ICE vehicles into EVs as well as in manufacturing EVs. Since its inception, EV Dynamics has converted various vehicles and successfully converted a 65-seater commuter bus, which has completed over 30 000 kilometres. EV Dynamics is currently finalising a contract with a Limpopo-based bus company to convert 500 of its buses into e-buses. With its own developed drivetrain, chassis and electric motor, EV Dynamics aims to transform South Africa’s transport sector through the manufacturing of its own electrical minibus taxis. In addition, the company has also partnered with global companies in the UK, US and South America, with hopes of being able to convert its public transport vehicles into EVs. The company assembles LFP battery packs, which are used across its product applications. The LFP cells and BMS are both imported from China, however, the company is currently in the process of developing its own BMS. It is also interested in establishing a factory.

To sum up, there is currently no commercial production of battery cells in the country and it remains to be proven whether such an activity would be competitive domestically. Battery manufacturing based on imported cells is, however, a vibrant industry in the country. Numerous firms have developed IP and expertise in the manufacturing of specific components, parts and systems as well as the assembly of battery packs. In some cases, companies have further leveraged this expertise to develop additional offerings, such as specialised vehicles.

3.4. Reuse and waste management

A number of companies are involved in marketing second-life batteries on the local (and regional) market. Indeed, LIBs used in EVs as their first life can be refurbished and repurposed to be used in stationary applications. In fact, some second-life batteries even display better performance for stationary applications than new battery packs. This is critical to extend the useful life of LIBs.[21]

One such company is Revov (historically 2ia), headquartered in Gauteng. Revov focuses on providing second-life LFP batteries in South Africa and the rest of the continent.[22] The firm covers both the residential and light commercial segments as well as the heavy industrial market. Revov has struck a strategic partnership (reinforced through a share swap agreement) with a Chinese company repurposing LFP batteries (from Tier 1 manufacturers) used in EVs in China. These second-life batteries comprise of cells removed from battery packs of EVs (including e-buses) then assembled into battery packs for energy storage. The Chinese partner tests and, if required, refurbishes battery packs with new cells. Revov markets (through a network of wholesalers and dealers) the batteries and serves the warranty locally, repairing and repurposing faulty packs. Revov is also in the process of developing its own standalone BMS, specific for second-life batteries, which would be manufactured domestically in Gauteng. Over the past 18-24 months, Revov has imported approximately 16 000 battery packs from China. The company currently sells around 600 packs a month across South Africa and surrounding countries, including Botswana, Zimbabwe, Mozambique and Namibia.

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[21] R&D is underway globally on developing third use, based on the rejuvenation of cells to 60%-70% of their lives.
[22] The firm also provides new LIBs (LFP) as a side business.

Beyond second (and in the future, third) use, battery packs have to be dismantled and recycled. Only a few facilities globally are currently in a position to effectively recycling LIB. No such facility exists in South Africa. Batteries are currently stockpiled and/or shipped to available facilities around the globe.

In November 2020, DEFF published the regulations on EPR, in line with the National Environmental Management: Waste Act No. 59 of 2008. The regulations aims, through the establishment of Producer Responsibility Organisations (PROs), to: (1) provide the framework for the development, implementation, monitoring and evaluation of EPR schemes by producers; (2) ensure the effective and efficient management of the identified end-of-life products; and (3) encourage and enable the implementation of circular economy initiatives. Importantly, PROs would include all relevant stakeholders in the value chain, including firms manufacturing, converting, refurbishing and importing new and/or products, as well as waste pickers and recyclers. According to the regulations, value chains have six months to submit their EPR/PRO plans to the department. Infrastructure required for implementation should, furthermore, be established within three years from the inception of the EPR scheme.

Large batteries, including LIBs, are covered by the regulations for the electrical and electronic equipment sector. Regulations published in November 2020, however, excludes portable batteries (as well as lead-acid batteries), which will be covered separately (notice expected mid-2021). While the opportunity for the LIB industry to request its own, specific EPR notice remains open, as of December 2020, LIBs would be covered under the November 2020 regulations for large-scale batteries as well as upcoming regulations on portable batteries for small-scale batteries.

While the economic viability of a full-blown recycling facility remains to be established, the e-Waste Association of South Africa (eWASA) is exploring (pending approval of EPR schemes and PROs by the DEFF) the possibility of setting up a pilot plant within the next 12-24 months. This is critical as all hazardous e-waste, including LIBs, are banned from being landfilled from 23 August 2021 by the National Norms and Standards for Disposal of Waste to Landfill (in terms of the Waste Act).[23]

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[23] Hazardous Waste Electric and Electronic Equipment (lamps) and lead acid batteries have been prohibited from being disposed to landfill since August 2016.

4. POLICY IMPLICATIONS FOR THE LITHIUM-ION BATTERY VALUE CHAIN IN SOUTH AFRICA

A number of key policy insights arises from the developments detailed in this report as well as stakeholder engagements. They can be clustered into four categories:

- Identifying where in the entire LIB value chain South African industries are (or could be) competitive;
- Formulating key components of an enabling policy framework for the development of the LIB value chain;
- Facilitating access to markets, both domestically and globally; and
- Shaping R&D and skills development in line with South Africa's competitive advantage.

4.1. Finding a competitive advantage

The LIB value chain, as highlighted in Section 2, is highly competitive. Effectively dominated by a limited number of firms (originating from an even smaller group of countries), the LIB value chain presents relatively high barriers to entry for firms aiming to enter the market going forward. At the same time, the value chain is rapidly evolving, with cutting-edge technological innovation constantly shaking the status quo in the market. The combination of these two dynamics bears important considerations for South Africa's industrial development in the space. In order to sustainably grow the local industry and compete in the global LIB value chain, it is imperative to identify the niches (or market segments) where South Africa displays (or could display) a strong competitive advantage.

As illustrated in Sections 3 and 4.2, South Africa (and even more so Southern Africa) hosts a wide array of minerals relevant for the development of LIBs. This provides a valuable comparative advantage but is not in and of itself a competitive advantage for the country. Minerals are generally priced at global level and the price sensitivity of a battery pack to mineral prices is relatively small. It warrants, however, that South Africa considers how to foster mineral beneficiation for LIBs.

Whether or not South Africa provides, currently, the adequate conditions to develop mineral beneficiation is debatable. The country has a longstanding history of mineral beneficiation, supported by established companies, a strong pool of skills and expertise, and renowned expertise in the field. The underlying conditions which led to a strong mineral beneficiation industry in South Africa have, however, shifted. Most importantly, the end of the commodity boom (in 2011) and fast-rising electricity prices have significantly eroded the position of local industries on global markets. The industry has been rapidly shrinking over the past two decades. On the whole, the South African mineral value chains are furthermore not currently servicing the LIB market. Yet some companies, such as MMC and Hulamin, have demonstrated the possibility of playing competitively in the LIB market, leveraging niche expertise.

At the manufacturing level, similar considerations apply. The South African industry would appear unable to compete with leading firms producing LIB cells. Economies of scale, combined with the volume and innovative nature of IP, place leading firms significantly ahead of the pack. While local projects are in development, they are yet to be proven economically viable, particularly in the current market conditions (i.e. limited local demand).

A more complex picture emerges at the level of battery manufacturing. On the one hand, barriers to entry to the automotive industry are extremely high. Traditional OEMs have established partnerships with manufacturers in China, Japan, South Korea, the US and Europe, through which they develop and improve LIB technologies as per their requirements. Collaboration with the local automotive industry (including through the design of the APDP), would contribute to overcoming such a barrier. Competing for large-scale energy storage systems also requires volumes and a track-record that most local manufacturers are not in a position to provide. On the other hand, based on imported cells, a myriad of local firms are actively competing (domestically, regionally and globally) in the market. Most local companies in the LIB value chain (particularly battery producers) focus on applications outside the automotive industry, such as telecommunications, logistics and industrial equipment. Leveraging local expertise and intellectual property in battery design, BMS and EMS, South African firms are domestically assembling competitive and cutting-edge battery packs for a variety of markets. In some cases, firms are leveraging such battery packs to successfully market EVs for specific applications (such as refrigeration trucks, mining vehicles and utility vehicles).

4.2. Enabling policy support

Overall, beyond direct support, sending clear, positive signals in favour of the development of the industry would contribute to attracting investments into the sector.

Access to funding remains a key hindering factor to the development of the LIB value chain in South Africa. As a nascent industry relying on innovative technologies, the domestic LIB sector is primarily composed of SMMEs. The development of some operations (such as mineral refining) is furthermore particularly capital intensive. Effectively, to date, while some have been supported (such as Thakadu, Bushveld and Balancell), most of the local industry has developed with little to no financial support from government and development finance institutions.

This lack of financial support has directly hindered the growth (in scale and speed) of the local industry. While this is experienced by SMMEs across sectors, the highly competitive and fast-moving nature of the LIB market exacerbates the challenges faced by firms entering the value chain. This is particularly the case for commercialisation. Despite some existing programmes (such as the Manufacturing Competitiveness Enhancement Programme and the Black Industrialists Scheme), support to expand operations is similarly lacking.

Other support mechanisms could help grow the industry by removing factors hindering developments.

A key area is around the testing and certification of LIBs. While selling into the African market (including South Africa) does not require specific certification (beyond the one provided by cell manufacturers), entering the US as well as European markets carries additional requirements. This requires to test and certify for performance and reliability as well as stability and safety.

For transportation, all LIB packs are required to undergo testing and certification prior to shipping, in line with UN 38.3 transportation testing requirements. These tests subject cells and batteries to conditions they would experience during shipping and handling. In addition to the UN 38.3, for the European market, cells and batteries must be certified to IEC standards. For the US market, UL certification is increasingly a requirement. As mentioned in Section 4.1, South Africa does not currently have the testing facilities or certification for UN, IEC or UL safety testing. This makes entering the European and US market particularly challenging and expensive for companies. Indeed, certification has to be obtained from foreign, private (and therefore expensive) laboratories. Certification can cost up to R3 million.

Another key aspect is the provision of warranty by new entrants. While some companies have managed to bypass warranty problems (by relying on the warranty of the cells provided by leading manufacturers or setting up competitive offerings), others have experienced difficulties in this space. Considerations could be given to a warranty guarantee scheme to support new (for instance, less than five years) businesses.

4.3. Access to market

Accessing markets, both domestically and globally, remains a challenge for firms operating in the LIB value chain from South Africa.

On the domestic front, the lack of demand is a critical factor hindering development. Due to the scale of demand required to support manufacturing, this is moreover a factor set to remain prevalent for the foreseeable future. Increasing local (and regional) demand would support the business case for establishing local manufacturing capacity, and many companies are waiting for positive signals on this front before confirming investments. Importantly, the dearth of local demand is a constraint throughout the value chain, from cells to battery packs, to EVs and energy storage solutions, and somewhat of a catch-22 situation, as stages of the value chain depend on one another.

In the short term, a dual strategy aimed at growing local demand as well as local manufacturing (primarily on the back of global demand) would therefore be required (see Montmasson-Clair et al., 2020) for a discussion on this). Importantly, high levels of local content at the energy and automotive industry levels are conditioned on high levels of local content at the battery manufacturing level. While mining, battery pack manufacturing and mineral refining are all already occurring domestically and could be materially enhanced with the right enabling environment, the local development of cell manufacturing, which captures a large share of value addition, has not been proven viable to date. In the absence of a policy accepting a price premium for cell manufacturing, this emerges as a key constraint for local content targets in associated industries.

As raised earlier, access to global markets is, moreover, very competitive and requires niche expertise. As discussed in Section 4.1, firms active in battery manufacturing face significant challenges with testing and certification. Firms involved in mineral beneficiation deal with other challenges, primarily linked to transportation issues. Costs as well as administrative and technical delays linked to road infrastructure, ports and customs effectively erode the competitiveness of South African exporters of bulk commodities.

Challenges related to transport infrastructure remain a key concern for South African battery producers exporting across the African region. Producers have identified efficient infrastructure and associated transport services as being critical for the competitiveness of their exports, particularly when exporting by road or sea. Transport costs in the form of delay charges, red tape and bureaucracy as well as the low quality and poorly functioning transport infrastructure are factors said to undermine the competitive advantage of producers.

In addition, the nature of electricity supply in South Africa is an increasing concern for firms operating in the LIB value chain. Besides the unreliable supply and fast-rising electricity prices (which hinder competitiveness), the carbon intensity of the local power supply is increasingly problematic for manufacturers involved in the value chain (see Montmasson-Clair, 2020 for more on this). Access to clean energy is rapidly becoming a requirement for industries across the board, and particularly in the LIB field.

4.4. Skills development and R&D

Access to a pool of skilled and experienced people is critical for the development of the innovation-heavy LIB value chain in South Africa. Different skills and qualification levels are required in LIB R&D and manufacturing. These range from operators, technicians and engineers to mechanics, electricians and highly-skilled PhD graduates.

Effectively, most local SMMEs involved in the LIB industry originated from research and academia, with founders and key staff members arising directly out of programmes at universities or research councils. Often, local startups have also leveraged and further developed IP (including patents) initiated in such R&D environments.

Some companies have also developed (at their own cost) in-house training to train new recruits (most of them university graduates) in relevant fields. In some cases, companies have collaborated with local universities to develop a knowledge base in battery R&D and manufacturing. Indeed, the Energy Storage Consortium, spearheaded by DSI, has positively contributed to the development of relevant skills in the country (see Section 4.1). It has also enabled key partnerships with institutions in leading countries (US, Germany, Singapore, China) to develop skills and R&D capabilities.

As such, to date, access to skills has not been a key constraint for most SMMEs operating in the value chain. Furthermore, the economic downturn generated by the COVID-19 crisis has led to an excess of skills on the labour market.

However, South Africa remains far behind leading countries in LIB-related R&D and skills development. As shown in Section 2.6, LIB-related patents are highly concentrated in a few countries. On the skills development front, to date, only a few universities in the country provide teaching and research opportunities in the field of LIB technology. The limited volume of expertise available domestically is evidence when compared to global leaders. Who Owns Whom (2019) reports that, since 2011, the RDI programme supported by the DSI has produced a total of 29 Master's graduates, 12 PhDs and seven postdoctoral students. In comparison, Chinese battery manufacturer CATL, in 2017, had a total of 119 PhDs and 850 Master's graduates.

In the long run, the LIB value chain in South Africa faces a heavy shortage of R&D and technical skills to compete with incumbent firms. Already, some companies have had difficulty retaining their skilled employees. More resources are required to develop skills and IP in niches in which South Africa displays a competitive advantage (see Section 5.1).

Scaling up R&D and skills development is a joint responsibility of government, academia, the private sector and civil society (the so-called "quadruple helix"). Both government and the battery industry should address this skill gap with specific funding programmes.

Looking ahead, the DSI with support from the EWSETA has made a commitment to promote skills development and support the LIB industry. The Services Sector Education and Training Authority (SETA) is expected to train and develop candidates to work in energy storage alongside the energy consortium members at the respective universities involved in the RDI programme. The training is aimed at N4 to N6 graduates[24] in chemical and electrical engineering with a focus in materials study, testing and verification and computational modelling. Other SETAs, such as the Manufacturing, Engineering and Related Services Sector Education and Training Authority (MerSETA) and the CHIETA, also have a role to play in skills training and development in battery technology development, and should follow suit.

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[24] A National Accredited Technical Education Diploma qualification combines theory and practical work experience, of between 18 and 24 months. This type of qualification is aimed at giving graduates, specifically in engineering studies the theoretical, technical and practical knowledge required in a trade or vocational area (Job, 2020).

5. WEIGHING OPTIONS GOING FORWARD

Looking ahead, four avenues emerge as possible technical pathways to support the development of the LIB value chain in South Africa. Namely, these are fostering: 1) mineral refining; 2) cell manufacturing; 3) battery manufacturing and assembly; and 4) battery recycling. Importantly, such options are not mutually exclusive and are rather complementary in nature.

However, the viability of these pathways largely differs in the short term. Similarly, industrial development associated with these options is at different levels of maturity in the country. Pathways are investigated in their order of readiness. Indeed, only two pathways, namely developing battery manufacturing and mineral refining, are ready for scale-up. The below section considers the implementation requirements as well as high-level costs and benefits for these options. The other two avenues, i.e. developing commercially-viable cell manufacturing and recycling, are yet to be proven viable in the South African context and are considered at a higher level.

5.1. Boosting battery manufacturing

A first avenue to develop the LIB value chain in South Africa is to foster the growth of battery manufacturing (i.e. battery pack manufacturing). A wide array of South African firms are already active in this space, servicing various market segments. Leveraging local IP, multiple domestic firms have designed and manufactured a set of innovative, relevant and competitive products for both local and global markets. This also includes interesting developments for the second life of batteries. With the exception of cells (imported from Asia), the manufacturing of new battery packs generally relies on local inputs, materials and expertise.

Given South Africa’s existing position in the value chain, this avenue is the most viable option in the short to medium term. Most existing firms have developed in a difficult context, with limited to no support from government, and restricted domestic demand. Programmes aimed at nurturing existing companies (for expansion, particularly to global markets) as well as assisting the emergence of new, additional businesses would support multiple policy objectives. Most notably, focusing on development battery manufacturing capacity is directly aligned with the move towards a knowledge-based, green economy. Focused on SMMEs, it would also positively contribute to economic diversity and transformation.

A varied set of interventions would be required to proactively develop battery manufacturing in the country. Table 5 provides a high-level, aggregated overview of the implementation requirements as well as costs and benefits of these possible measures.

First, financial assistance, in the form of grants and/or concessional funding would go a long way in facilitating access to finance. As raised in Section 5, a particular gap exists for the commercialisation of newly-developed products. This could be disbursed through various entities, such as the dtic (Manufacturing Competitiveness Enhancement Programme, Black Industrialist Programme), Small Enterprise Finance Agency (SEFA), Small Enterprise Development Agency (SEDA) and the IDC. This could be actively enhanced by leveraging international development finance (such as the Global Environment Facility and the Green Climate Fund), innovative funding instruments (such as green bonds), and through greater access to both commercial debt and equity finance, notably venture capital, and multiple business development services.

Second, the domestic capacity to test and certify battery packs would need to be materially enhanced. This is particularly critical to enable domestic firms to supply the automotive market as well as export to the European and American markets. This could be channelled through the NMU’s existing facility.

An estimated R10 million would be necessary to offer performance as well as safety testing in the country. In collaboration with private laboratories (such as UL and Bureau Veritas), this could provide the platform to develop relevant certifications domestically.

Third, an increased focus on R&D and skills development, in partnership with South Africa's Energy Storage Consortium (and any other relevant institutions), would contribute to ensuring that local entrepreneurs and SMMEs have access to human and intellectual capital. As highlighted in Sections 4 and 5, the link between research institutions (universities and research councils primarily) and local SMMEs in the LIB value chain is remarkably strong. Making the existing R&D tax incentive (administrated by the DSI, as per Section 11D of the Income Tax Act No. 58 of 1962)[25] more easily accessible to SMMEs would also accelerate the development of innovative firms locally.

Last but not least, improving the ease of doing business for SMMEs would strongly enhance their development and growth. This could consist of reducing bottlenecks and hindering factors disproportionally impacting small businesses, such as regulatory burdens, simplified access to (governmental) procurement programmes (such as tenders from Eskom and municipalities, or procurement from automotive manufacturers under the APDP) and access to affordable and reliable services (such as electricity, water, transport). In addition, business facilitation services would improve the ecosystems in which small businesses operate. Along with the lines of the credit guarantee scheme recently established as part of the country's COVID-19 crisis response, a scheme to back warranty by SMMEs could be considered. Consideration could also be given to setting up local content requirements (thresholds and targets) for the public procurement of LIBs (known as "designation"). In doing so, the reality that local battery production relies, to date, on imported cells which capture a large share of the value added should, however, be recognised. As raised earlier, whether cells can be competitively produced in South Africa remains to be ascertained.

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[25] The incentive allows: a) a deduction equal to 150% of expenditure incurred directly for R&D; and b) an accelerated depreciation deduction (that is, 50:30:20) for capital expenditure incurred on machinery or plant used for R&D.

Table 5: Socio-economic implications of supporting battery manufacturing

STAKEHOLDER	IMPLEMENTATION REQUIREMENTS	ESTIMATED COSTS	ESTIMATED BENEFITS
MINING/ BENEFICIATION COMPANIES	Ensure access to competitively-priced inputs.	n/a	Increased local demand for relevant products.
CELL MANUFACTURERS	n/a	n/a	Domestic demand for (locally-produced) cells.
BATTERY MANUFACTURERS	Invest in manufacturing capacity, including R&D and skills development.	Investment costs, including risk taking.	Increased support from government.
BATTERY BUYERS/ USERS	Support locally-made batteries and associated products.	None in most cases. A price premium could exist in some cases.	Increased local content. Easy access to products, as well as parts and components. Access to potentially cheaper products, with positive spillovers on sales and waste management opportunities.
GOVERNMENT	Provide and leverage further financial support to local SMMEs. Facilitate the establishment of testing/certification facilities. Provide increased support for R&D and skills development. Reduce hindering factors and provide business facilitation services business support.	The cost of the financial and non-financial support.	Development of a new industry, including increased job creation and exporting opportunities. Positive contribution to many other policy objectives, including economic diversification and transformation.
STATE-OWNED ENTERPRISES	Eskom: Provide reliable, affordable and clean energy (in collaboration with Independent Power Producers – IPPs) Transnet: Provide reliable and affordable transport infrastructure (rail, port).	Investment in infrastructure (maintenance and new build).	Sustained/enhanced demand from manufacturing value chains.
RESEARCH INSTITUTIONS/ ACADEMIA	Engage in industry collaboration and support (skills development, R&D and testing).	Investment in equipment as well as human capital.	Development of cutting-edge expertise.

Source: Authors

5.2. Growing mineral refining

A second avenue to enhance the involvement of South Africa's industry in the LIB value chain is to develop the beneficiation of local minerals to battery grade. As highlighted in Sections 3 and 4.2, the country has a longstanding but declining mineral beneficiation industry. The country hosts a limited number of firms already refining minerals (manganese, aluminium) for battery manufacturing, while other companies are exploring new opportunities (such as refining lithium and nickel).

South Africa can leverage its expertise and existing value chains to develop battery-grade products. Importantly though, beneficiation operations are energy intensive and require reliable, affordable and, going forward, clean energy supply. In addition, the mineral endowment does not directly translate into a competitive advantage. The successful development of battery-grade products hinges on identifying competitive niche market segments as well as providing a conducive economic environment (especially in terms of energy supply and transport). A beneficiation policy (such as an export tax or developmental pricing) could, in relevant cases, support such developments.

Developing mineral refining for battery manufacturing hinges on a set of measures. Table 6 provides a high-level, aggregated overview of the implementation requirements as well as costs and benefits of these possible interventions.

First, access to modern infrastructure would be required. Interventions are needed to ensure access to reliable, affordable and clean energy. Combined with support for energy efficiency interventions (such as the existing 12L tax incentive[26]), this would require to decarbonise the electricity grid as well as allow industrial facilities to procure their own (low-carbon) electricity from IPPs. In addition, improved transport infrastructure (rail, road, ports) is necessary to reduce associated costs, particularly towards export markets.

Second, investment support could be enhanced through both financial (such as development finance) and non-financial assistance (such as special economic zones and industrial parks). This could also extend to R&D and skills development support, as mentioned in the previous section.

Last, a mineral beneficiation policy could be enacted to further improve the competitiveness of the industry.

A bottom-up approach, either through an export tax or a development pricing policy, would represent the most viable option. This would only be viable for minerals in which South Africa holds a dominant position (such as manganese). Imposing an export tax (as done for chrome from 2020) would raise the price of raw material for foreign markets, while reducing the relative price for domestic downstream producers, thereby creating an indirect subsidy in their production process. More of the raw material supply would become available for local manufacturers, at below world market prices. Developmental pricing, included as an option in the Mineral and Petroleum Resources Development Act No. 28 of 2002, would introduce regulated pricing with the aim to reduce input costs and ensure competitive local pricing for downstream industries in the components value chain.

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[26] The 12L tax incentive for energy savings has been implemented by the DoE (now DMRE) since December 2013, allowing businesses to claim a deduction against taxable income equivalent to the monetary value of proven energy efficiency savings.

A top-down approach, though the APDP and localisation requirements in procurement programmes, would also be supportive but likely insufficient to influence the refining stage of the value chain.

Table 6: Socio-economic implications of supporting beneficiation activities

STAKEHOLDER	IMPLEMENTATION REQUIREMENTS	ESTIMATED COSTS	ESTIMATED BENEFITS
MINING COMPANIES	Ensure access to minerals Negotiate mineral beneficiation policy if relevant.	Reduced mineral rent in case of beneficiation policy Reduced export competitiveness in case of export tax.	Sustained / increased domestic demand
BENEFICIATION COMPANIES	Identify relevant competitive niches. Invest in beneficiation capacity. Negotiate mineral beneficiation policy if relevant.	Investment costs, including risk taking. Higher mineral costs if export tax.	Sustained activity. Facilitated access to competitively-priced minerals. New products/ expanded access to markets.
BATTERY/CELL MANUFACTURERS	n/a	n/a	Local availability of battery-grade products, at competitive prices.
BATTERY BUYERS/USERS	n/a	n/a	n/a
GOVERNMENT	Negotiate mineral beneficiation policy if relevant. Support to beneficiation companies (development finance, economic/industrial zones). Facilitate access to reliable, affordable and clean energy.	Financial and non-financial support to beneficiation industry.	Sustained/enhanced manufacturing capacity, including employment.
STATE-OWNED ENTERPRISES	Eskom: Provide reliable, affordable and clean energy (in collaboration with IPPs). Transnet: Provide reliable and affordable transport infrastructure (rail, port).	Investment in infrastructure (maintenance and new build).	Sustained/enhanced demand from mining/ manufacturing value chains.
RESEARCH INSTITUTIONS/ ACADEMIA	Engage in industry collaboration and support (skills development, R&D and testing).	Investment in equipment as well as human capital.	Development of cutting-edge expertise.

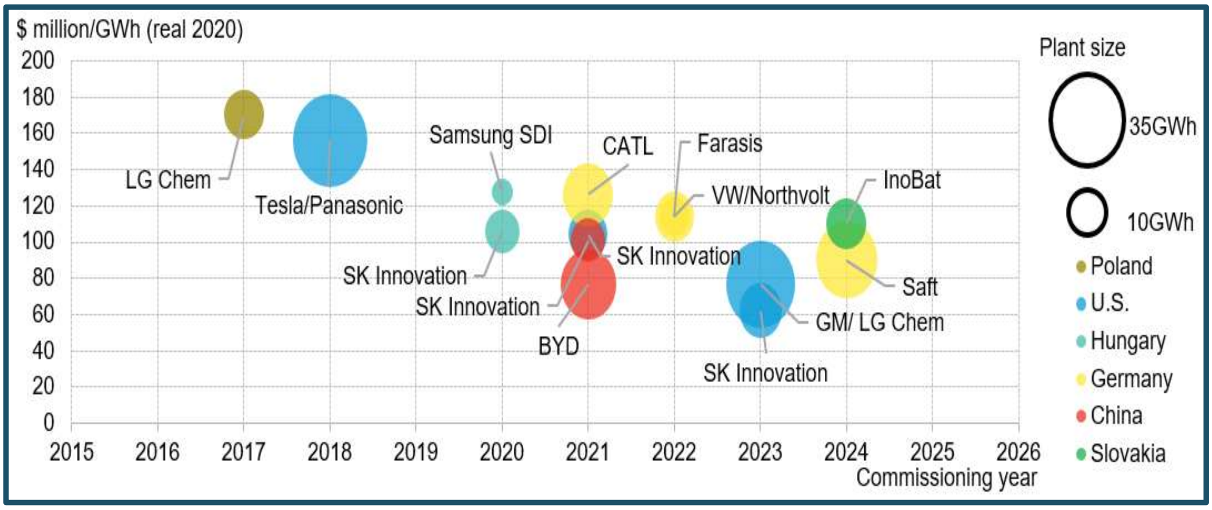
Source: Authors

5.3. Developing cell manufacturing

A third avenue to expand the LIB value chain is South Africa is to explore the possibility of building cell manufacturing capacity domestically. Although some companies are exploring the possibility of setting up manufacturing capacity locally, South Africa does not have, as of November 2020, any commercial cell manufacturing capacity. Effectively, it remains to be proven whether a South Africa-based company could be competitive on this market segment. As demonstrated in Section 2, cell manufacturing is concentrated around a few companies, with Asian firms leading the pack. Economies of scale, coupled with access to expertise/ intellectual property, are the primary determinants of competitiveness for cell manufacturing.

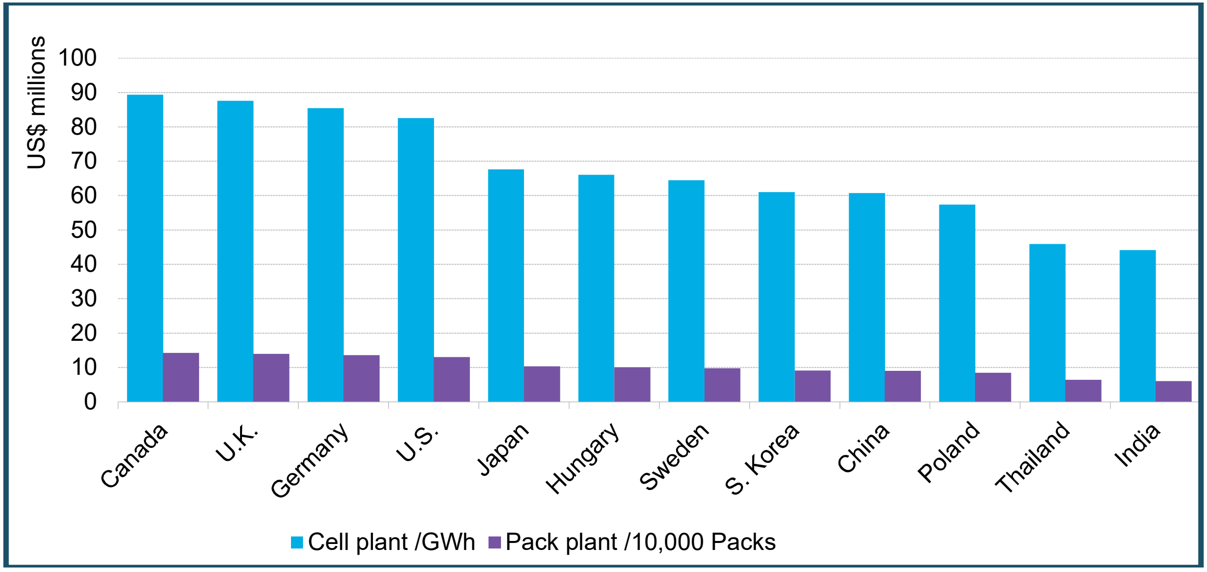
As depicted in Figure 35, despite decreasing costs, setting up mega-factories for cell manufacturing remains a costly exercise. For instance, BYD's 20 GWh per annum facility, to be commissioned in China in 2021, is estimated to cost US$1.5 billion. Establishing a facility manufacturing cells is indeed much more costly than setting up a plant to manufacture battery packs (see Figure 36).

Figure 35: Greenfield cell/battery manufacturing capital expenditure



Source: BNEF, 2020, Dataset on Electric Vehicle Outlook 2020 – Data
Note: it is not always clear if a facility will manufacturer cells, or cells and packs

Figure 36: Battery plant capital investment by region



Source: BNEF, 2020, Dataset on Electric Vehicle Outlook 2020 – Data
Note: The comparisons are respectively based on cell plants of 10 GWh annual manufacturing capacities and packs plant of 50 000 packs/year manufacturing capacities

Supporting the development of cell manufacturing in South Africa would require a long-term concerted effort, bridging investment support and market development. Attracting investors to set up a mega-factory in South Africa would require confirming the business case, both on the supply and demand sides. Access to capital (both development and commercial finance) would not materialise otherwise.

On the supply side, a multitude of factors would need to be met to ensure that cells can be manufactured competitively. These include access to competitively-priced precursors (i.e. refined minerals) and other inputs, cutting-edge IP, state-of-the-art equipment and advanced skills. While some local expertise is available, this would undoubtedly only be wholly accessible through a partnership with an existing manufacturer as well as a leading research institution. In addition, investment conditions would need to be competitive compared to other existing (and future) locations for such a giga-factory. SEZs near South Africa's major harbours (such as Coega in the Eastern Cape and Dube in KwaZulu-Natal) could be possible candidates. Reliable and competitive access to energy, water and transport would also have to be considered. Similar to battery manufacturing, local testing and certification would also be required.

On the demand side, a sizeable market would need to be serviced from such a giga-factory. Coupled with battery manufacturing, the ambition would be to position a South Africa-based plant as the supplier for the African continent.[27] Other markets are effectively already serviced by existing manufacturers. In the South African market, a symbiotic relationship would need to be established with the energy and transport sectors, and with the automotive value chain in particular.

The South African and broader African markets for LIB remain in their infancy and volumes required to sustain a factory are not expected to materialise in the short term. Until local/regional demand is sufficient to enable a competitive giga-factory, localising cell manufacturing would lead to a price premium for buyers. While this could be offset through policy in support of higher localisation (such as the IPP procurement programme and the APDP), it is unclear whether this would be desirable socio-economically and indeed accepted socio-politically. More research on the extent of the potential price premium and the benefits accrued to it would be required to inform such developments.

5.4. Developing battery recycling

A fourth avenue to consider in the development of South Africa's LIB value chain is battery recycling. Only a handful of recycling facilities currently exists worldwide. China, already the market leader, is expected to obtain a quasi-monopolistic position by 2030 (see Figure 37).

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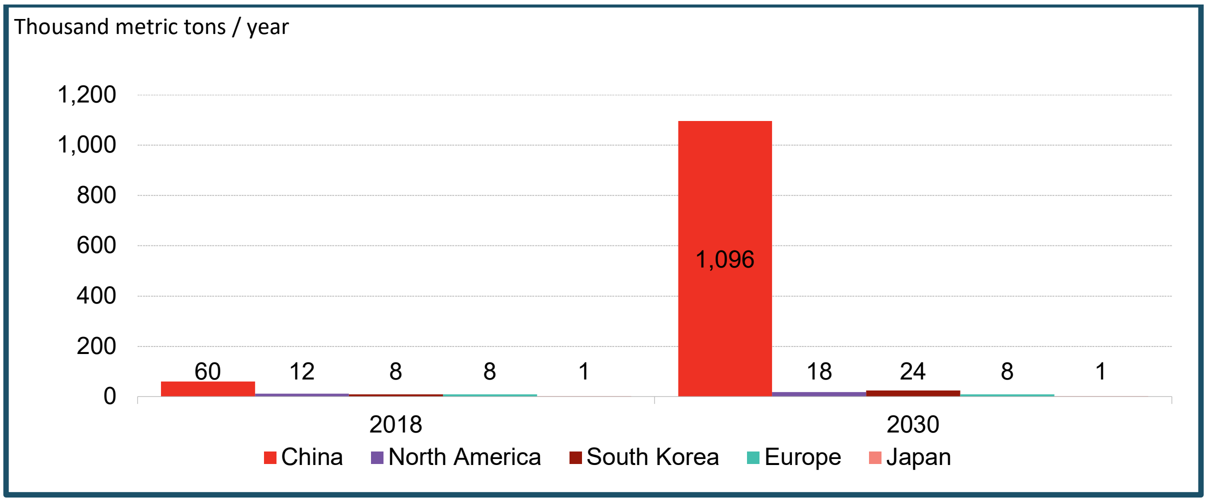
[27] While the state of transport infrastructure, particularly for land-locked countries, would hinder in this case the competitiveness of intra-Africa trade, the African market remains the most likely offtaker of South Africa-based LIB production.

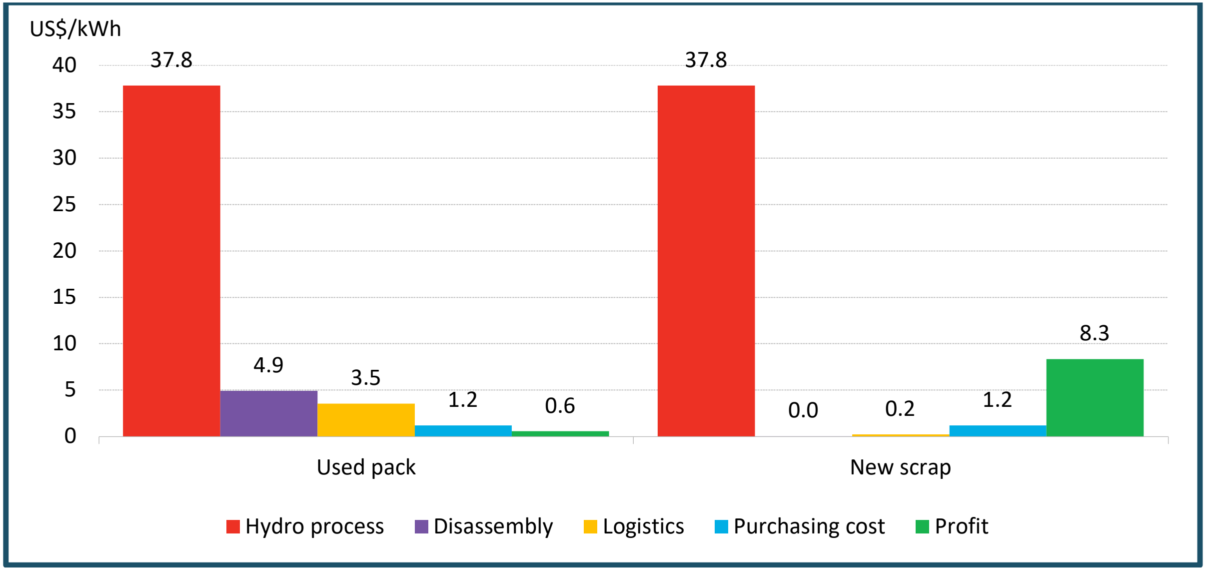
Figure 37: Global recycling capacity in 2018 and forecasted for 2030



Source: BNEF, 2019, Dataset om 2018 lithium-ion battery recycling: 2 million tons by 2030

South Africa does not at present have such a recycling facility for LIBs and, while the country has expertise in mineral processing and recovery, the economic viability of a possible plant is unknown at this point. The economic viability of a recycling facility hinges on sufficient volume (economies of scale), the price of key recovered minerals (such as cobalt, copper, nickel, and lithium hydroxide) and transportation costs. Figure 38 provides a high-level snapshot of the costs associated with recovering metals from LIBs.

Figure 38: Costs of recovering metals from a used NMC (111) battery pack / new scrap NMC (111)



Source: BNEF, 2020, 2019, Dataset om 2018 lithium-ion battery recycling: 2 million tons by 2030

Note: Based on NMC (111), U.S., Hydro, 250 mile, old and new scrap

As of November 2020, the DEFF, in collaboration with the private sector, is in the process of establishing an EPR scheme for batteries sold in the country. By providing detailed information on the state of the market (while arguably small, the extent of the stock of LIBs ready to be recycled in the country is unknown at this point) as well as a strategy for collection, storage and processing, this could provide the impetus for establishing a recycling facility in the medium term.

Mintek, in consultation with DEFF and the dtic, is also working on understanding the potential of the LIB recycling industry in South Africa. In any event, eWASA estimates that a pilot facility is 12-24 months away at best.

6. CONCLUSION

As e-mobility and energy storage capture increasing shares of the transport and energy markets, so is the demand for batteries rising. Battery technology has already undergone significant technological improvements and, every year, batteries are getting more powerful, durable, safe and cheaper to produce. Although other battery technologies exist, LIBs are currently dominating the battery market.

This report investigated the potential for a South African LIB value chain. It unpacked every stage of the LIB value chain, from mining to waste management, passing by mineral beneficiation and manufacturing, with the objective of identifying existing and potential competitive advantage.

The investigation into South Africa's capabilities in the LIB value chain showed a vibrant value chain. Not all stages are, however, at the same level of development. Mining of multiple LIB-relevant minerals, such as manganese, iron ore, nickel and titanium, is already underway in the country and the region. Mineral beneficiation for battery production, while limited, is also present in the country, with existing pockets of excellence in manganese and aluminium and interesting developments in lithium, nickel and titanium. Importantly, battery manufacturing (off imported cells) and battery refurbishing (second-life batteries) is a booming opportunity with many firms operating in this space, leveraging unique expertise and IP, notably in the development of BMS. By contrast, cell manufacturing, while explored at the R&D level, is yet to be proven commercially viable in the country. Similarly, the development of recycling is still in the early days in the country.

The assessment highlighted the need to identify where, in the entire LIB value chain, South African industries are (or could be) competitive. This is critical to channel support and resources into the most sustainable activities. Four avenues emerged as possible technical pathways to support the development of the LIB value chain in South Africa. These are fostering: 1) battery manufacturing; 2) mineral refining; 3) cell manufacturing; and 4) battery recycling. Importantly, such options are not mutually exclusive and are complementary. In terms of readiness, only two pathways, developing battery manufacturing and mineral refining, are ready for scale-up. Cell manufacturing and recycling could be explored in the medium to long term, provided they prove to be economically sustainable.

In any event, supporting the development of the LIB value chain in South Africa will require a long-term concerted effort, bridging investment support and market development. This will require providing an enabling policy framework, facilitating access to markets, finance and support for commercialisation, both domestically and globally, and shaping R&D and skills development in line with South Africa's competitive advantage. Strong partnerships and collaboration between public and private institutions, as well as between local and international players will be required to build a competitive industry in the country.

Looking ahead, the possibility of developing the domestic LIB value chain should not be overestimated. South Africa displays key pockets of excellence in battery manufacturing, mineral beneficiation and mining. Efforts and resources should be focused on these activities. The business cases for cell manufacturing and battery recycling remain to be established, and while opportunities should be explored, it should be done with caution. At the same time, the importance of developing the LIB value chain should be not underestimated. Beyond the opportunities associated with the activities in the value chain itself, an established LIB industry is instrumental to the local development of both the (renewable) energy and (electric) transport industries. Indeed, going forward, achieving high levels of local content in renewable energy and automotive manufacturing will be conditional on localising the battery value chain as much as possible. In turn, the long-term growth of the LIB value chain, both in scale and depth, is dependent on strong partnerships with anchor clients (i.e. battery buyers/users), from the automotive industry, to the energy sector, to telecommunication and logistics companies.

In sum, provided the emphasis is put on the country's evidenced strengths, rather than unsubstantiated aspirations, an electrifying opportunity lies ahead for South Africa. Eureka?

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ANNEXURE A: MINERALS FOR EV-SPECIFIC APPLICATIONS

Given the diversity of chemistries, many raw materials are used in LIBs, including lithium, cobalt, manganese, nickel, graphite, aluminium, copper, iron, phosphate and titanium. These materials are either naturally occurring or recovered from brines. The increase in EVs (and energy storage) is expected to incur high production of raw materials and related beneficiated products. Nickel, manganese, graphite, aluminium, and copper have sufficient production volumes established for other industries and vast reserves still available, however lithium and cobalt for example are limited and their value chains are often complex compared to other materials. This annexure discusses key production and trade dynamics for each mineral.

Lithium

Lithium, which has given its name to the batteries, is the most prominent mineral in the value chain. The most important use of lithium is in rechargeable batteries for consumer electronics and EVs, accounting for 39% of the global lithium market in 2015 (Ding et al., 2019). As the “lightest metal and the least dense solid element” with a high electrochemical potential, lithium became a valuable component of high-energy density rechargeable batteries (Commonwealth of Australia, 2018).

A few countries dominate the market for producing lithium. South America contains 63% of global lithium reserves,[28] located in Chile (52%), Argentina (10%) and Brazil (1%). Consequently, Chile and Argentina are the second and third largest lithium producers in the world. Australia has world’s second-largest reserves of lithium (17%) and is the largest lithium producing country.

Zimbabwe is expected to become one of the world’s largest producer of lithium. According to USGS data from 2017, Zimbabwe was ranked fourth among top lithium producing countries (40 000 tons), with proven reserves of 230 000 tons of lithium ore (1% of global reserves) (see). Most of the country’s reserves remain unexplored due to low investment. According to Mir (2019), Zimbabwe aims to supply 10% of the world’s lithium by 2025 through the Bikita mine located in southern Zimbabwe in the Masvingo Province and the Arcadia open-pit lithium project near Harare. The open-pit project is considered as the largest hard rock lithium resource in the world. Once in production, the project could produce 2.4 million tons of lithium per annum over the 15-year lifespan of the mine (Africanews, 2019).

As the demand for LIBs grow in popularity, the latest USGS figures show that global lithium production reached close to two million tons in 2017, up from about 650 000 in the previous year (Figure 39). Australian producers significantly increased lithium production in 2017 due to price increases caused by strong forecast demand growth for LIBs. In 2019, however, lithium prices plummeted due to the oversupply of the metal by new suppliers.[29] Output production from Chile and China also increased, with other countries seeing a similar increase in their production over the same period.

Various compounds are derived from lithium, but the main ones used for LIBs are lithium carbonate and lithium hydroxide.

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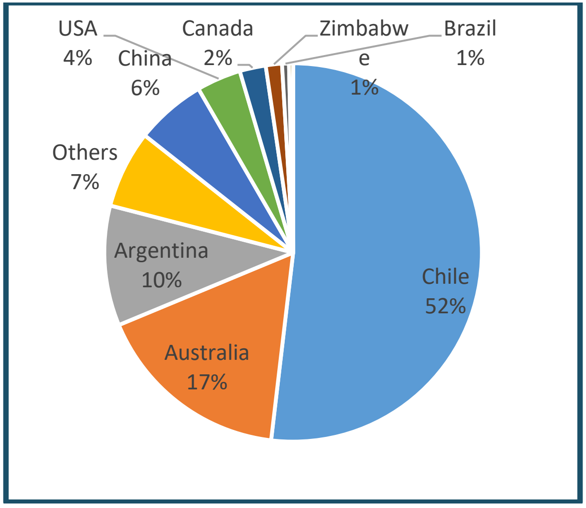
[28] A resource is the amount of a geologic commodity that exists in both discovered and undiscovered deposits. It is by definition an estimate. Reserves are a subgroup of a resource that have been discovered, have a known size, and can be extracted at a profit.

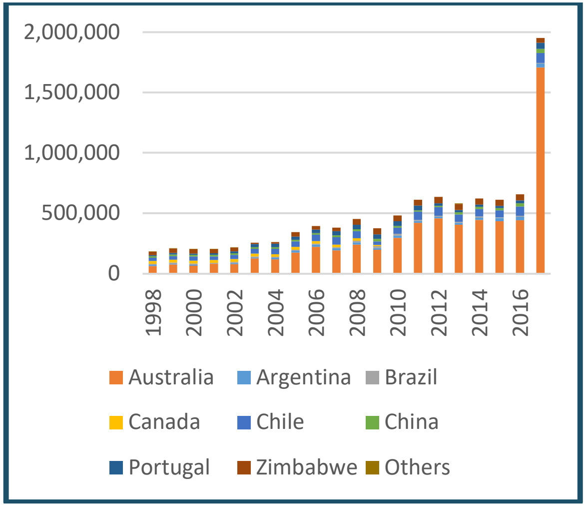
[29] In addition, prices were worsened by Beijing’s cut in government subsidies for new EV purchases in China.

Figure 39: Global reserves of lithium (in metric tons, gross weight)



Source: *Authors, based on data from the US Geological Survey Minerals Yearbook, Series on lithium, downloaded July 2020 at https://www.usgs.gov.*

Figure 40 Global production of lithium (in metric tons, gross weight)



Source: *Authors, based on data from the US Geological Survey Minerals Yearbook, Series on lithium, downloaded July 2020 at https://www.usgs.gov.*

According to Argus (2019), in 2018, lithium carbonate accounted for 60% of total lithium demand; however, with increasing demand for lithium hydroxide (particularly for NMC 8:1:1 cathodes), lithium hydroxide demand is expected to account for a larger share of the lithium market by 2024. Global lithium carbonate exports quadrupled between 2001 and 2019, with exports increasing from about 35 000 tons to about 148 000 tons. In 2019, the top five exporters of lithium carbonate were Chile (84 715 tons), Argentina (27 333 tons), China (12 933 tons), Belgium (7 645 tons) and the Netherlands (6 799 tons). Combined exports by Chile and Argentina, in 2019, accounted for 75% of total global exports. The lithium carbonate importers are concentrated in Europe and Asia – in 2019, South Korea, China and Japan accounted for 63% of all lithium carbonate imports. China's exports of lithium oxides and hydroxides more than doubled from 28 812 tons in 2018 to 49 844 tons in 2019 on rising demand from EV manufacturers in Asia and the major battery consumers (South Korea and Japan). Other significant exporters of lithium hydroxide include Netherlands, Canada, the US and Chile.

Figure 41: Global exports of lithium carbonate (in metric tons, gross weight)

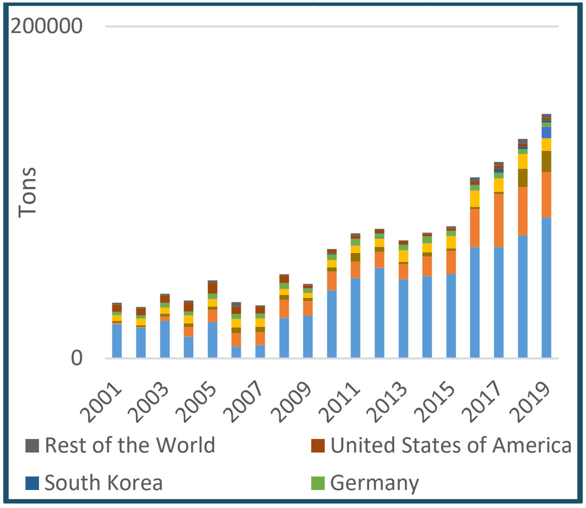
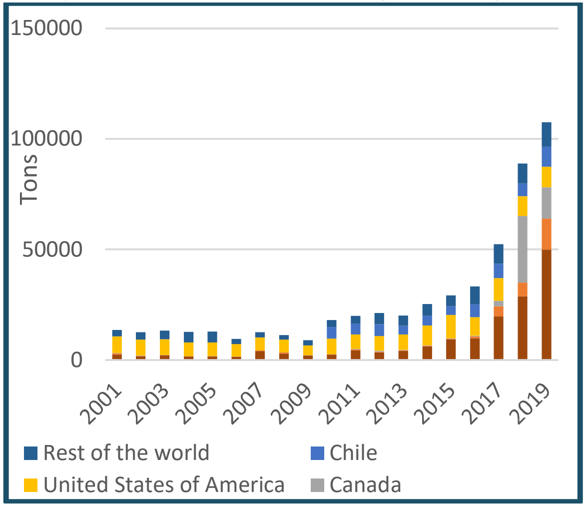


Figure 42: Global exports of lithium oxides and hydroxides (in metric tons, gross weight)



Source: *Authors, based on data from ITC Trade Map. Series on lithium carbonates and lithium hydroxide exports, downloaded on 20 July in 2020 from www.trademap.org.*

Cobalt

Cobalt is a critical element in the cathode material for NMC, NCA and LCO battery technologies. The demand for cobalt for LIBs grew exponentially during the past decade (Benchmark Mineral Intelligence, 2018). Prices increased from US$25 000 per tonne to US$90 000 per tonne in two years, making cobalt the most expensive material used in battery production (Financial Times, 2019).

Although cobalt can be either mined independently or as a by-product of nickel and copper production (Ding et al., 2019), effectively, the output of cobalt is largely dependent on copper production. As more copper is processed, more cobalt is collected as a by-product (Forbes, 2018). Moreover, cobalt reserves and production are concentrated in the DRC and Zambia. Efforts are, however, underway by battery manufacturers and OEMs to reduce the dependency on cobalt required in LIBs. The DRC has the largest cobalt reserves in the world – more than half of the world's reserves at 51% or 3.6 million tonnes. Australia is ranked second for global cobalt reserves (17%), while Cuba's cobalt reserves are the third largest globally (7%). South Africa accounts for 1% (50 000 tonnes) of global cobalt reserves.

As seen in Figure 43, in 2016, total production for cobalt reached 113 000 tonnes, with the largest global supply (55%) sourced from the DRC (Congo Kinshasa). Even though more than half of the world’s cobalt production comes from the DRC, sourcing cobalt from the country is considered complex and challenging. Concerns about mining conditions,[30] in addition to the high cost of cobalt, are forcing battery producers to move toward battery chemistries that rely on magnesium, sodium or lithium-sulphur as these have the potential to compete with LIBs on energy density and cost, with the added benefit of reduced cobalt requirement in their application (Darton Commodities, 2016).

Figure 43: Global production of cobalt (in thousand metric tons of cobalt content)

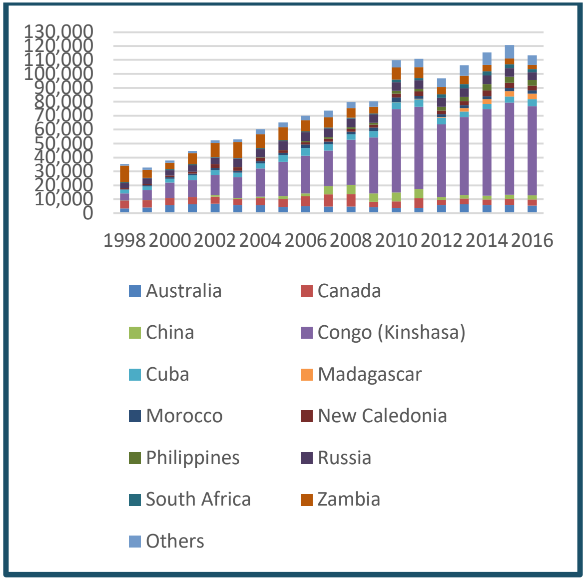
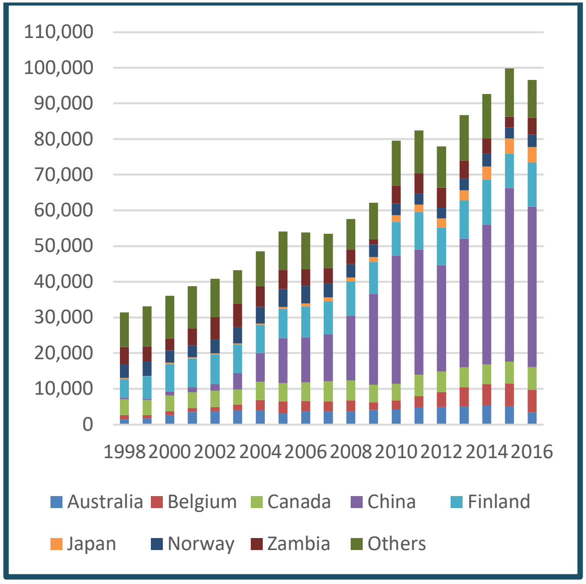


Figure 44: Global production of refined cobalt (in thousand metric tons of cobalt content)



Source: Authors, based on data from the US Geological Survey Minerals Yearbook, Series on cobalt, downloaded in July 2020 at https://www.usgs.gov.

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[30] Criticism of the DRC’s cobalt mining and trade has been linked to environmental pollution, ecosystem destruction and human rights abuses including the use of child labour (The Washington Post, 2016). Concerns about ethical procurement of raw material, supply chain transparency and geopolitical tensions in the DRC are identified risks to the global supply chain of cobalt.

Zambia, as one of Africa's leading cobalt producer, could act as an alternative supplier.[31] However, Zambia's production capacity has decreased in the last few years, from 8 648 tons in 2010 to 3 000 tons in 2016 (Figure 43). Cobalt production has not kept pace with rates of copper production in Zambia. The greatest challenge Zambia faces in growing its cobalt production is the massive capital investment required to set up cobalt processing plants (Conca, 2019). The second challenge for the country is sourcing enough clean power to produce cobalt in a manner that is climate compatible.

South Africa, Morocco and Madagascar also feature in the top miners of cobalt. In 2016, South Africa's mines produced approximately 2 300 tons of cobalt mainly as a by-product of PGM mining activities. It is dominated by Anglo Platinum. In Morocco, cobalt production comes from the Bou-Azzer mine which produced 2 400 tons of cobalt, while Madagascar's Ambatovy nickel and cobalt project produced 3 800 tons of cobalt, with estimated 140 000 tons of reserves.

For refined cobalt, as shown in Figure 44, China was most dominant producer in 2016, contributing 47% to the global refined cobalt production. Other important producers of refined cobalt included Finland (13%), Canada (7%) and Belgium (7%), with Zambia's Chambishi mine accounting for 5% of refined cobalt production, as the only top producer of refined cobalt in Africa. As seen in Figure 45, the DRC is the main exporter of cobalt ores. Between 2001 and 2019, exports from the DRC accounted for 44% up to 95% of global exports. China and Morocco were the top two importers of cobalt ores. In 2019, China[32] and Morocco's imports accounted for 89% and 7% of global cobalt ore imports, respectively. Finland's imports declined between 2001 and 2019 from 61 785 tons in 2001 to 1 743 tons in 2019. China imports cobalt from the DRC for processing into rechargeable batteries for laptops, smartphones and EVs. According to Business Wire (2018), in 2017, 77.4% of global cobalt imports into China were used in LIBs.

Figure 45: Global exports of cobalt ores (in metric tons, gross weight)

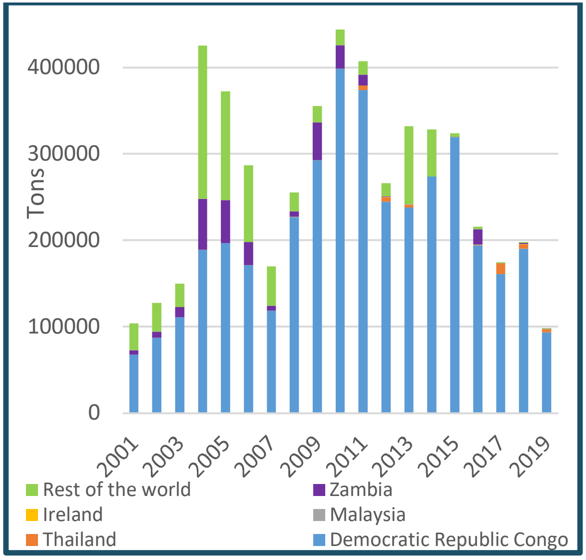
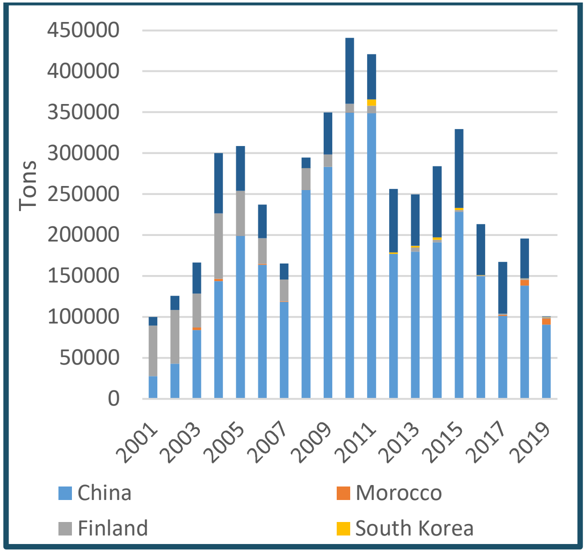


Figure 46: Global imports of cobalt ores (in metric tons, gross weight)



Source: Authors, based on data from ITC Trade Map. Series Cobalt ores and concentrates exports, downloaded on 23 July in 2020 from www.trademap.org.

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[31] Recycling could be another way to reduce the burden on mining cobalt in the Congo.

[32] Eight of the 14 largest cobalt mines in the DRC are Chinese-owned, accounting for almost half of the country's output (Farchy and Warren, 2018).

Manganese

Manganese is used as a component of the cathode material in LIBs based on NMC and LMO battery technologies. However, to date, manganese remains primarily used in steel production and the production of manganese closely follows the steel industry. Only 6% of manganese production ends up in non-steel production and around 90% of the manganese consumed globally is used to produce manganese ferroalloys, consisting of various grades of ferro-and silico-manganese (Steenkamp and Basson, 2016).

South Africa is the largest producer and exporter of manganese ore. South Africa's manganese production accounts for approximately 34% of global production. South32 and Tshipi é Ntle are among leading manganese producers in South Africa.

The country also hosts the largest reserves (32%), followed by Brazil (17%), Ukraine (17%), Australia (12%) and Gabon (8%).

Figure 47: Global production of manganese ore (in thousand metric tons of manganese content)

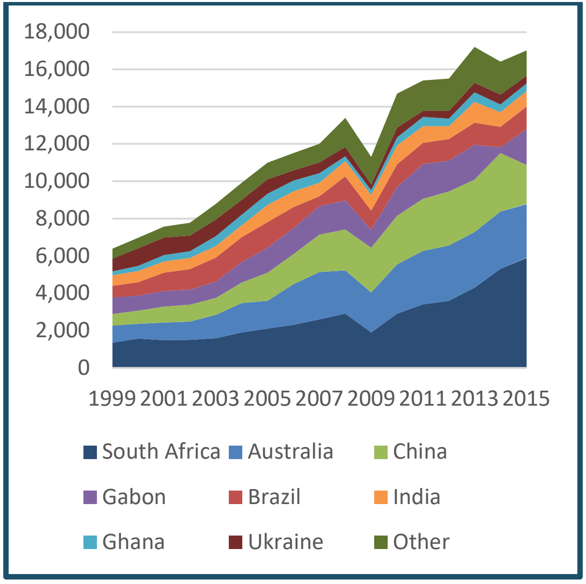
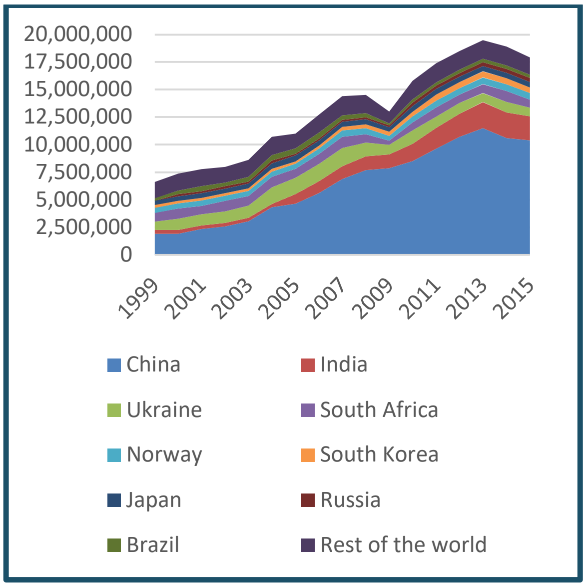


Figure 48: Global production of ferro-and silico-manganese (in metric tons, gross weight)



Source: Authors, based on data from the US Geological Survey Minerals Yearbook, Series on manganese, downloaded in January 2020 at https://www.usgs.gov.

The processing of manganese primarily occurs in China, followed by India and Ukraine (see Figure 48. South Africa only ranks fourth, despite its primary role in mining. Rising electricity prices have led to a decline in South Africa's foundry capacity. According to the Energy Intensive Users Group (2016), up until 2001, 50% of South Africa's manganese was processed locally but, by 2014, this figure had fallen to only 16%. More than 40 furnaces that produced ferroalloys in the manganese industry were shut down, mainly due to the high cost of electricity in South Africa.

Although South Africa is well-endowed with manganese, accounting for 49% of global manganese ore exports in 2019 (Figure 49), 95% of South Africa's manganese is exported for beneficiation in China, India, Norway and Malaysia, the top four importers of South African manganese ore, as shown in Figure 50 (Steenkamp and Basson, 2016; HeraldLIVE, 2019).

Chinese imports grew from about two million tonnes in 2001 to 341 million tonnes in 2019. Once the largest exporter of ferromanganese, South Africa ranked third in 2019. Malaysia and India dominated the export market (see Figure 51). Both China and India have strong smelting and refining capacity relative to South Africa, and Indian manganese alloy producers mostly rely on imports from Gabon and South Africa to fulfil their manganese ore requirements.

Figure 49: Global exports of manganese ores (in metric tons, gross weight)

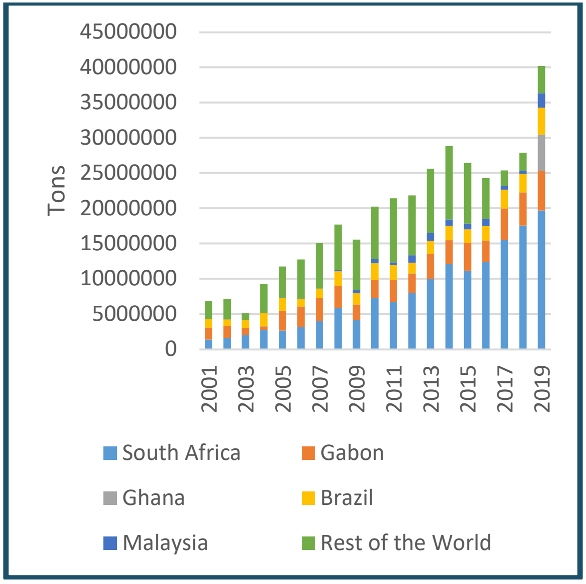
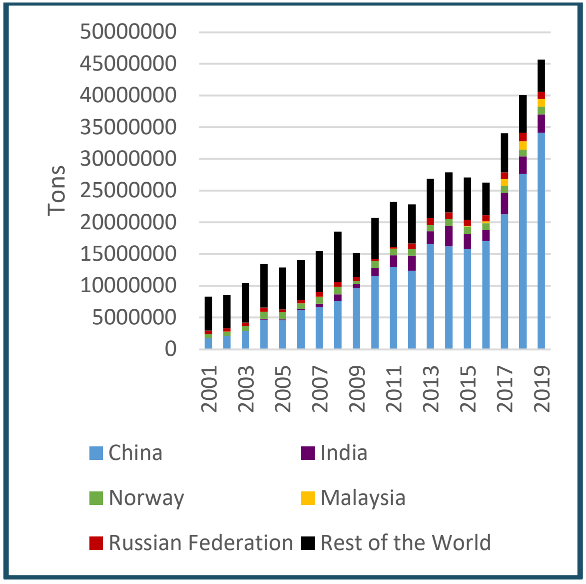
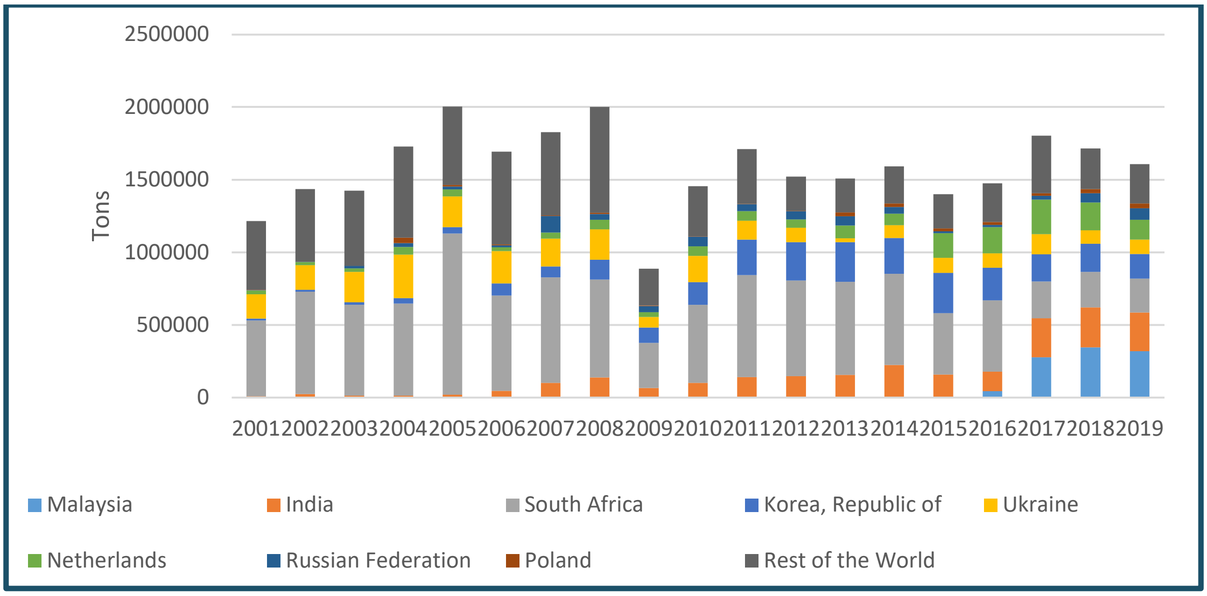


Figure 50: Global imports of manganese (in metric tons, gross weight)



Source: Authors, based on data from ITC Trade Map. Series Manganese ores and concentrates, downloaded on 23 July 2020 from www.trademap.org*.*

Figure 51: Global exports of ferromanganese (in metric tons, gross weight)



Source: Authors, based on data from ITC Trade Map. Series Ferro-manganese, downloaded 23 July 2020 from www.trademap.org*.*

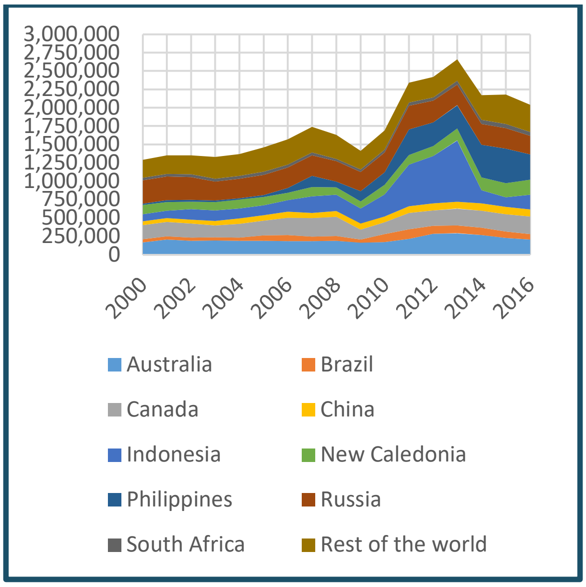
Nickel

Nickel is a key primary material used in NMC and NCA chemistries. Nickel makes up 80% of an NCA cathode, and about one-third of NMC or LMO/NMC-blended cathodes. The major advantage of using nickel in LIBs is its ability to deliver higher energy density and greater storage capacity at a relatively lower cost.

Demand for nickel is rising in response to the accelerated rise in demand for LIBs. As battery formulations evolve, the proportion of nickel in LIBs is expected to grow because increased nickel provides higher energy density. As EV sales climb, Roskill forecasts nickel demand from the battery sector to rise to 258 000 tonnes or nearly 10% of the total demand in 2022 (Reuters, 2019). Reuters (2019) predicts that OEMs manufacturing EVs will be driving demand for nickel by around 16 times to 1.8 million tonnes in the coming years fuelled by meeting large EV markets, and other global markets where demand for nickel is expected to grow.

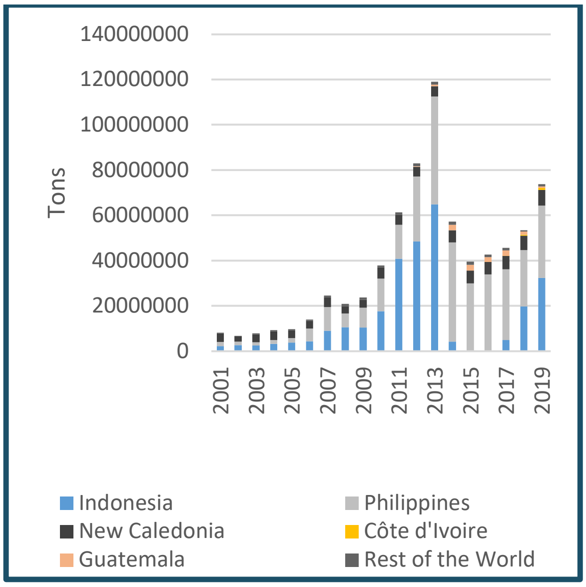
The world's largest nickel reserves are in Indonesia (24%), Australia (23%), Brazil (12%) and Russia (8%). Strong EV production in China, India and other emerging markets should continue to fuel demand for nickel from 2018 to 2022. In 2016, the largest nickel producer was the Philippines producing around 347 500 tonnes, followed by Russia which produced approximatively 252 500 tonnes (see Figure 52).

Figure 52: Global production of nickel ore (in metric tons, contained nickel)



Source: Authors, based on data from the US Geological Survey Minerals Yearbook, Series on nickel, downloaded in January 2020 at https://www.usgs.gov.

Figure 53: Global exports of nickel ores (in metric tons, gross weight)



Source: Authors, based on data from ITC Trade Map. Series Nickel ores and concentrates exports, downloaded on 23 July in 2020 from www.trademap.org*.*

South Africa hosts 4.7% of the world's nickel reserves. In South Africa, about 87% of nickel output is a coproduct of PGM operations. In 2016, South Africa produced about 49 000 tonnes of nickel. It was the ninth largest producer, accounting for only 2% of global production. South Africa has several nickel-producing mines, with one of the largest being the Nkomati mine in Mpumalanga with an estimated 409 million tonnes of reserves. Two new nickel mining projects led by mining company Uru Metals are underway in Zebediela, Limpopo, and Burgersfort in Mpumalanga (Uru Metals, 2019). According to Moolman (2018), BMI Research estimates that the Zebediela mine has 1.5 billion tonnes of inferred and indicated resources and should be able to produce 20 000 tonnes of nickel a year.

Global nickel ores exports are dominated by Indonesia and the Philippines. In 2019, Indonesia and the Philippines accounted for 44% and 43% of global nickel ores exports, respectively. Since 2007, China has been the leading importer of nickel ores, accounting for over 70% of global nickel ore imports. Imported nickel in China is mainly used in stainless steel production.

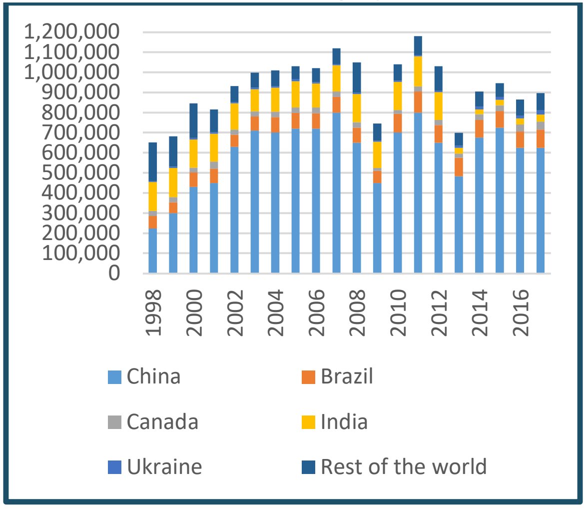
Graphite

The majority of LIBs use graphite powder as the dominant active material in the anode. Graphite material is either synthetic (artificial graphite) or mined from the ground in the form of natural graphite, then processed before being coated with a copper foil. Both synthetic and natural graphite can be used in LIBs. Importantly though, despite the higher cost of synthetic graphite, this form of graphite is currently preferred due to its superior technical performance. Graphite's optimal qualities, such as low electrochemical reactivity, lightness, relatively low cost and structural stability, make it suitable to be used for an anode (Targray, n.d.). It enables lithium ions to move freely between the cathode and anode.

Global reserves of graphite (in tonnes of graphite content) are primarily located in Turkey (30%), China (24%), Brazil (24%), Mozambique (8%) and Tanzania (6%). Mozambique has one of the largest deposits of high-quality graphite in the world. According to US Geographic Survey 2016 data, the graphite deposit is owned by Syrah Resources Limited, an Australian company, which has estimated resources of 1.1 billion tons, thereby containing more natural graphite than all other identified global deposits combined. In the region, Tanzania and Madagascar could also become significant key players. Both countries are said to have some of the world's largest untapped deposits of graphite (E&MJ, 2019). South Africa does not produce natural graphite and currently imports all its graphite ore.

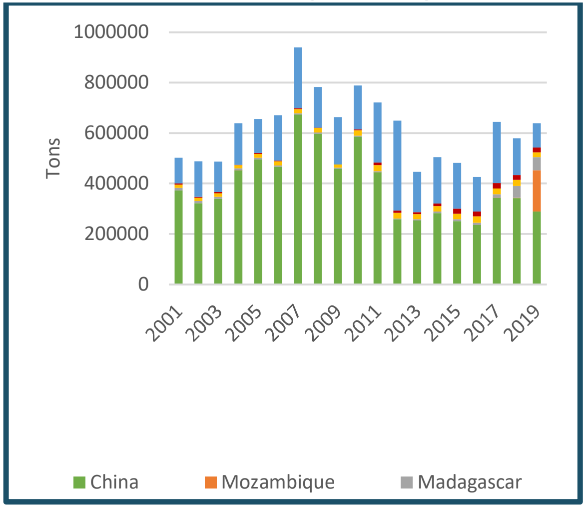
China is the biggest exporter of natural graphite. Prior to 2016, Mozambique did not export natural graphite, but in 2019, its exports accounted for 25% of global natural graphite exports. Chen (2019) reports that 82% of Mozambique's natural graphite imports were destined for China.

Figure 54: Global production of graphite (in thousand metric tons of graphite content)



Source: Authors, based on data from the US Geological Survey Minerals Yearbook, Series on graphite, downloaded in July 2020 at https://www.usgs.gov.

Figure 55: Global exports of natural graphite (in metric tons, gross weight)



Source: Authors, based on data from ITC Trade Map. Series natural graphite, downloaded on 23 July in 2020 from www.trademap.org.

Aluminium

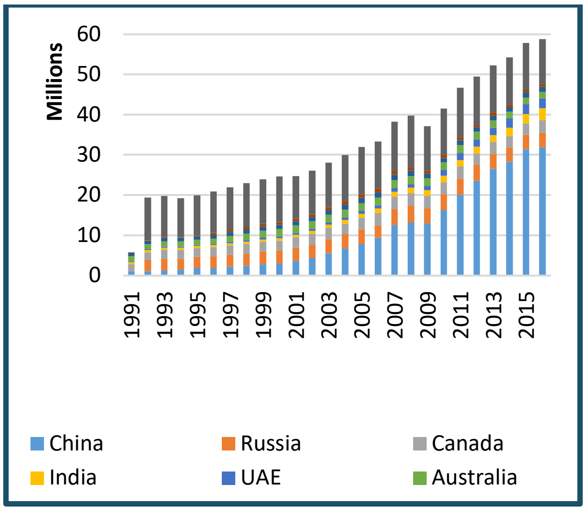
Aluminium has a number of uses in LIBs. It is often used as a current collector due to its low reactivity in lithium electrolytes. Aluminium is also part of the NCA battery cathode, accounting for 5% of the NCA battery portion (Ding et al., 2019).

Primary aluminium production relies on bauxite. Total global bauxite reserves are estimated at 30 million metric dry tons. Guinea has the highest amount of bauxite reserves (24%). In 2016, bauxite reserves in Guinea were 7.4 billion metric dry tons. Other leading reserves were located in Australia

(20%), Vietnam (12%), Brazil (9%) and Jamaica (7%). South Africa does not have any bauxite and imports it from Australia.

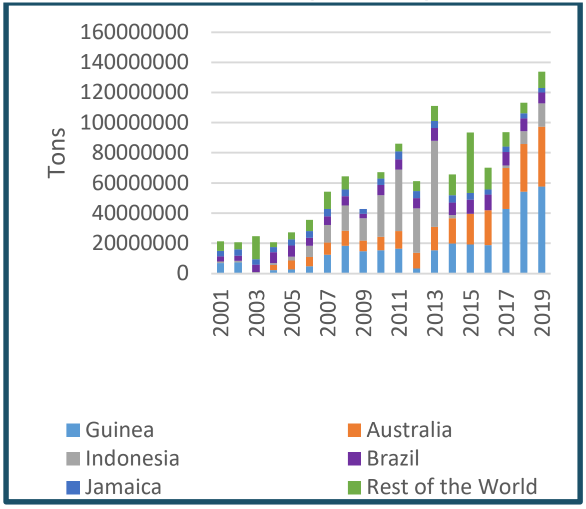
China dominates the production of aluminium, accounting for nearly half of the global production (31.8 million) in 2016. The seven largest producers of primary aluminium in 2016 were China (54%), Russia (6%), Canada (5%), India (5%), United Arab Emirates (UAE) (4%), Australia (3%) and Norway (2%) (see Figure 56). South Africa only accounted for 1.2% of aluminium production.

Figure 56: Global production of aluminium



Source: Authors, based on data from the British Geological Survey

Figure 57: Global exports of aluminium ores (in metric tons, gross weight)



Source: Authors, based on data from ITC Trade Map. Series Aluminium ores and concentrates, downloaded on 23 July in 2020 from www.trademap.org

Guinea and Australia are the top two exporters of aluminium ores. Combined, their exports accounted for 73% of global aluminium ores exports in 2019. A significant proportion of global aluminium ore is refined in China. Since 2011, China has been the main importer of aluminium ores. In 2019, China's imports accounted for 77% of global aluminium ore imports.

Copper

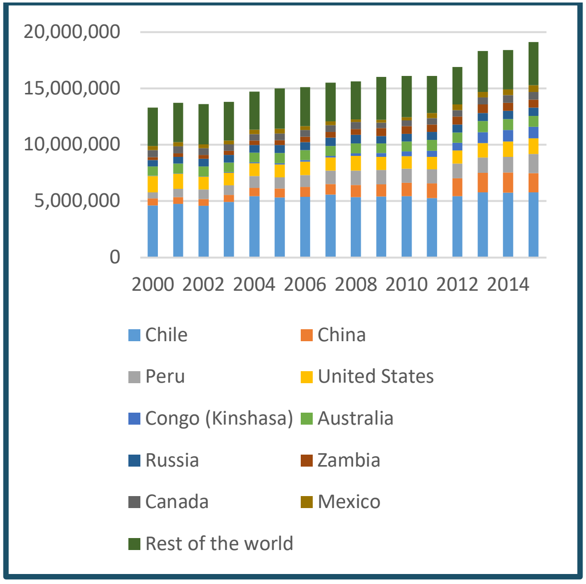
Copper foils are commonly used as a current collector in the processing stage of the graphite anode in LIBs (Commonwealth of Australia, 2018). According to Nanografi (n.d.), copper's high electrical and thermal conductivity are desired properties for a LIB to have a long cycle life. Additionally, copper foils show "good tensile strength and elongation properties which prevents cracking" when they used in anode part for coating in LIBs (Molchem Chemical Technologies, n.d.).

Global copper reserves are primarily found in Chile (23%), Australia (10%), Peru (10%) and Russia (7%). Zambia and the DRC, with about 19 000 tonnes, each account for 2% of copper reserves.

Copper production is also dominated by Chile, followed by China, Peru and the United States. Since 2010, the top eight exporters of copper ores have been Chile, Peru, Australia, Mexico, Mongolia, Brazil, Kazakhstan and Spain. Chile and Peru are the leading exporters of copper ores. In 2019, their combined exports accounted for 58% of global copper ores exports. Global copper imports are concentrated in Asia and Europe. China, Japan and South Korea account for the lion's share of copper imports (78% of global exports in 2019).

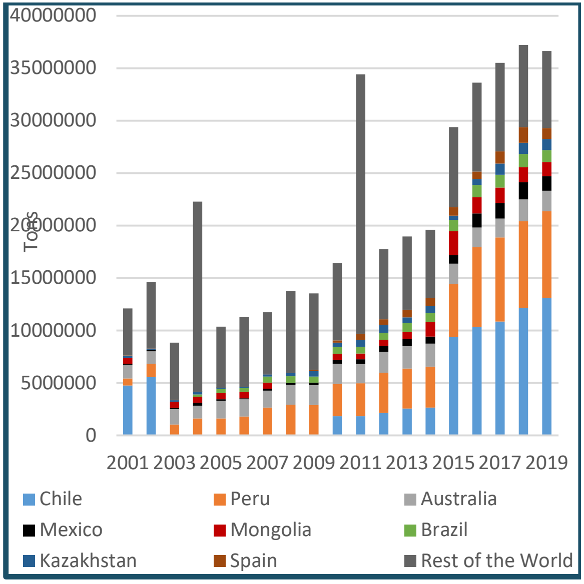
The production of beneficiated copper is dominated by China, both for refining and smelting. Chile and Japan follow.

Figure 58: Global production of copper (in thousand metric tons of copper content)



Source: Authors, based on data from the US Geological Survey Minerals Yearbook, Series on copper, downloaded in July 2020 at https://www.usgs.gov.

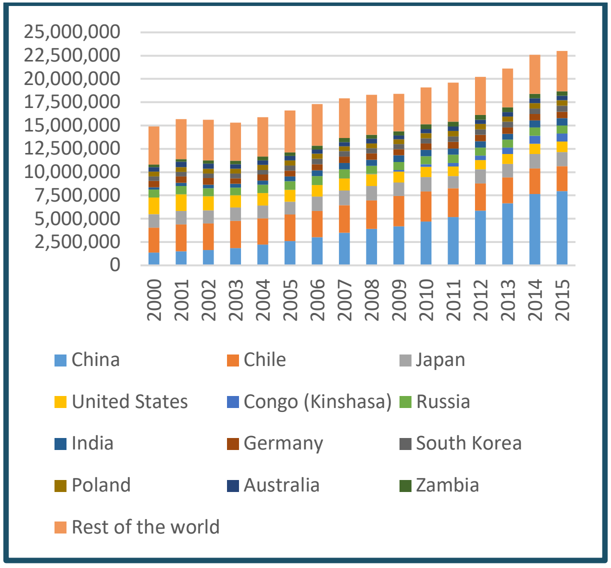
Figure 59: Global exports of copper ores (in metric tons, gross weight)



Source: Authors, based on data from ITC Trade Map. Series Copper ores and concentrates exports, downloaded on 23 July in 2020 from www.trademap.org

Figure 60: Global production for refined copper (in thousand metric tons of copper content)

Figure 61: Global production for copper smelting (in thousand metric tons of copper content)



Source: Authors, based on data from the US Geological Survey Minerals Yearbook, Series on copper, downloaded in July 2020 at https://www.usgs.gov.

Iron

Iron is the dominant component in the LFP cathode. Reserves of iron ore are predominantly found in Australia (28%), Brazil (19%), Russia (17%), China (9%) and India (4%). South Africa hosts slightly less than 1% of global reserves. Australia (36% in 2017), Brazil (18%), China (15%) and India 8%) mine the lion's share of iron ore globally. South Africa accounted for 3% of global iron ore mining in 2017. Iron production, which is predominantly linked to steelmaking, is heavily dominated by China (57% in 2017).

Figure 62: Global production of iron ore (in thousand metric tons of iron content)

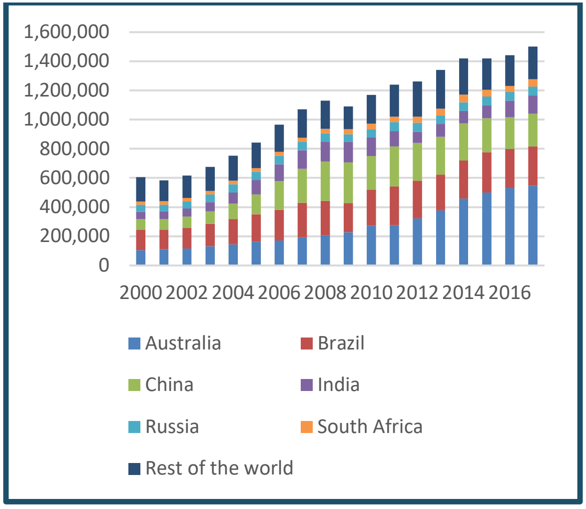
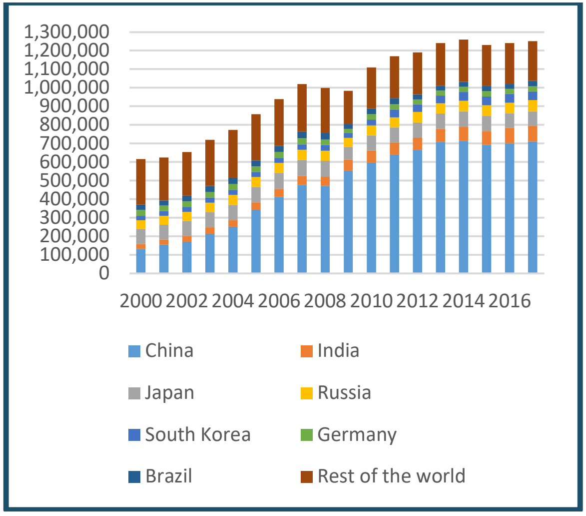


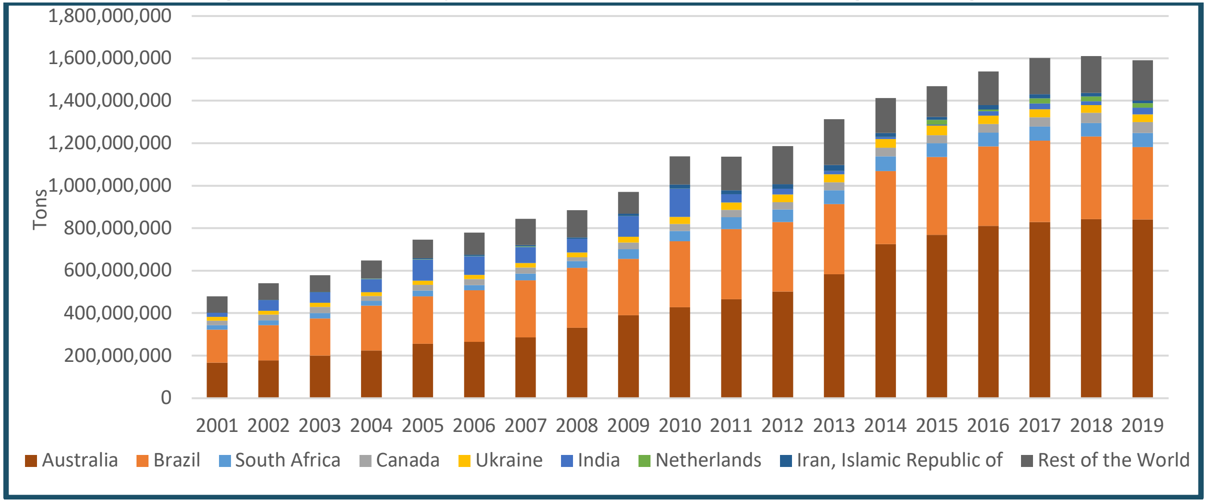
Figure 63: Global production of iron (in thousand metric tons, gross weight)



Source: Authors, based on data from the US Geological Survey Minerals Yearbook, Series on Iron and Iron and Steel, downloaded in July 2020 at https://www.usgs.gov.

In 2019, global iron ores (agglomerated and non-agglomerated) exports were dominated by Australia (840 million tons) and Brazil (340 million tons). Their exports accounted for 74% of global exports. South Africa's iron exports are largely agglomerated iron ore exports, the raw materials used for primary iron production. In 2019, South Africa's iron ores exports stood at 66 million tons, 62% of which were agglomerated iron ores. Global iron ore imports are largely from Asia and Europe. China is the top importer of iron ore, accounting for 68% of global iron imports in 2019.

Figure 64: Global exports of iron ores (in metric tons, gross weight)



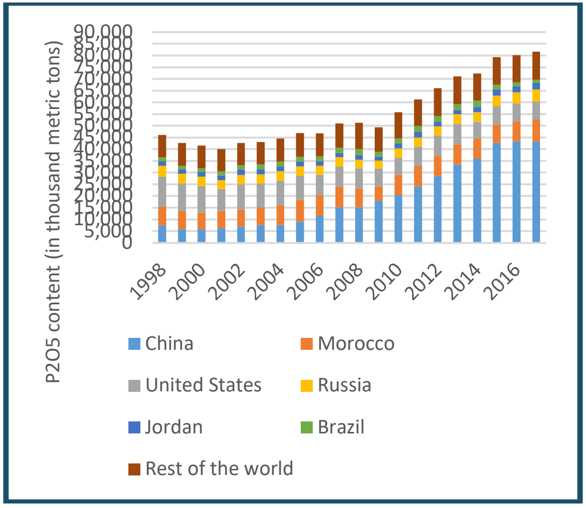
Source: Authors, based on data from ITC Trade Map. Series Agglomerated ores and concentrates exports and series Non-agglomerated ores and concentrates, downloaded 26 July 2020 from www.trademap.org

Phosphate

Phosphate material is found in the LFP cathode of a LIB. Phosphate is also a component used in the most common electrolyte salt in LIBs – $LiPF_6$ (Commonwealth of Australia, 2018).

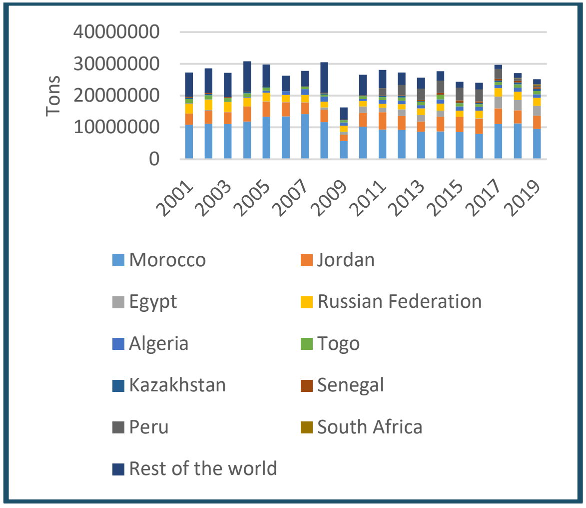
USGS data estimates that phosphate rock reserves stood at 69 million tons in 2016, while global mining production in 2016 was 81 600 tons, as shown in Figure 56. Phosphate mining production largely takes place in mines located in China, Morocco, the US and Russia. The majority of global phosphate reserves (72%) are found in Morocco (including the Western Sahara).[33] Other countries with notable phosphate reserves include China (5%), Algeria (3%), Syria (3%) and Brazil (3%). South Africa is also an important holder of reserves accounting with 2% of phosphate reserves and 772 tons of production in 2017. Mining of phosphate is done by Foskor in Phalaborwa, Limpopo, a region known for its widespread phosphate and copper reserves.

Figure 65: Global production of phosphate rock (in metric tons)



Source: Authors, based on data from the US Geological Survey Minerals Yearbook, Series on phosphate rock, downloaded in July 2020 at https://www.usgs.gov.

Figure 66: Global exports of natural calcium phosphates (in metric tons, gross weight)



Source: Authors, based on data from ITC Trade Map. Series Natural calcium phosphates and natural aluminium calcium phosphates, natural and phosphatic chalk, downloaded on 23 July in 2020 from www.trademap.org

The Middle East and North Africa region account for the lion's share of exports of phosphate rock (natural calcium phosphate), with Morocco accounting for 37% of total exports in 2019. Morocco, Jordan, Egypt and Russia are leading exporters of phosphate rock. The main importers are India, Brazil and the United States, mainly to be used in fertiliser.

Titanium

The LTO battery employs titanium in its anode instead of the conventional graphite material used in LIBs. The improvement in the surface area of the LTO battery increases the batteries' stability and re-charge rate significantly, while also further improving the batteries safety aspects (The Motorship, 2019).

Rutile (TiO_2) and ilmenite ($FeTiO_3$) are common ores of titanium. Rutile contains the highest concentration of titanium – over 90% of titanium, while ilmenite contains between 30%-65% of titanium (Joo et al*.*, 2020). Ilmenite is more often used for industrial applications than rutile because rutile reserves are often limited and not as readily available as ilmenite. The ilmenite titanium is smelted and transformed into titanium slag. In LIBs, however, titanium rutile flakes are the most preferred anode materials (Yang et al., 2012).

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[33] The occupation of Western Sahara by Morocco and geopolitical uncertainties, however, create concerns surrounding the supply of phosphate from the region.

In the case of titanium reserves, according to USGS data, ilmenite accounts for about 94% of the world's reserves of titanium. Australia has the most abundant titanium reserves (34%), followed by China (28%), India (12%), Brazil (5%) and South Africa (5%). Major reserves of ilmenite are in Australia, China, India and Brazil, while 62% of rutile reserves are concentrated in Australia, 16% in India and South Africa (13%).

Australia has the world's largest production of rutile and ilmenite titanium. Outside of Australia, African countries (Kenya, Sierra Leone and South Africa) are global leaders in rutile production, while the production of ilmenite titanium is led by China, India, Mozambique, Madagascar and Norway, as shown in Figure 67: and Figure 68:.

Figure 67: Global production for ilmenite titanium

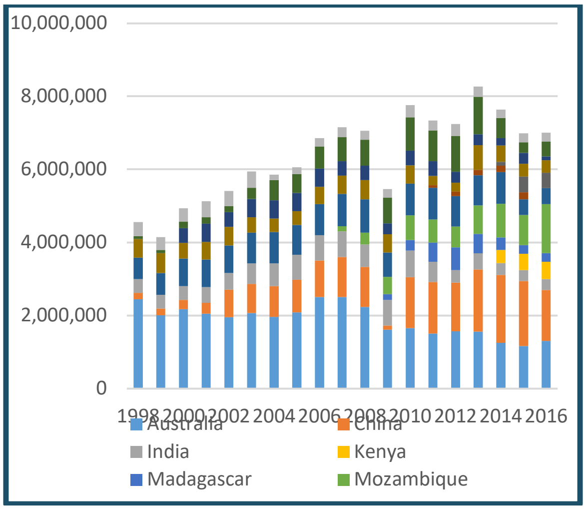
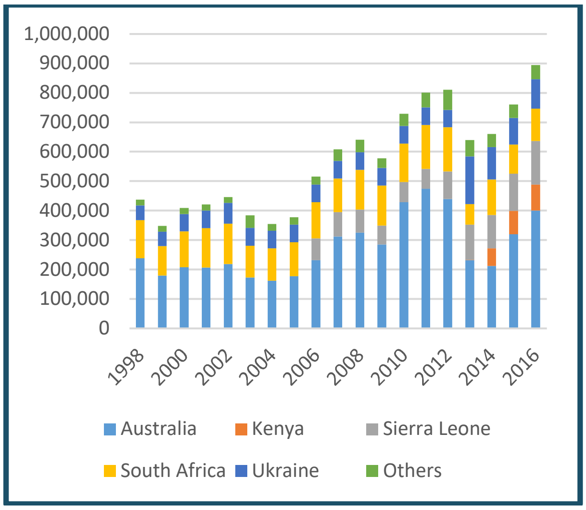


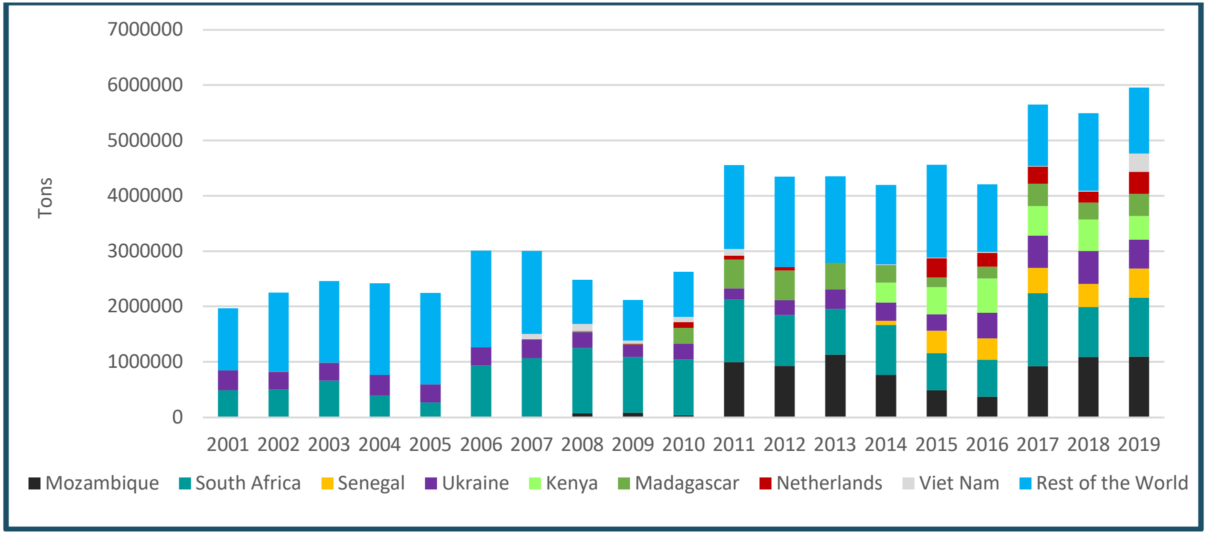
Figure 68: Global production for rutile titanium



Source: Authors, based on data from the US Geological Survey Minerals Yearbook, Series on titanium rutile and ilmenite, downloaded in July 2020 at https://www.usgs.gov.

In 2019, the top exporters of titanium were Mozambique (109 000 tons), South Africa (106 000 tons), Senegal (52 500 tons), Ukraine (52 200 tons), Kenya (42 000 tons) and Madagascar (40 000 tons). Top importers of titanium ores in 2019 were China, the US, Germany, Netherlands and Japan, accounting for 67% of global titanium ore imports.

Figure 69: Global exports of titanium ores (in metric tons, gross weight)



Source: Authors, based on data from ITC Trade Map. Series Titanium ores and concentrates, downloaded 23 July 2020 from www.trademap.org

ANNEXURE B: LIST OF COMPANIES INTERVIEWED

In addition to ongoing engagement with the Project Steering Committee, a total of 30 stakeholders were consulted for this study. The interviews, attended by TIPS and UNIDO colleagues, were primarily conducted through Zoom from September to December 2020.

AutoX	Mellow Cabs
BlueNova	Metair
Bushveld	MegaMillion
Balancell	Minerals Council
Council for Scientific and Industrial Research	Mintek
Department of Environment, Forestry and Fisheries	Manganese Metals Company
Department of Science and Innovation	Nelson Mandela University
EV Dynamics	Revov
e-Waste Association of South Africa	South32
FreedomWon	Transalloys
Glencore South Africa	University of Limpopo
Hulamin	University of Western Cape
Industrial Development Corporation	University of the Witwatersrand
Lithium Lion	uYilo
Maxwell and Spark	Waste Bureau