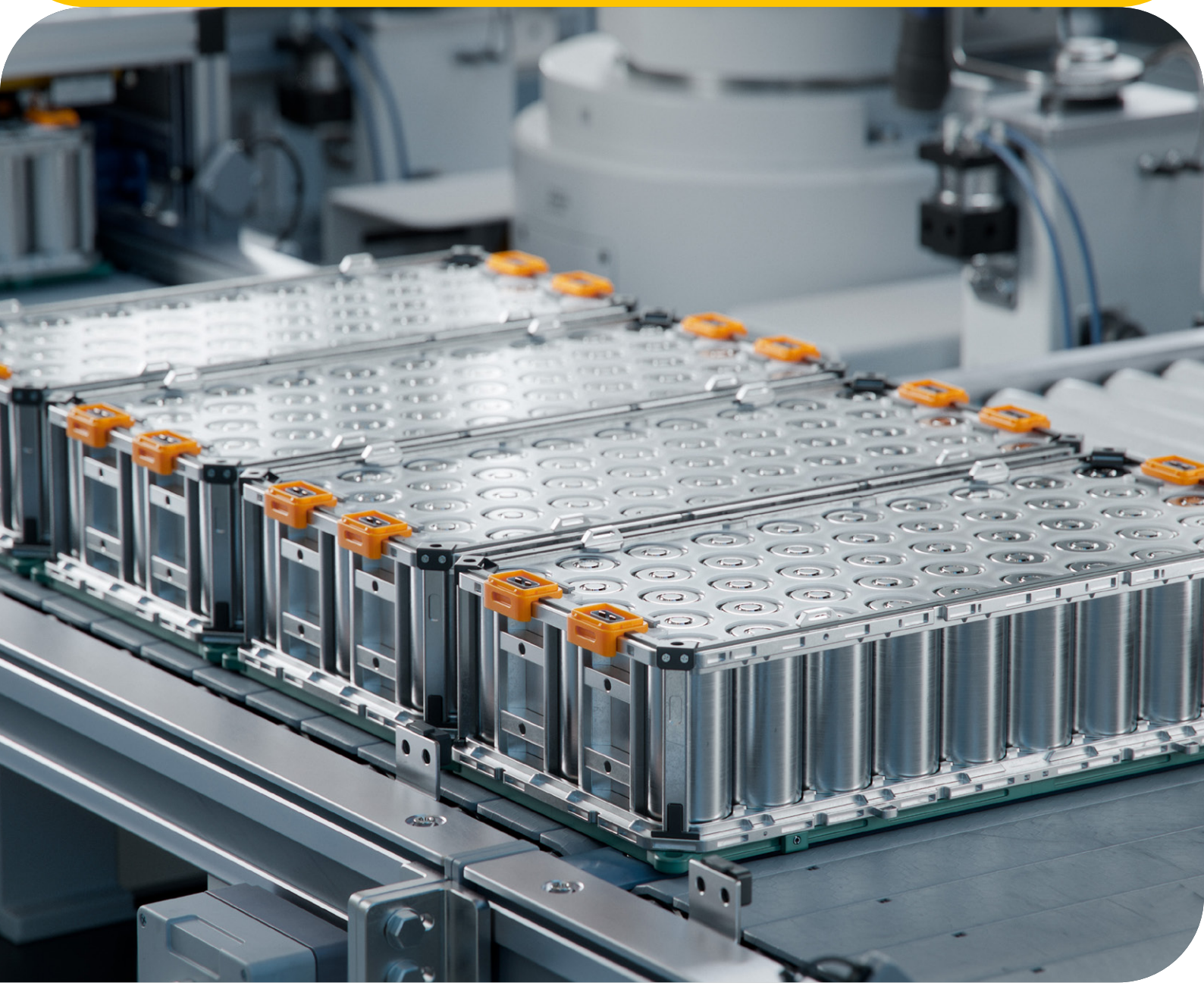
ELECTRIC MOBILITY TRANSITION & LOCALISATION

Towards Unlocking the NEV Value Chain for Africa

BATTERY VALUE CHAIN ASSESSMENT REPORT



AIH GROUP

IDC
Industrial Development Corporation

September 2024

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1. EXECUTIVE SUMMARY

This report provides an evaluation of the 'Battery Value Chain' within the New Energy Vehicle (NEV) eco-system. It also determines how the rapidly expanding opportunities in this market, including the establishment of a 'Gigawatt Factory', could be harnessed and expanded upon in South Africa and Africa.

The rapid development of battery gigafactories reflects the growing demand for electric vehicles and energy storage solutions, as well as the strategic importance of battery production capacity for national economies and the transition to sustainable energy. The concept of battery gigafactories has gained significant traction in recent years, with the battery value chain being integral. By 2030 the industry is seen as having the potential for 350 000 new employment opportunities and investments of 325 billion Euro[1].

The battery value chain has been categorised as comprising of four primary sub-clusters, with material and system innovation underpinning them all: 1) upstream materials building stock; 2) the core Original Equipment Manufacturing (OEM) cell manufacturing cluster; 3) system building blocks; and 4) an associated manufacturing block for battery plants, machinery and components. These sub-clusters are closely linked in global value chains and within plants.

The report provides an overview of the development and status or the battery value chain and market, the geographical distribution of early and current industry participants, the battery chemistry trends, and price trends, culminating in the South African opportunities.

An overview of the battery cell manufacturing process with prevailing cost benchmarks has been undertaken with specific attention paid to the prismatic cell, pouch cell, cylindrical cell, and battery pack and coin cell assembly lines. It is noted that the manufacturing of lithium-ion batteries is a highly complex process requiring the inclusion of different consecutive and interconnected units within a highly competitive and capital-intensive market. All costing models undertaken in this report require further assessment at a pre-feasibility stage to narrow estimates.

The role of precursor materials is investigated in detail with an emphasis on battery material supply in Africa, particularly cobalt, manganese, nickel and lithium. The various production processes required to produce the refined active material components in the battery are considered, namely electrode manufacturing, battery cell assembly and battery cell finishing processes. The anode of a battery is the costliest component, and costs are exposed to the sought after refined battery minerals of lithium, nickel, cobalt and manganese, with volatile prices. All these minerals are available in Africa and the opportunity is available to increase mining production and beneficiate the minerals into lithium, cobalt and manganese sulphate, as well as lithium hydroxide.

Value addition opportunities across the battery value chain are assessed and a Techno-Economic model for benchmarking of the production cost of lithium-ion batteries is considered and contextualised against a full 'Giga Factory' plant establishment and operation costs. Porsche Consulting estimate that bringing battery gigafactories online requires investments of € 1.5–3 billion per 30–40 GWh capacity.

Battery precursors are materials used in the final step before becoming cathode active materials (CAM) for lithium-ion batteries. They play a crucial role in determining the performance and characteristics of the battery. Precursor material production and the associated raw materials processing as an input is considered, and various authorities reviewed with divergent opinions and costs being established. Using BloombergNEF's top-down approach, it was estimated that a 100 000 metric tons precursor plant built in the DRC could cost $301 million.

A 'cost example' for a 1 GWh Gigafactory together with the supporting sulphate and lithium hydroxide production is undertaken, with the two-, three- and four-wheelers in Africa as potential market to support the plant, and concludes that the full African market would only require 19.7% of a potential gigafactories production capacity in a year and therefore could not be the main driver to support the establishment of such a factory, with additional markets required.

[1] Porsche Consulting Services, 2024. Battery Manufacturing 2030: Collaborating at Warp Speed. What it takes for equipment manufacturers to ride the coming wave of breakneck growth. https://www.porsche-consulting.com/international/en/publication/battery-manufacturing-2030

The report concludes that the modelling versus the actual costs of the various announced projects shows a large variation depending on size, level of automation and location of the plant. For South Africa, a battery cell plant cost of around $125 million per GWh is considered realistic, and could be even higher based on South Africa's location. Factors that could increase the costs include:

- South Africa's ability to secure a reputable international partner with experience in the establishment and operation of such a gigafactory.
- The availability of manufacturing equipment and associated shipping, installation and commissioning costs for such a plant in South Africa.
- Local costs structures such as energy, labour and the like being less competitive, compared to the dominant regions.

In this context it is clear that South African and African battery manufacturing needs to be considered in a broader context due to the high capital investment requirements, which requires economies of scale to achieve financial viability.

As far as raw material processing is concerned, South African supply could form part of the global battery raw material supply chain, as the mineral resources are present and currently being mined for the battery market and other applications, with primary mineral processing also being undertaken.

Both the battery minerals mining and battery mineral processing, or beneficiation, could be expanded in the various value chains indicated in this report.

2. INTRODUCTION

The battery value chain forms a key element within any New Electric Vehicle (NEV) strategy and its impact needs to be considered from capital investment, raw material availability and operational perspectives.

An illustration of the ecosystem associated with battery cell production is illustrated below. It categorises the value chain within materials, core cell cluster, system building and associated manufacturing of equipment for achieving this. This segmentation cannot be seen as mutually exclusive and all need to function in harmony to achieve a successful outcome[2].

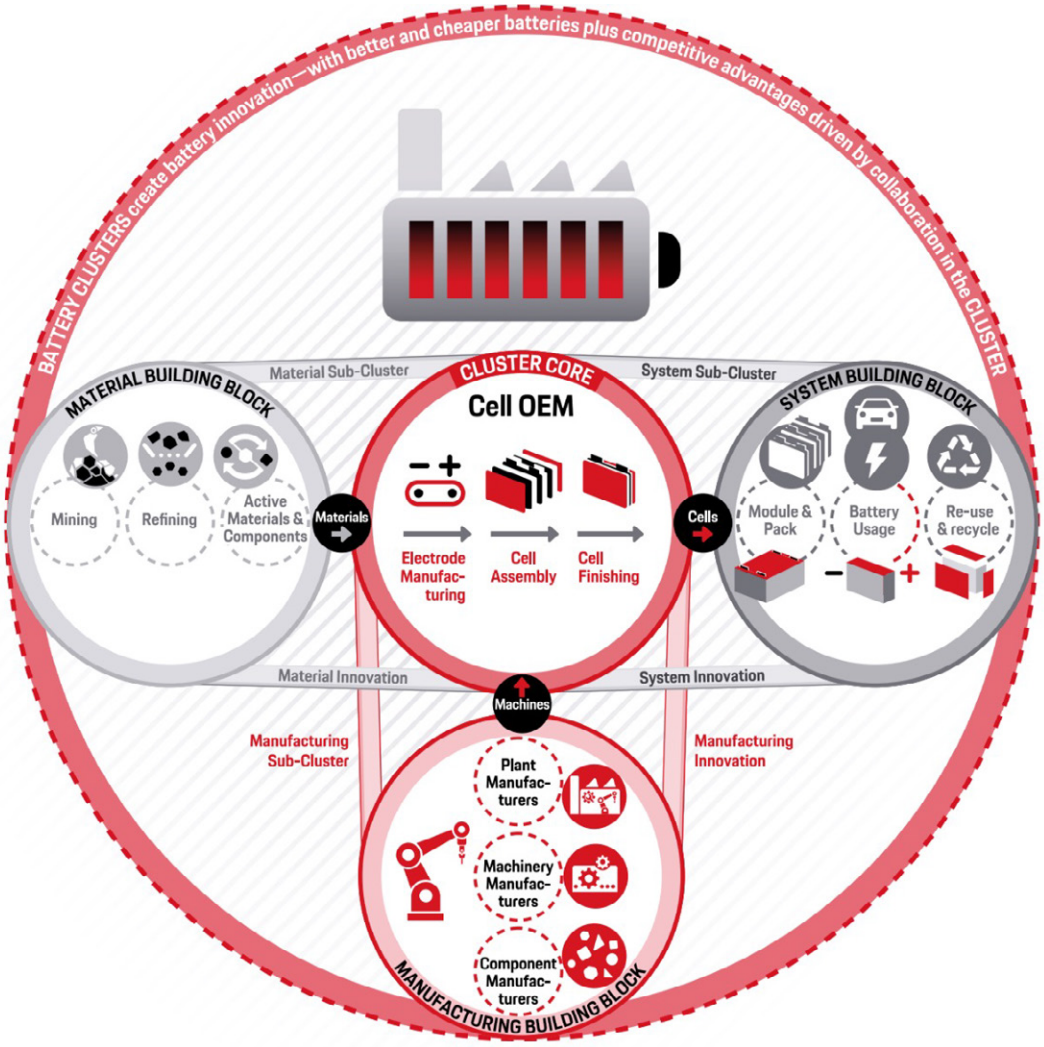


Figure 1: Battery Cell Production Ecosystem

[2] Battery Manufacturing 2030: Collaborating at Warp Speed; Porche Consulting Services; 2024 https://www.porsche-consulting.com/international/en/publication/battery-manufacturing-2030

2.1 Market Overview

Battery cell production and its associated building blocks is a rapid growing market - a summarised snapshot of the market trend as per a EV market report.com (Jan 2023) is as follows[3]:

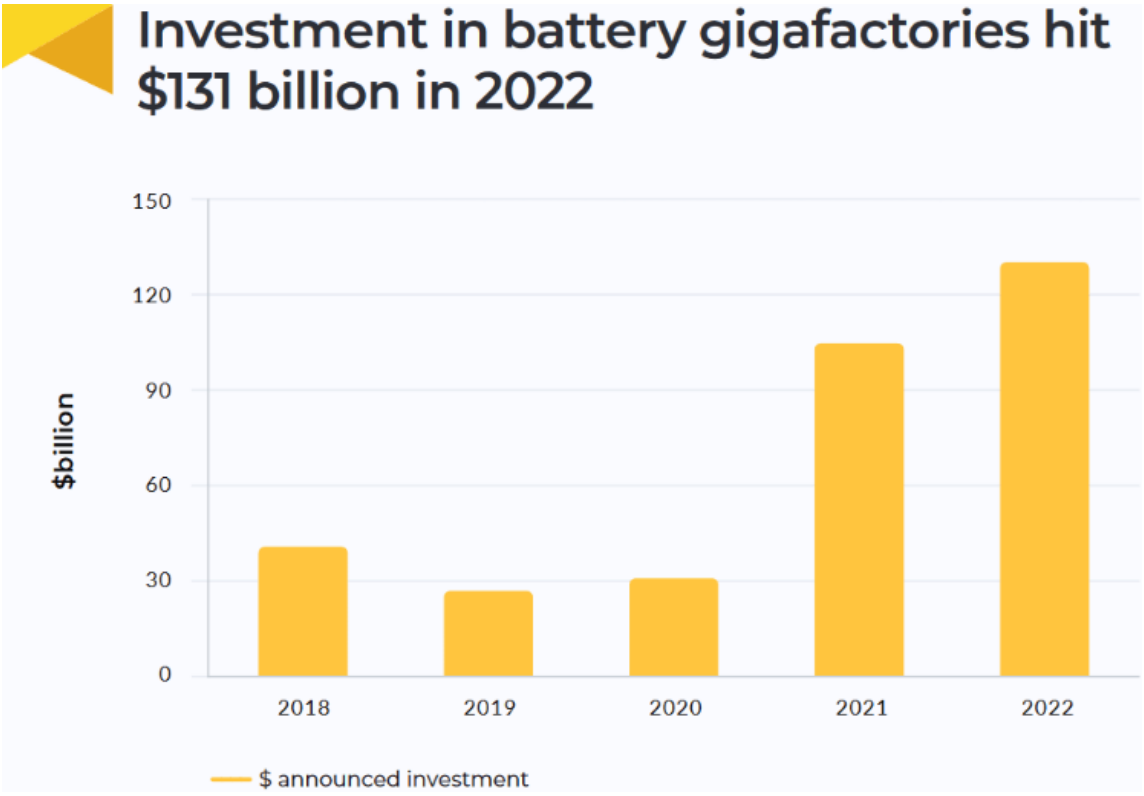


Figure 2: Investment in Battery Gigafactories

In the past four years (between 2019 and 2023) about $300 billion investments in new lithium-ion battery gigafactories have been announced, underpinned by the exponential industry expansion in China, the world's largest producer.

The term gigafactory was coined by Elon Musk and refers to factories capable of producing multiple GWh per year of battery cell capacity. Gigafactories require high amounts of energy to power and the focus for choosing the location to build a gigafactory is access to uninterrupted clean energy.

According to Benchmark and as a result of the above expenditures, worldwide manufacturing of lithium-ion batteries will be more than fivefold by the end of 2030. In 2022, the world added 102 gigafactories to the ten-year pipeline with a total capacity of 3.1 terawatt-hours and $131 billion investment pledged.

[3] Battery Design. 2023. https://www.batterydesign.net/lithium-battery-manufacturing-equipment-capex/

A different presentation of the envisaged growth by Porsche Consulting is below:

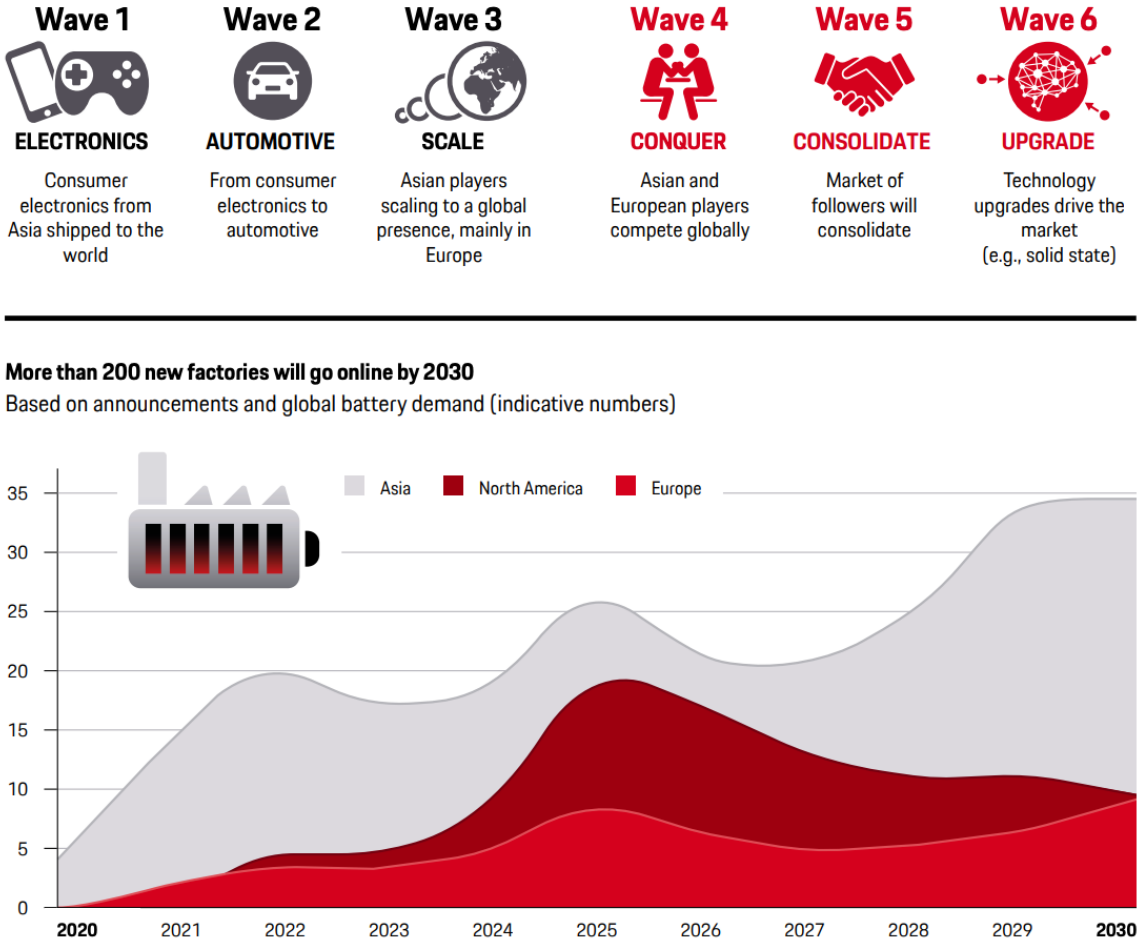


Figure 3: Envisaged Growth of Factories

China is expected to remain the leading producer by the end of the decade. According to Benchmark's estimates, China will produce 69% of the world's lithium-ion batteries by 2030.

It is expected that the demand for Tier 1 cells will outpace supply over the next years with a developing cell shortage anticipated starting in 2028, as demand for EVs and energy storage is anticipated to increase as nations get closer to net zero objectives. Current Tier 1 suppliers as identified by Benchmark include CATL, Envision AESC, LG Energy Solution, Panasonic, Samsung SDI, SK On, BYD, Northvolt and Sunwoda.

Porche Consulting provides the follow view of the stakeholders within the cell production sector:

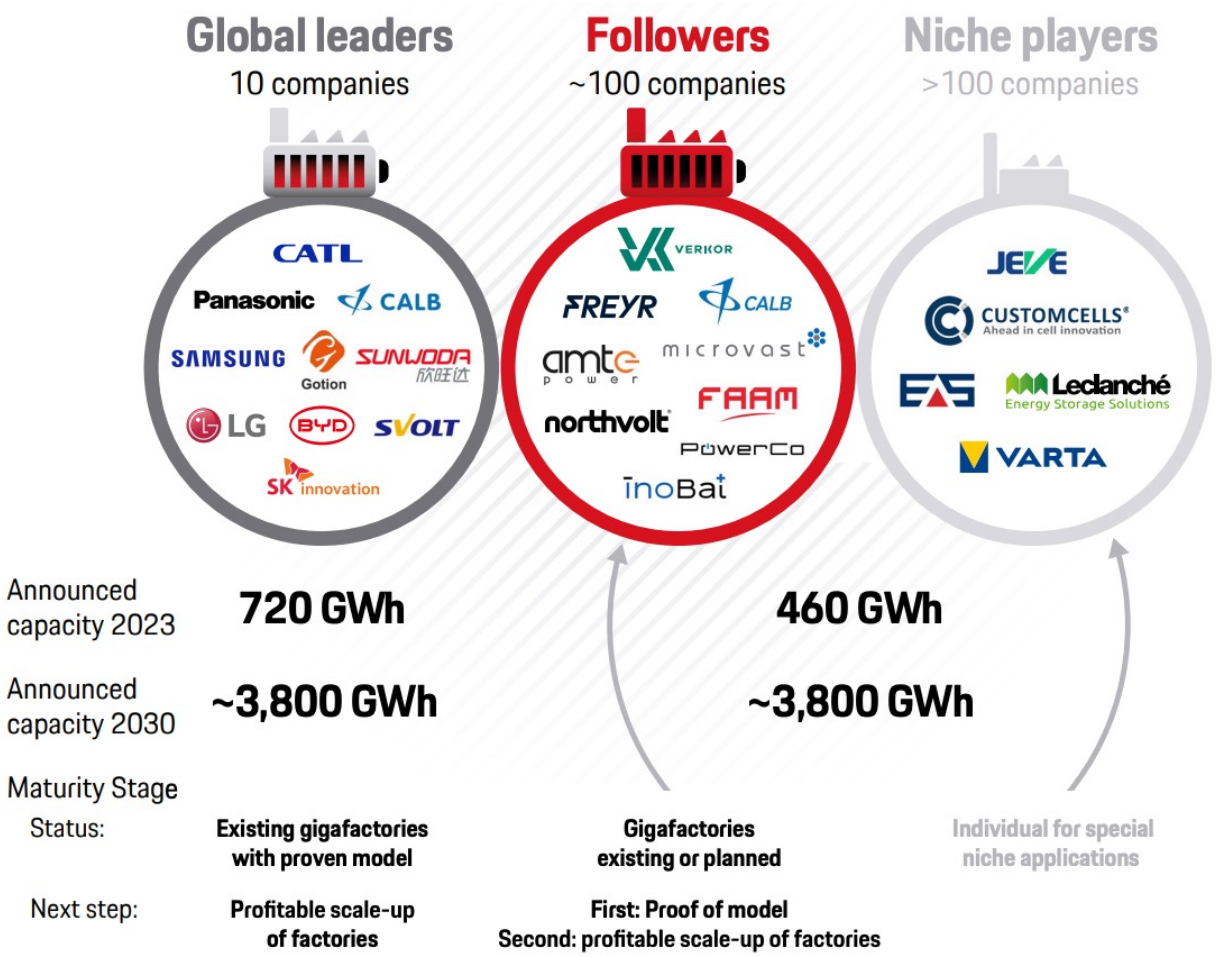


Figure 4: Identified Suppliers

According to Porsche Consulting, current estimations of battery cell production by some of the respective major players are CATL (191 GWh installed in 2023), BYD (70GWh), SVOLT (78 GWh), CALB (20 GWh), Gotion High-Tech (14 GWh), Sunwoda Electronic (9.2 GWh) and Korean brands SK Innovation (120 GWh), Samsung (80 GWh), LG Energy Solutions (300 GWh) as well as Japan's Panasonic (50 GWh).

In 2022 the world's largest battery manufacturer, CATL, announced an investment of $12.6 billion in new battery capacity additions. By 2031, CATL is expected to have a battery production capacity of 1042.6 GWh per annum. Within the USA, $20.8 billion investment was pledged over the course of 2022. While CATL announced it will invest RMB 14 billion ($1.9 billion) in a plant in Henan with an anticipated nameplate capacity of 26 GWh, Sunwoda said it would invest RMB 33.3 billion RMB ($4.7 billion) in two cell sites in Hefei and Zhejiang.

The USA pipeline capacity expanded by 49.0% to 1046.6 GWh in 2022, while China's pipeline capacity increased by 65% year on year to 5462 GWh. In addition, the pipeline capacity in Europe rose from 855.2 to 1 193.2 GWh, a 39.5% increase.

An average North American gigafactory costs over $100 million to construct, which is 46% more expensive per gigawatt-hour than Chinese gigafactories. A GWh of output at LG Energy Solution's proposed $1.3 billion project in Arizona would cost around $127 million compared to China's average cost per GWh of new battery manufacturing capacity - roughly $72 million, however some plants are around $55 million per GWh. To increase the capacity of its Spring Hill factory from 35 GWh to 50 GWh, Ultium Cells, a joint venture between LG Energy Solution and General Motors, stated it would only invest $275 million.

Bloomberg NEF[4] sees two- and three-wheeler electrification as a big opportunity for African markets as it has been over the last decade in Asia. Less than 0.1% of electric vehicles sold globally during 2016 to 2021 were in Africa. This low demand has hindered the continent's growth into downstream sectors such as cell manufacturing. Global lithium-ion battery demand from two- and three-wheeler vehicles will be 171 GWh in 2030. In major cities like Lagos, Nairobi and Accra, replacing ICE two- and three-wheelers with electric ones could create sufficient demand to support domestic cell manufacturing in Africa.

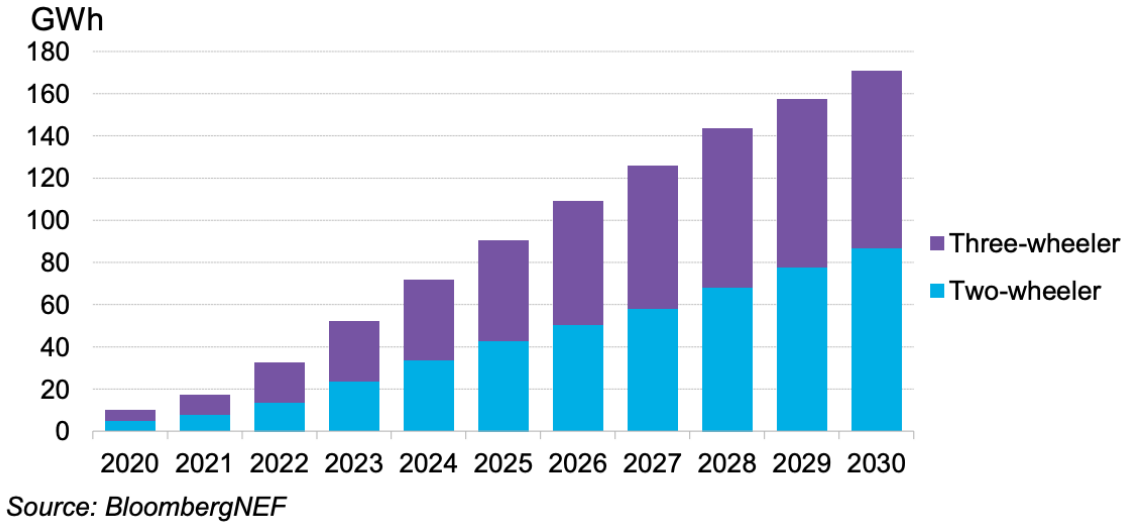


Figure 5: Two- and Three-Wheeler GWh Output Projections

2.2 Geographical Distribution

The GFP Handbook provides the following global mapping of the geographical distribution for lithium-ion battery manufacturing capacity[5]:

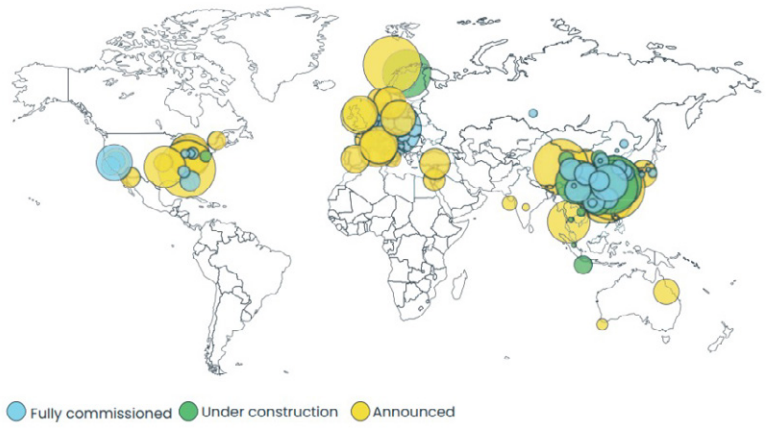


Figure 6: Geographical Distribution for Lithium-Ion Battery Manufacturing Capacity

[4] BloombergNEF. 2021. The Cost of Producing Battery Precursors in the DRC. https://assets.bbhub.io/professional/sites/24/BNEF-The-Cost-of-Producing-Battery-Precursors-in-the-DRC_FINAL.pdf

[5] Green Finance Institute. 2023. https://www.greenfinanceinstitute.com/wp-content/uploads/2023/06/GFI-BATTERY-HANDBOOK.pdf

As is clear from the above, Asia leads the global battery supply chain and is home to the headquarters of the ten largest companies, including CATL (32.6% market share), LG Energy Solution (20.3%), Panasonic (12.2%) and BYD (8.8%). The Chinese companies account for 56% of the EV battery market followed by Korea (26%) and Japan (10%). The graph below shows the share of different parts of the supply chain by the different regions.

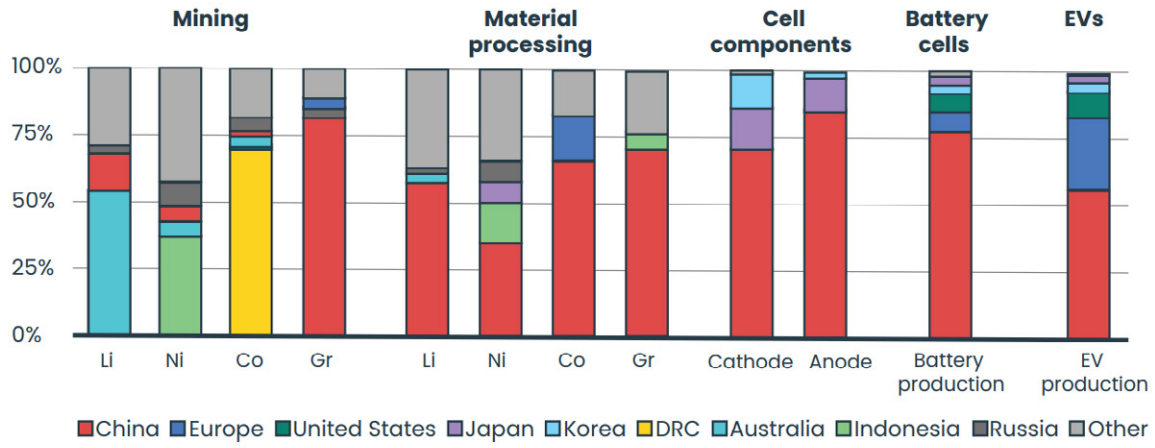


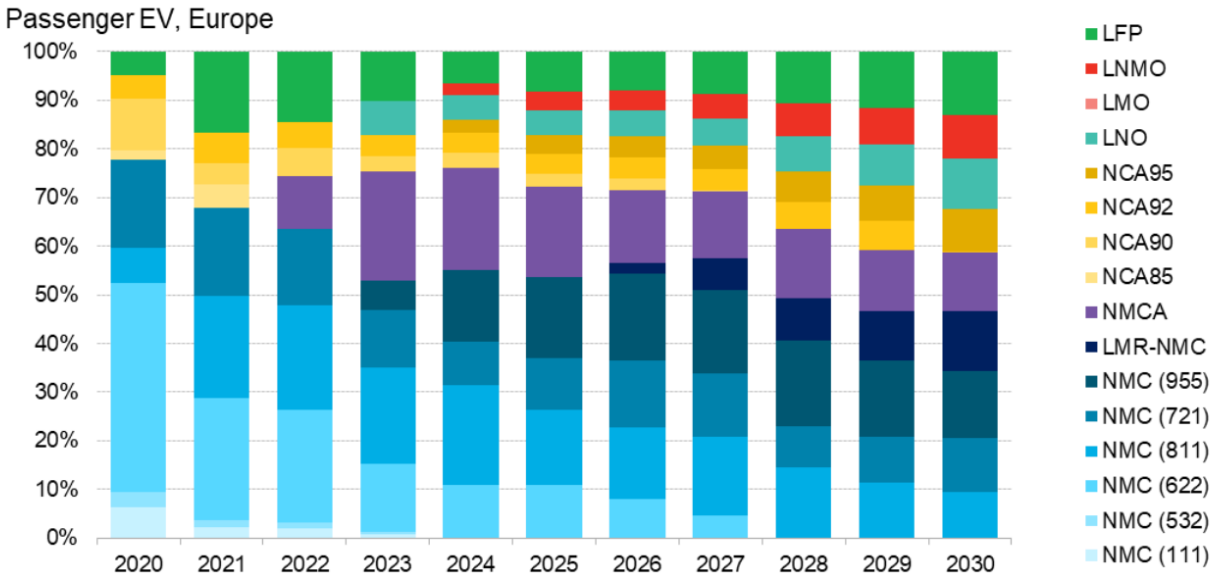
Figure 7: Various Parts of Supply Chain by Different Regions

As of 2022, China accounts for the majority of global processing capacity for key raw materials and a growing proportion of extraction capacity; up to 85% of the global market for anodes, cathodes, separators and electrolytes which together account for between 70% and 85% of a cell's cost, and up to 75% of the global pipeline for gigafactories, with 226 due to be operational by the end of the decade. The Chinese battery manufacturing capacity is expected to exceed domestic demand, meaning Chinese battery manufacturers are accelerating plans to grow exports into European markets which could lead to Western automakers being forced to reduce the cost of their EVs. Despite the implication of the Chinese growth, it does not yet mean that Chinese dominance to date is not prohibiting growth elsewhere.

2.3 Battery Chemistry Trend

A Bloomberg NEF's battery chemistry forecast confirms that the selected battery chemistry type determines the required upstream raw material and associated minerals processing/precursors that need to be produced. The factors that influence these are the availability of these raw materials and the market demand for a specific battery chemistry - more specifically the demand within the country or region where the buyer and or consumer is located.

To illustrate the movement in chemistry trends the below graph reflects the envisaged movements in chemistries for passenger vehicles in Europe between 2020 and 2030.



Source: BloombergNEF

Figure 8: Envisaged Movements in Chemistries for Passenger Vehicles in Europe

Bloomberg NEF expects NMC 622 and NMC 811 to be commonly used in passenger electric vehicles in Europe this decade. Most European original equipment manufacturers (OEMs) have announced their reliance on high-nickel chemistry batteries for performance applications, although they will use LFP for low-cost entry-level vehicles. This perspective aligns with the current view to preferred LFP for the two-wheeler segment proposed for South Africa. It would be more practical for the Southern Africa region to focus its production of precursors towards what would ultimately have commercial value in its most dependent market, as Africa works toward building its domestic demand.

2.4 Price Trends

The graph below illustrates the announced capital costs per unit of new EV and energy storage battery manufacturing capacity during the period 2010 to 2019[6], showing a downward trend which is currently continuing.

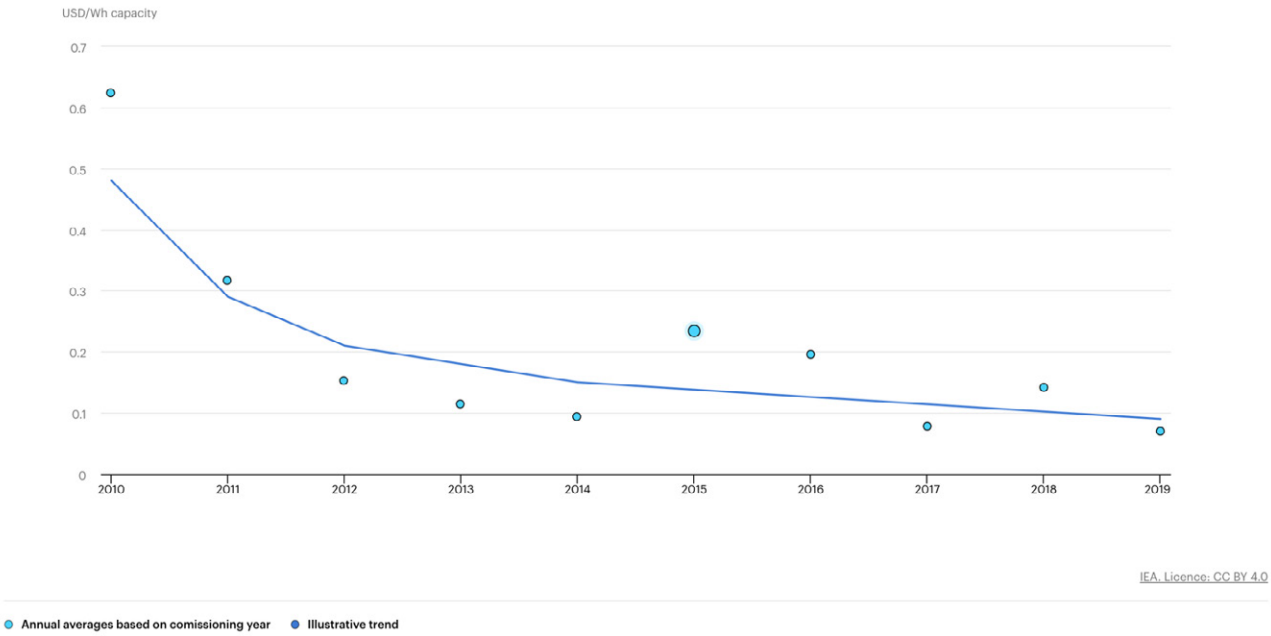


Figure 9: Capital Costs per NEV Unit & Energy Storage Battery Manufacturing Capacity

[6] iea. 2018. https://www.iea.org/data-and-statistics/charts/announced-capital-costs-per-unit-of-new-ev-and-energy-storage-battery-manufacturing-capacity-2010-2019

The typical composition of the price of a battery cell is as follows[7]:

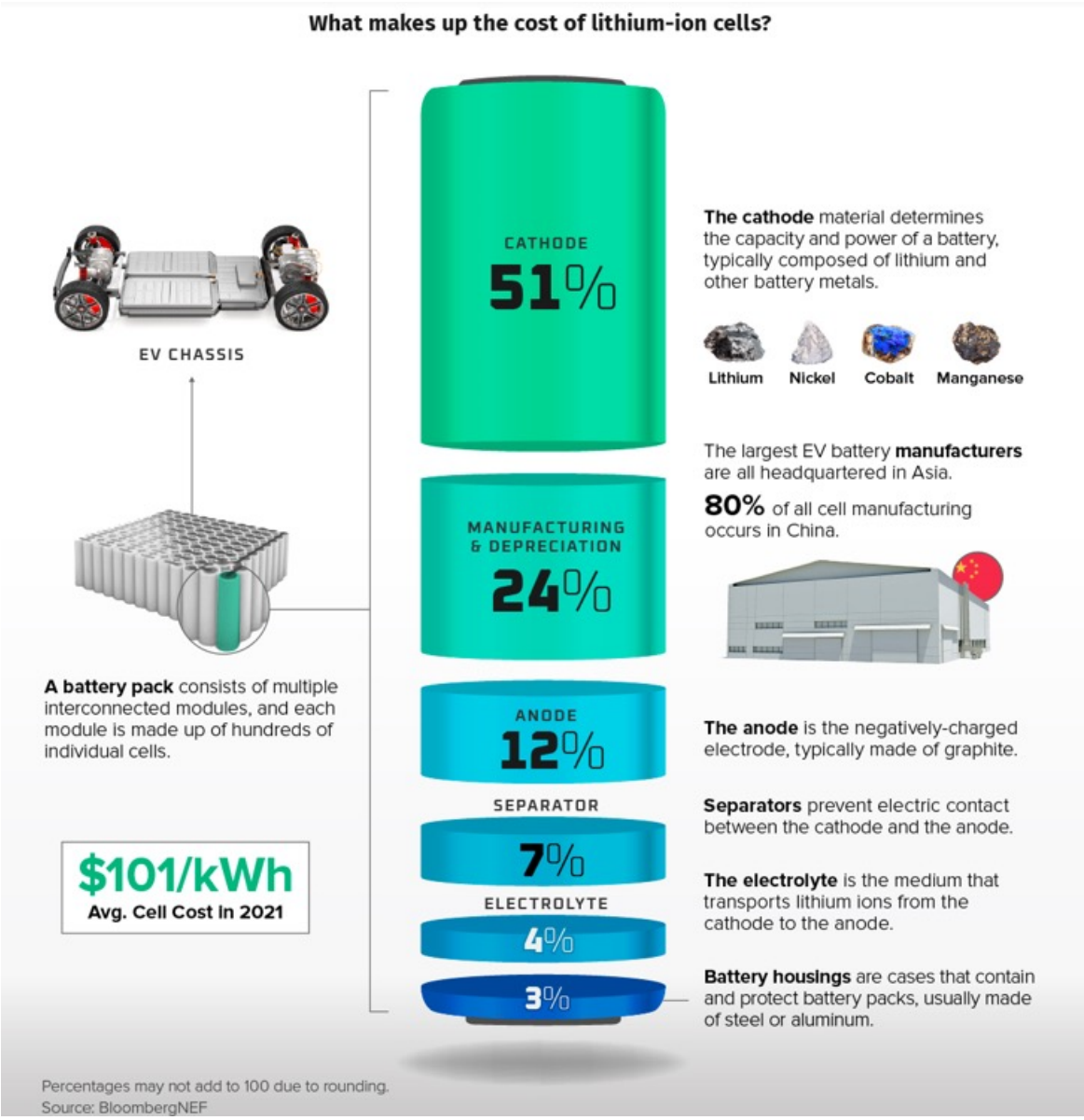


Figure 10: Composition of the Price of Battery Cell

As EV battery prices keep dropping the global supply of EVs and demand for their batteries is ramping up. Since 2010 the average price of a lithium-ion EV battery pack has fallen from $1,200 per kilowatt-hour (kWh) to just $132/kWh in 2021 and currently still decreasing.

Each EV battery pack consists of multiple interconnected modules made up of tens to hundreds of rechargeable Li-ion cells. Collectively these cells make up roughly 77% of the total cost of an average battery pack or about $101/kWh.

The cathode is the positively charged electrode of the battery. When a battery is discharged, both electrons and positively charged molecules (the eponymous lithium ions) flow from the anode to the cathode, which stores both until the battery is charged again. The means that cathodes effectively determine the performance, range and thermal safety of a battery and therefore of an EV itself, making them one of the most important components.

The cathode is composed of various refined metals and, dependent on the cell chemistry, typically including lithium, nickel, manganese, cobalt and other, or a combination thereof.

[7] Bhutanda, G. 2022. Visual Capalist. https://www.iea.org/data-and-statistics/charts/announced-capital-costs-per-unit-of-new-ev-and-energy-storage-battery-manufacturing-capacity-2010-2019

The battery metals that make up the cathode are in high demand and cell manufacturers are rushing to secure supplies as EV sales increases. As illustrated above, the cathode accounts for the highest portion of the overall cell cost.

The anode is the other significant component of the battery and it makes up 12% of the total cost. The anode in a lithium-ion cell is typically made of natural or synthetic graphite which tends to be less expensive than other battery commodities.

Although battery costs have been declining since 2010, the recent surge in prices of key battery metals like lithium has cast a shadow of doubt over their future; however, a downward trend is still visible and is putting pressure on the cell manufacturing margins. The impact of this is that the cell manufacturers require extensive volumes for sustainability and the result is larger fully automated gigafactories.

3. BATTERY CELL MANUFACTURING PROCESS

The manufacturing of lithium-ion battery cells is a highly complex process requiring the inclusion of different consecutive and interconnected units. A slight variation in one parameter might have an immense impact on the functionality of other units and, consequently, on the performance and cost of the process chain output.

In general, the production chain of a battery cell is repeatedly divided into three principal categories: electrode manufacturing, cell assembly and cell finishing. Every single category consists of individual units. A schematic diagram of the battery cell process chain, which illustrates constituent units in each category, is represented below[8]:

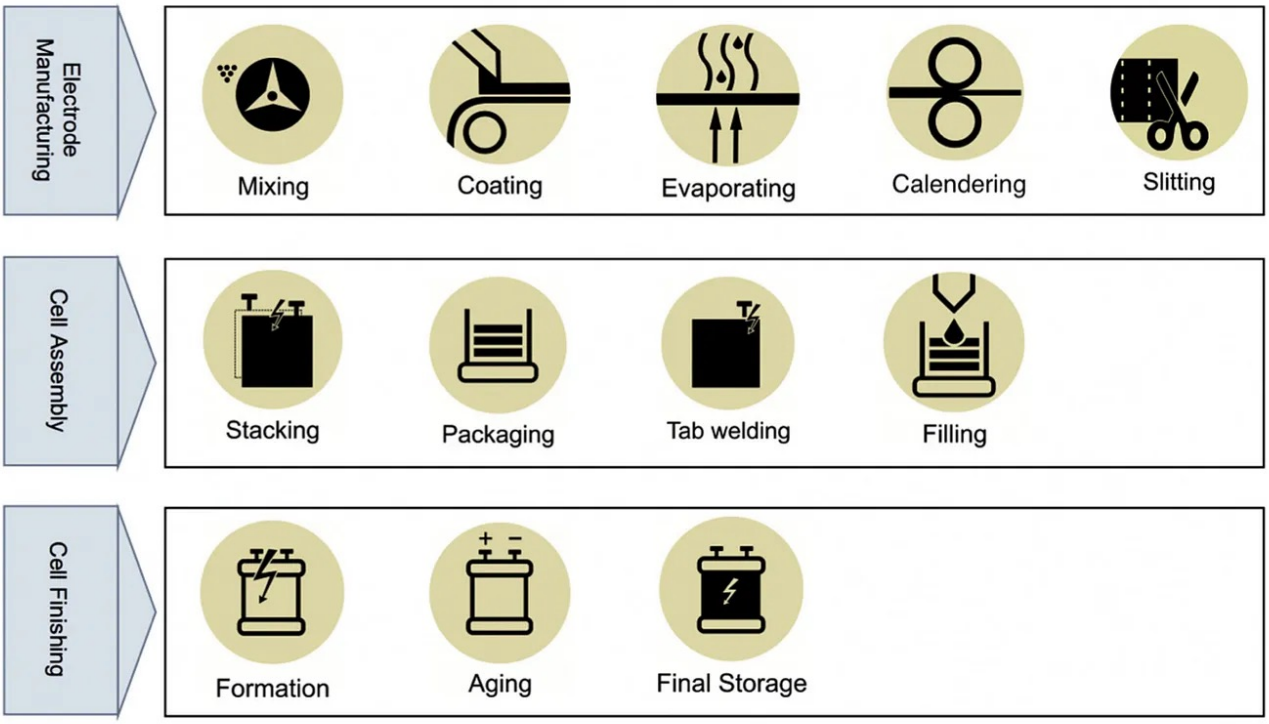


Figure 11: Schematic Diagram of Battery Cell Process Chain

[8] Orangi, S. 2022. MDPI. https://www.mdpi.com/2313-0105/8/8/83

Equipment plays a critical role in determining the performance and cost of lithium-ion batteries. Mirroring the three manufacturing stages, equipment can be divided into three categories as well:

- **1st stage equipment** - Mixer, Coater, Roller Press, Splitting machine, Filming machine, Die-cutting machine, etc.
- **2nd stage equipment** - Winding/lamination machine, electrolyte injection machine, packaging equipment.
- **3rd stage equipment** - Charging and discharging machines, testing equipment, etc.

In the case of CATL, the capital cost for each of these three stages represents approximately 40%, 30%, 30% of the cost of the production line.

Electrode manufacturing of battery cells begins with a mixing unit, where active materials, conductive nano microscopic carbon black, electrochemical inert binder, and conductive additives, e.g., carbon, are carefully mixed as powders (dry mixing) with a specific weight ratio between components to ensure the high electrochemical performance of the electrode, followed by adding solvent to form a homogenous slurry (wet mixing).

Production scale and quality requirements lead battery cell producers to select different mixer systems. Planetary, intensive high-speed, universal and static mixers are suitable for industrial scale production.

A well-mixed slurry of mixing units is pumped to be coated, with a fixed thickness, on Al or Cu foil as a cathode or anode respectively, typically using an automated, continuous and integrated slot-die coater. The coating unit is conventionally integrated into the drying and solvent recovery units.

Within a dryer unit solvent from a wet-coated slurry layer on current collectors evaporates by the application of heat energy from hot air in a conventional convective drying unit, which is currently a predominant method for electrode drying. Supplementing infrared drying to the dryer mentioned above enhances the efficiency of the dryer unit, causing a reduction in battery cell manufacturing costs.

The process model proceeds with calendaring, where constant pressure is exerted using a set of top and bottom rollers to decrease the thickness and porosity of the electrodes, then ends up with a slitting unit, where rolling knives cut the prepared electrodes into the desired dimensions.

Within the winding unit of the process model, the separator is fed as an endless band between the dried cathode and anode electrodes being wound around a winding mandrel. Current collectors are welded, most commonly via ultrasonic technology, and then are inserted into a casing and sealed. By the application of high-precision dosing needles, the filling is conducted where the cell is filled with electrolytes and then closed.

After connecting the cells to the contact pins in formation racks, the formation and aging begin with the charge and discharge of battery cells based on precisely predefined current and voltage profiles under a low rate. The rate gradually increases to ensure the formation of a protective interface layer, called a solid electrolyte interphase (SEI), between electrolytes and the anode electrode. In search of measurements for quality assurance of cell characteristics and performance, the cells are stored on aging shelves and monitored for an extended time. This process might take up to several weeks based on the aging temperature. The defective cells are regarded as rejected ones.

3.1 Production Equipment Required for Different Cell Configurations

The manufacturing equipment required to produce the various types of cells is not uniform and varies. According the TMAX Battery Equipment's website, the typical equipment and associated production line is as follows[9]:

- Prismatic Cell Assembly Line,
- Pouch Cell Assembly Line,
- Cylindrical Cell Assembly Line,
- Battery Pack Assembly Line, and
- Coin Cell Assembly Line.

3.1.1 Prismatic Cell Assembly Line

The production line typically consists of an electrode coating machine, calendar, slitting machine, stacking machine, welding machine, etc., as illustrated below.



Figure 12: Automatic Prismatic Cell Production and Manufacturing

[9] TMAX Battery Equipment. 2023. https://www.batterymaking.com/lithium-battery-assembly-plant_c80?gad_source=1&gclid=EAIaIQobChMIg-O67MychgMVw5JQBh2CwQMaEAAYASAAEgIJJPD_BwE

3.1.2 Pouch Cell Assembly Line

The production line typically consists of a sealing machine, stacking machine, ultrasonic welder, etc., as illustrated below.

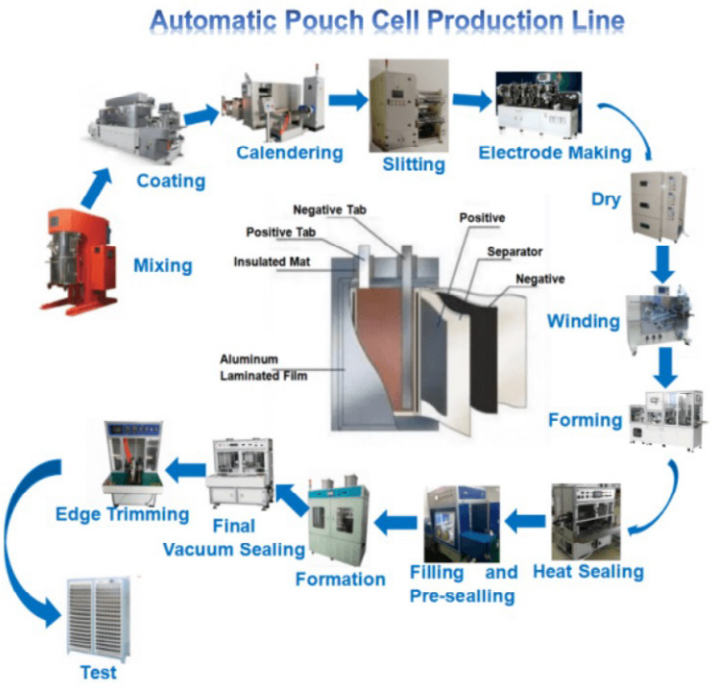


Figure 13: Automatic Pouch Cell Production Line

3.1.3 Cylindrical Cell Assembly Line

The production line typically consists of a winding machine, grooving machine, sealing machine, etc., as illustrated below:

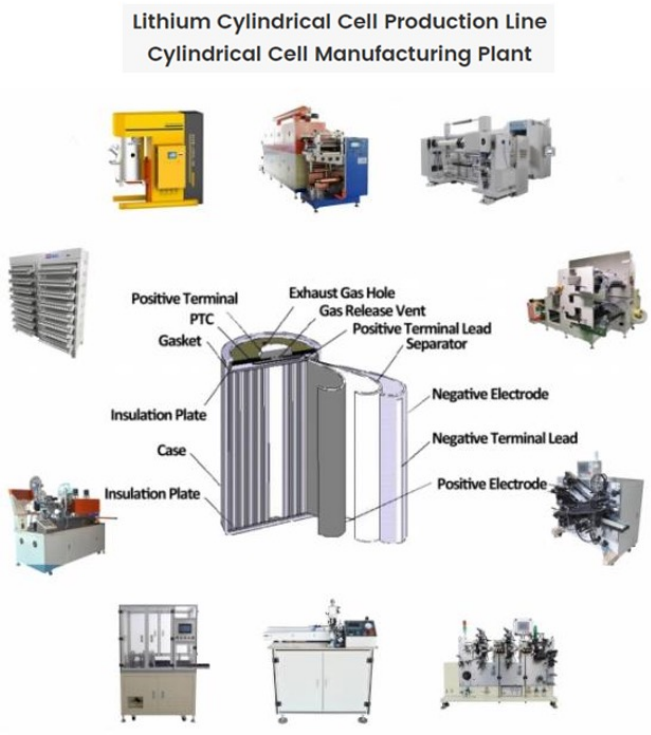


Figure 14: Lithium Cylindrical Cell Production Line

3.1.4 Battery Pack Assembly Line

The production line suitable for solar lights, electric scooters, E-bikes typically consists of a sorting machine, spot welder, BMS tester, aging tester, etc., as illustrated below:



Figure 15: Cylindrical Battery Pack Assembly Equipment

3.1.5 Coin Cell Assembly Line

The production line typically consists of a coin cell crimper, disc punching machine, coater, tester, etc., as illustrated below:

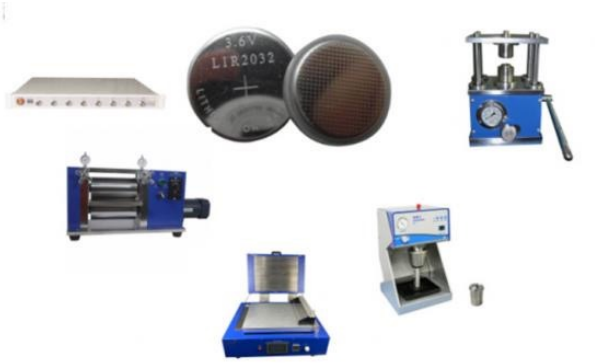


Figure 16: Coin Cell Assembly Line

3.2 Fully Integrated Gigafactories

When reviewing fully automated gigafactories, the magnitude is of a different scale and size, including full clean room facilities etc.

See the below links to two videos of fully automated gigafactories includes full robotic lines:

CATL : https://www.youtube.com/watch?v=NtWfm4_eJxI

Tesla : https://www.cnbc.com/video/2019/05/02/we-went-inside-teslas-first-gigafactory.html

4. PRECURSOR MATERIALS

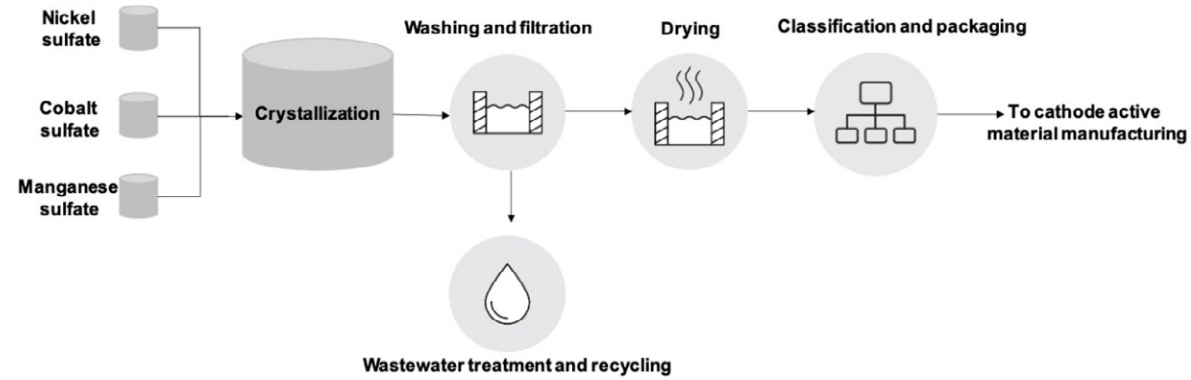
The second key metric in the battery value chain is related to the precursor materials used to produce the battery cell's cathode and anode. As stated, the anode is the most expensive portion and costs are exposed to highly sought-after refined battery materials consisting of lithium, nickel, cobalt, manganese, etc.

Global players within the precursor market include Fuijan, Evergreen New Energy Technology, Umicore, Beijing EA Spring and Huayou, as a minimum. The precursor market is currently concentrated in China but countries like Australia are looking to move downstream to produce precursor materials to complement their raw materials.

Producing precursors for NMC cathode chemistries requires three main raw materials – nickel sulfate, cobalt sulfate and manganese sulfate. The cathode active material is produced from NMC hydroxide through lithiation and calcination to form the lithium nickel manganese cobalt oxide.

The ratio of nickel, manganese and cobalt can be varied within NMC materials to achieve different performance. When first introduced into the market, NMC materials had equal parts nickel, manganese and cobalt - this material was known as NMC (111). Today companies typically produce NMC with six-parts nickel for every two-parts cobalt and manganese, known as NMC (622). To achieve these varying ratios, the required mix of each metal needs to be used during precursor production.

A simplified schematic of the precursor manufacturing process, as per Bloomberg NEF entails:



Source: BloombergNEF

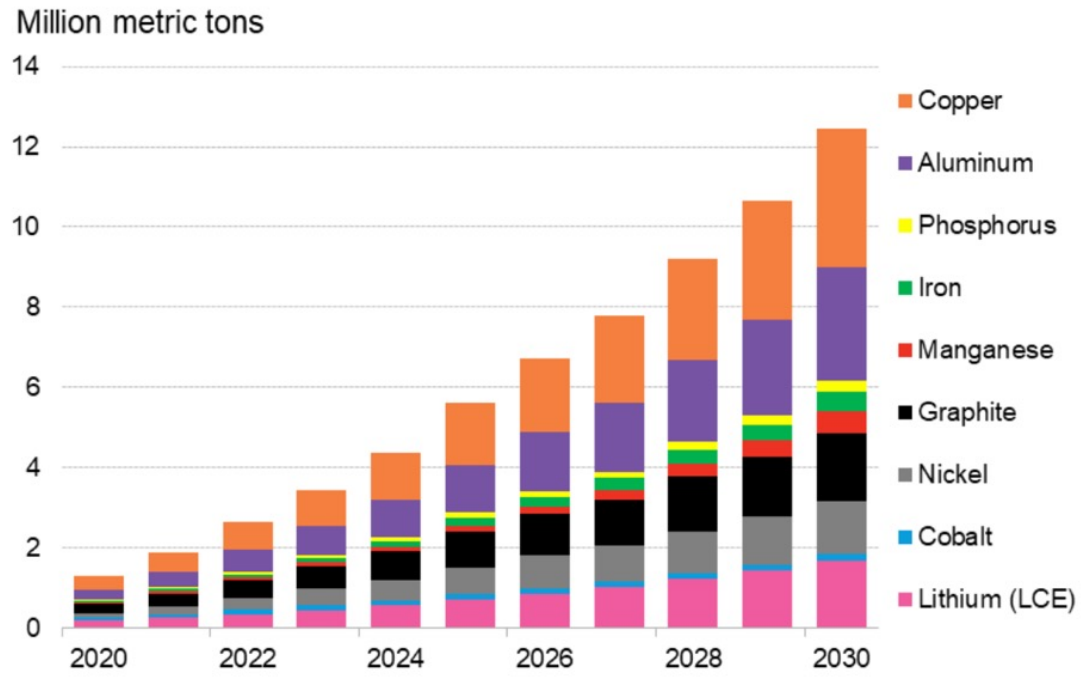
Figure 17: Schematic of the Precursor Manufacturing Process

Cathode active material, and particularly high nickel cathode material, is sensitive to moisture and air. While it can be transported, the logistics are complicated and expensive. It therefore makes sense to have cathode production close to cell production. Cell production for electric vehicles tends to be near electric vehicle manufacturing to fit into the 'just-in-time' manufacturing model of the auto industry. Precursor materials are not as complicated to transport over long distances compared to cathode active materials.

It needs to be acknowledged that the implementation of this process is not as simplistic as presented above given the quality requirements of the end product. It is higher energy and water-intensive and securing the required quality of sulphates from the pre-metal refining processes is critical.

4.1 Battery Material Demand

According to BloombergNEF the forecast battery material demand up to 2023 is as presented below. It should be noted that the metals demand occurs at mine mouth, one-year before battery demand, and all metals are expressed in metric tons of contained metal, except lithium, which is in lithium carbonate equivalent (LCE).



Source: BloombergNEF. Note: Metals demand occurs at mine mouth, one-year before battery demand. All metals expressed in metric tons of contained metal, except lithium, which is in lithium carbonate equivalent (LCE).

Figure 18: Battery Material Demand in Million Metric Tons

4.2 Battery Material Supply in Africa

4.2.1 Cobalt

The DRC produced about 70% of global cobalt supply in 2020. Cobalt is predominantly produced as a by-product from either copper or nickel mines.

The Bou-Azzer mine in Morocco is the only primary producing cobalt mine in the world. It has capacity of about 3 000 metric tons. Glencore is the leading producer of cobalt with about 31% of global capacity coming from its Katanga and Mutanda mines in the DRC. China Molybdenum's (CMOC) Tenke Fugurume mine in the DRC produced about 15 436 tons of cobalt in 2020.

BloombergNEF forecasts new cobalt projects and discoveries coming online in Canada and Australia. The latter has the most capacity coming online, around 24 000 metric tons by 2030. Australia's growth is fuelled by the country's ease of raising capital, stable tax regime and welcoming fiscal policies toward the mining industry – particularly cobalt, which has been classified as a strategic mineral by government. Despite this growth in cobalt mining in other jurisdictions, production from the DRC will still dominate the market, with 239 000 metric tons of global supply by 2030, partly due to the quality of its deposits and the lower cost of extraction and processing.

4.2.2 Manganese

Manganese is the twelfth most common element in the earth's crust and is often found with iron ore deposits. South Africa and Gabon account for about 43% of global manganese ore production. Manganese is an abundant mineral. According to the U.S. Geological Survey (USGS), the world has over 810 million tons of recoverable manganese reserves. South Africa accounts for 20% of recoverable reserves, followed by Brazil, Ukraine and Australia. Manganese is a low value raw material within the battery cell.

According to BloombergNEF, manganese ore mining capacity will grow to 26.7 million tons in 2030 from about 22 million tons in 2020. South Africa will only add about 800 000 tons of new capacity by 2030 due to companies holding back on new investment because of legacy challenges associated with rail capacity, electricity reliability and cost. Eramet, a France-based mining and refinery company, is building a new mine close to the Moanda mine in Gabon, which will increase the mine's annual capacity from 4 million tons to 7 million tons by 2023.

4.2.3 Nickel

The Ambatovy mine in Madagascar has capacity to produce about 60 000 metric tons of refined nickel and 5 600 metric tons of refined cobalt. Nickel is also produced in South Africa and Zimbabwe as a by-product of platinum group metals (PGM), mainly from the Bushveld Complex and the Great Dyke mining regions. South Africa produced about 35 000 metric tons of nickel in 2020.

4.2.4 Lithium

Africa could produce about 140 000 metric tons of lithium carbonate equivalent by 2025. The DRC's Manono project could contribute about 14% of Africa's upcoming capacity. In June, Ganfeng Lithium acquired 50% of the company that owns the Goulamina spodumene mine in Mali for $130 million. Goulamina could produce about 55 660 metric tons of lithium carbonate equivalent by 2025. The Bikita mine as well as the Glencova and Arcadia lithium projects could make Zimbabwe a significant lithium producer by 2030. Namibia and Ghana have made recent lithium discoveries as well.

4.3 Lithium and Cobalt Sulphate Production

A typical process to produce nickel and cobalt sulphate as raw materials for precursor materials is presented below and will not be discussed in detail[10].

It, however, needs to be noted that precursor material producers have very stringent specifications to which the nickel and cobalt sulphate need to comply. As such, the higher the level of impurities in the original nickel resource, the higher the cost of producing the pure required battery-grade sulphatec.

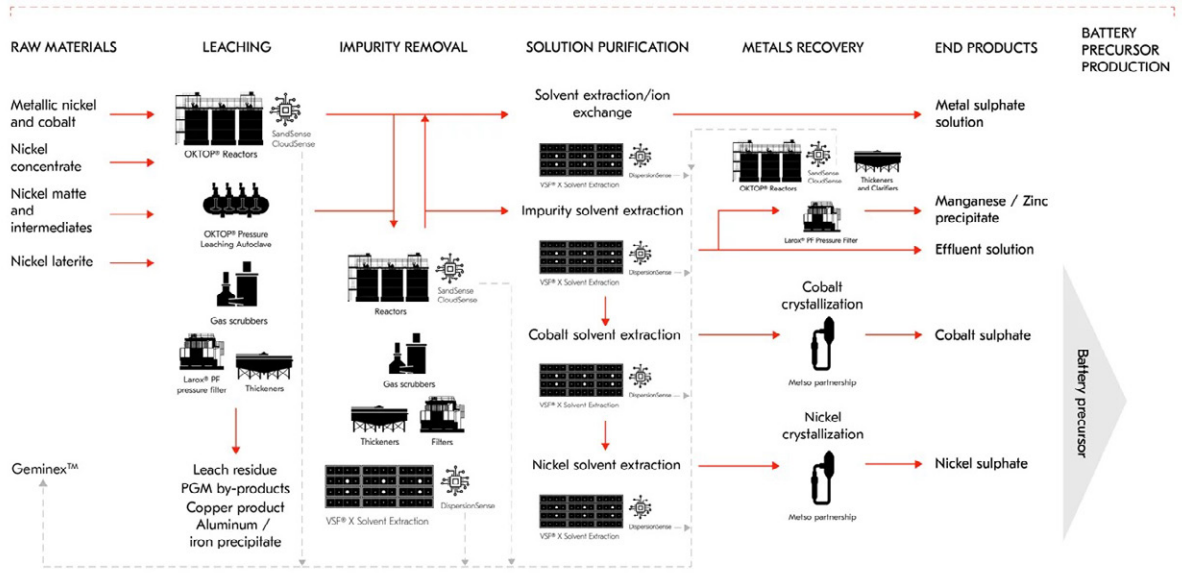


Figure 19: Lithium and Cobalt Sulphate Production Process

4.4 Manganese Sulphate

The Manganese Metal Company (MMC) in Mbombela uses its proprietary manganese ore. MMC has developed a highly effective combination of chemical and physical processes to remove impurities from manganese ore and sustainably produce crystals with a low carbon footprint (when compared to the metal dissolution route).

[10] Metso. 2024. Battery Minerals. https://www.metso.com/commodities/battery-minerals/?creative=686160612687&keyword=battery%20production&matchtype=b&network=g&device=c&gad_source=1&gclid=EAIaIQobChMIg-O67MychgMVw5JQBh2CwQMaEAAYAyAAEgKGpvD_BwE

The below is a reflection of the MMC process[11].

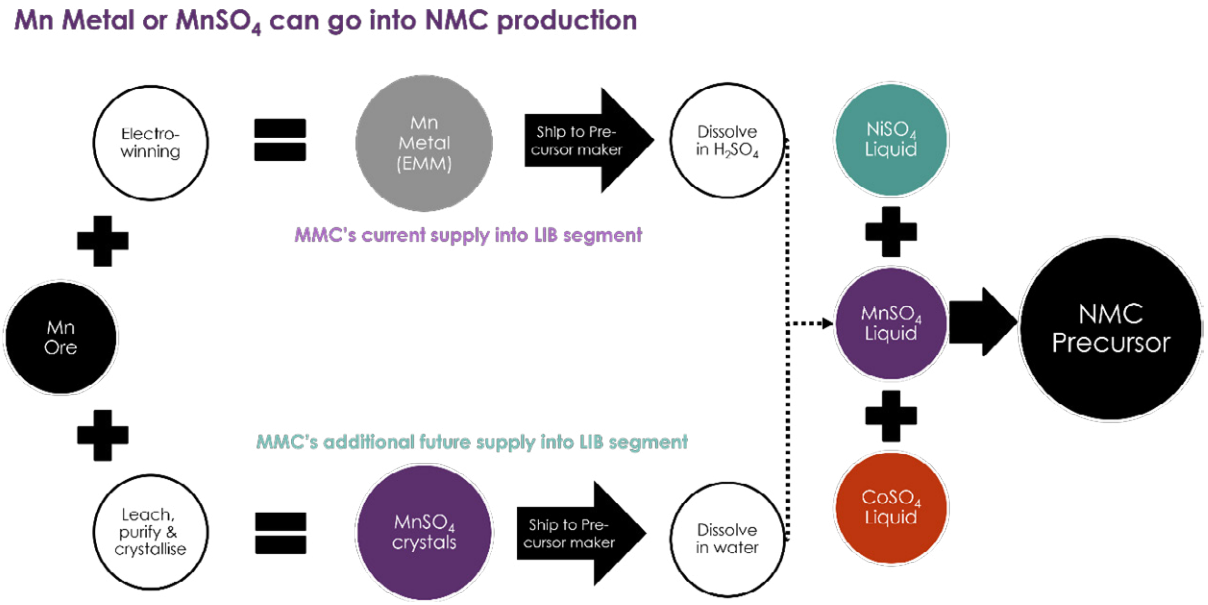


Figure 20: MMC Process

4.5 Lithium Hydroxide Production

Similarly to producing nickel and cobalt sulphate as raw materials for precursor materials, the process below reflects the production of lithium hydroxide for use within the active material process[12].

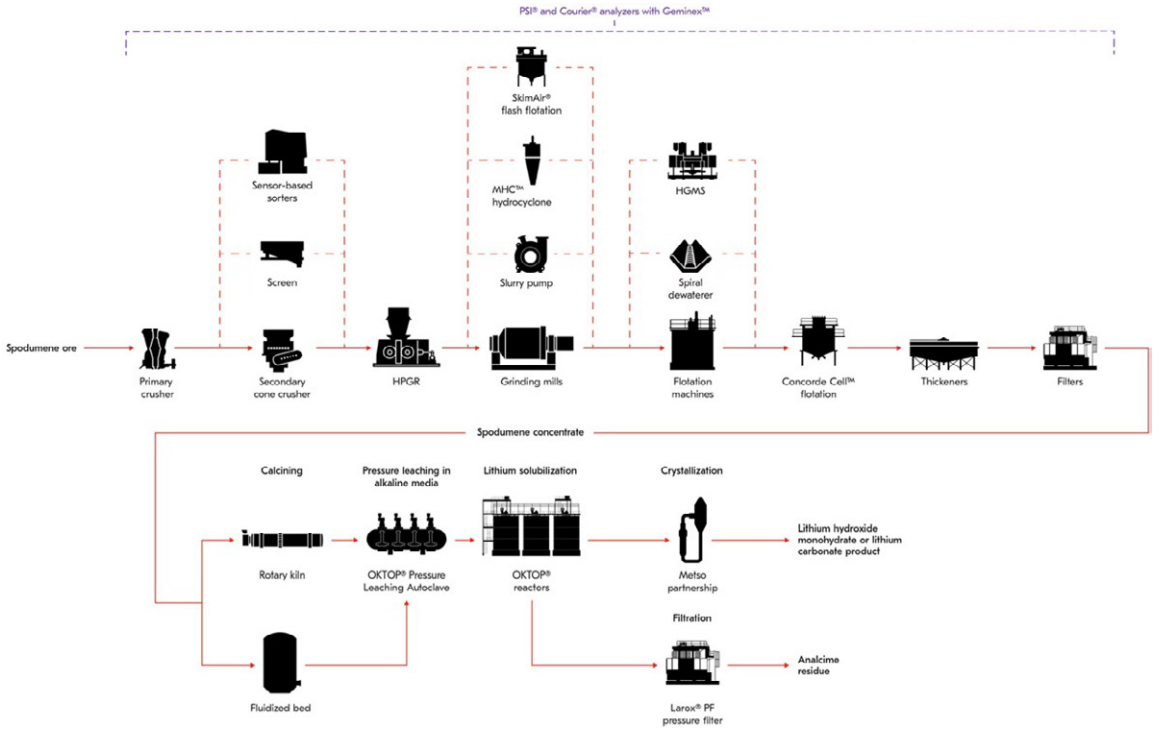


Figure 21: Lithium Hydroxide Production Process

[11] Manganese Metal Co. 2023. https://www.metso.com/commodities/battery-minerals/?creative=686160612687&keyword=battery%20production&matchtype=b&network=g&device=c&gad_source=1&gclid=EAIaIQobChMIg-O67MychgMVw5JQBh2CwQMaEAAYAyAAEgKGpvD_BwE

[12] Metso. 2024. Battery Minerals. https://www.metso.com/commodities/battery-minerals/?creative=686160612687&keyword=battery%20production&matchtype=b&network=g&device=c&gad_source=1&gclid=EAIaIQobChMIg-O67MychgMVw5JQBh2CwQMaEAAYAyAAEgKGpvD_BwE

A capture image clip from a Metso video showing a lithium hydroxide plant[13].

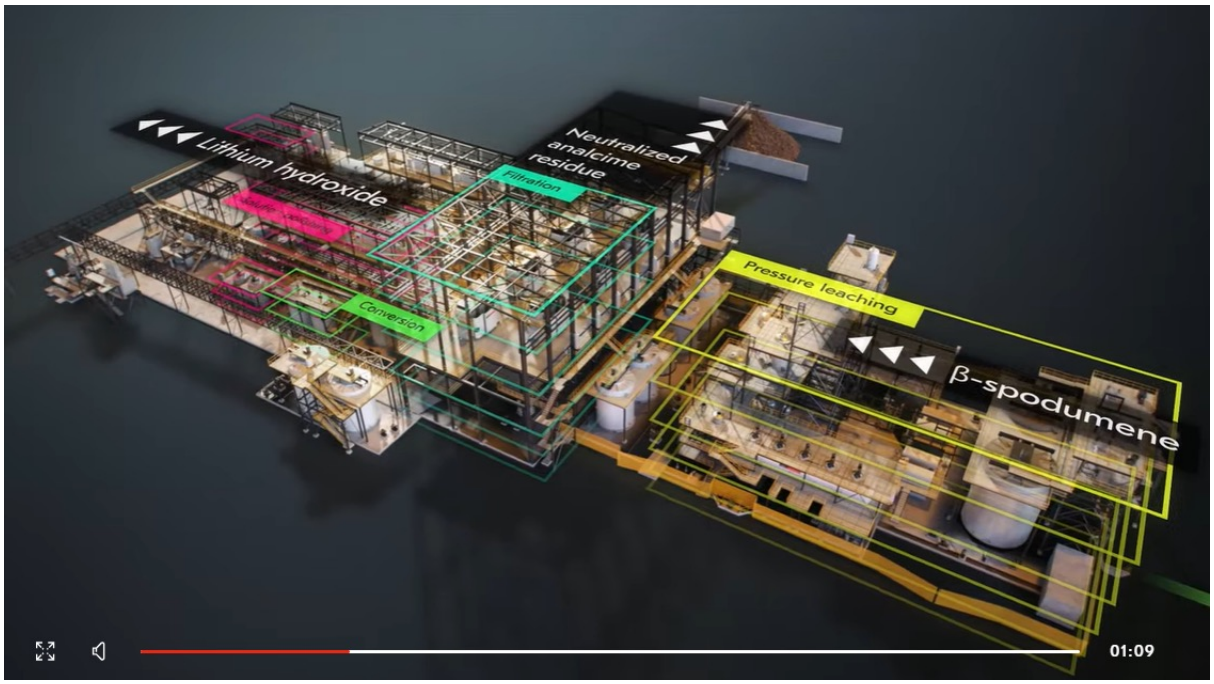


Figure 22: Lithium Hydroxide Plant

[13] Metso. 2024. Lithium Hydroxide Process. https://www.metso.com/commodities/lithium/

5. VALUE ADDITION ACROSS THE BATTERY VALUE CHAIN

Porsche Consulting estimates that the battery sector, comprising cell manufacturers, materials including mining, refining and active materials, equipment manufacturers, and other players around systems, is growing at record speed, surging from € 20 billion at the beginning of the decade to an estimated € 550 billion by 2030.

Porsche Consulting qualified the very interesting dimension related to the value addition envisaged across the building blocks of the battery value chain as per the figure below.

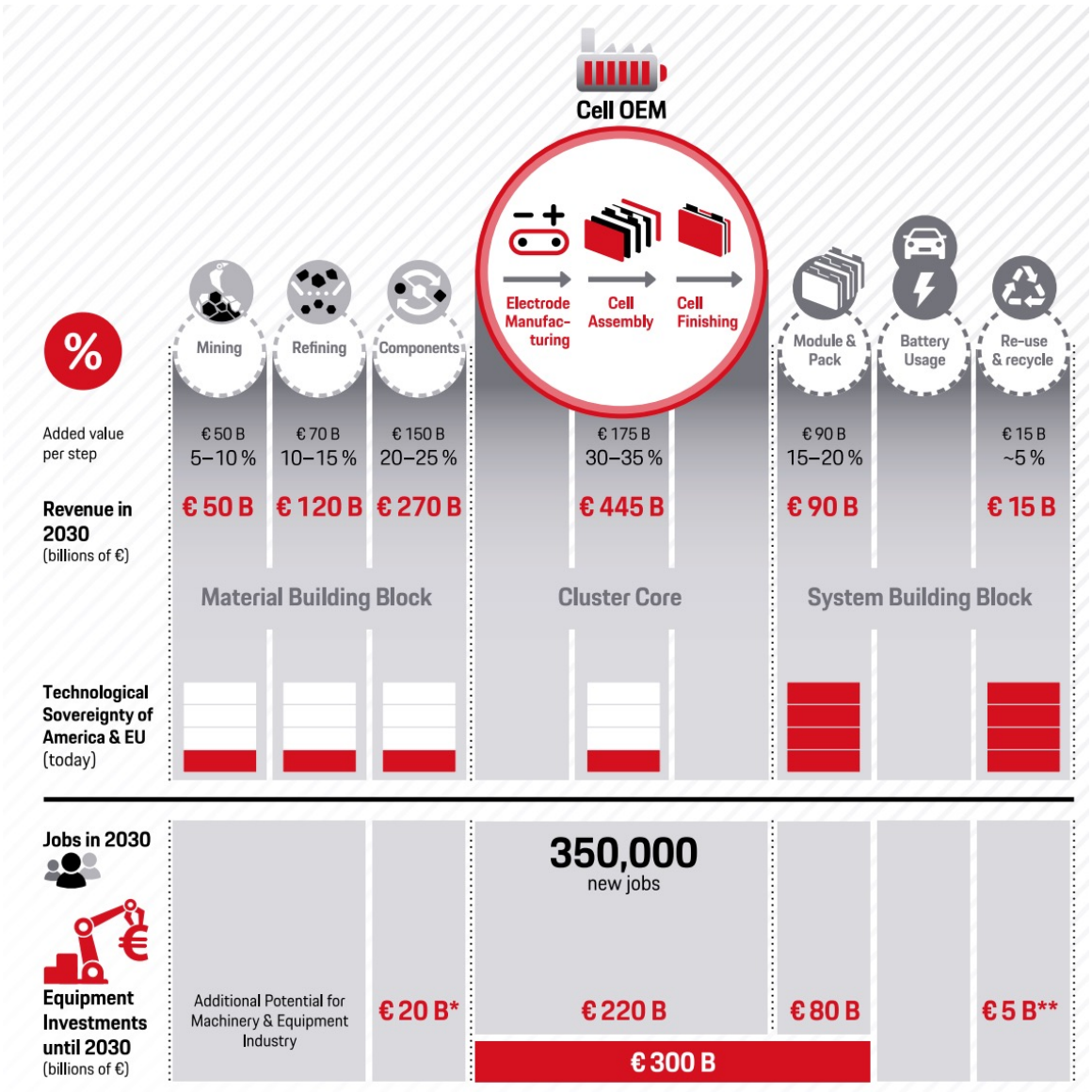


Figure 23: Value Addition Envisaged Across Building Blocks of Battery Value Chain

It is clear from the above the bulk of value addition resides within battery components, cell productions and battery module/pack assembly. As such, primary processing and refining, where the Southern Africa region is rich, does not present the biggest value additions.

5.1 Battery Value Chain Costs

5.1.1 Porsche Consulting

Size matters when it comes to building battery cell factories, of which 65–95 will be located in Europe and North America. Every gigafactory is a giga-scale project across multiple dimensions, including capital expenditures. Since there is a minimum size for a factory below which it is not economically viable, smaller players are generally at a 15–20 % disadvantage in costs per cell compared to large-scale volume manufacturers.

Based on Porsche Consulting assessment, the average gigafactory has an annual output of 30–40 GWh p.a., plant size varies depending on its individual characteristics. Some players even plan for larger gigafactories with double that capacity or more. Bringing such gigafactories online requires investments of € 1.5–3 billion per 30–40 GWh capacity, divided equally between:

- € 0.75–1.5 billion for machinery and another
- € 0.75–1.5 billion for buildings and infrastructure.

This translates to between €50m (ca $55m) and €75m ($82m) per GWh.

Running a 30–40 GWh factory also requires around 2 500 to 3 500 employees.

It is further estimated that more than 200 such gigafactories will have been established by 2030.

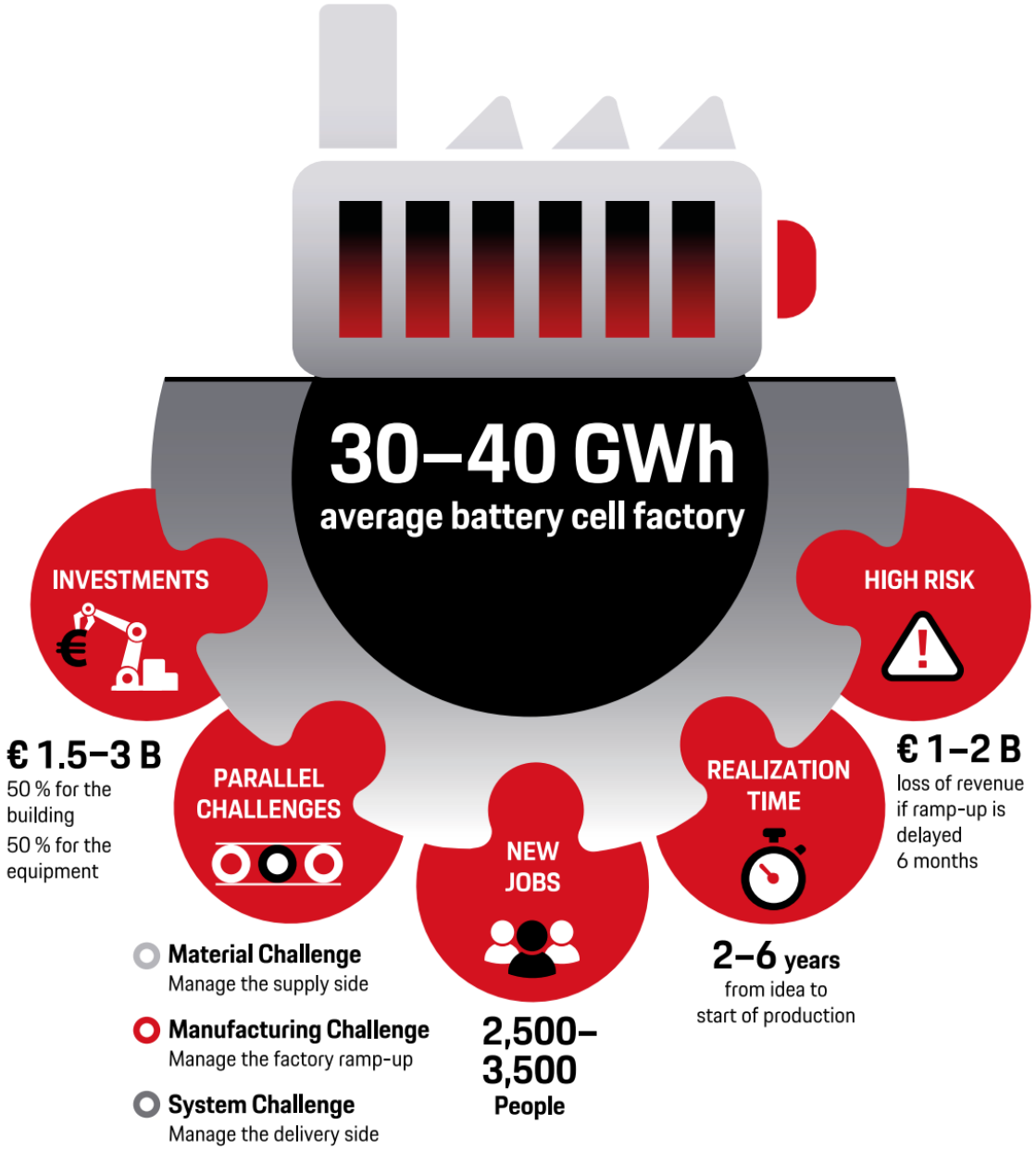


Figure 24: 30-40 GWh Battery Cell Factory Cost Summary

This growth will not only place pressure on the equipment manufacturers for such facilities but may open opportunities for other.

5.1.2 Finmodelslab

According to the Finmodelslab breakdown of costs for battery production plant[14], the cost structure in Table 1 is applicable in the USA.

The cost structure base capacity in terms of GWh is not disclosed and provides ranges. It is further unclear if this cost structure is inclusive of land and building, and associated infrastructure.

Correlation with the information from Porsche Consulting lets us believe it is also on a per GWh basis but exclusive of land and building, and associated infrastructure. It is therefore assessed to not reflect the full costs.

[14] Ryzhkov, A. 2024. https://finmodelslab.com/blogs/startup-costs/lithium-ion-battery-production-startup-costs#One

Table 1: Costs Structure for GWh Factory

Startup Costs	Average Cost Range (USD)
Equipment purchase and installation	$6,000,000 - $8,000,000
Raw material sourcing and acquisition	$1,000,000 - $3,000,000
Research and development expenses	$2,000,000 - $4,000,000
Infrastructure and facility construction	$10,000,000 - $15,000,000
Employee training and hiring costs	$500,000 - $1,000,000
Legal and regulatory compliance costs	$500,000 - $1,500,000
Marketing and advertising expenditures	$1,000,000 - $2,000,000
IT system and software implementation costs	$500,000 - $1,000,000
Initial inventory and working capital expenditures	$5,000,000 - $7,000,000
Total	**$27,500,000 - $43,000,000**

The costs are qualification to be dependent on location, size and the level of automation.

5.2 Techno-Economic Model for Benchmarking Production Cost

Based on the work done by Sina Orangi and Anders Hammer Strømman, they have derived comparisons based on a breakdown of Lithium-Ion battery cell production cost on a process-based cost model for a manufacturing plant of 5.3 GWh, annually produces approximately 24 215 000 NMC111-G prismatic cells, assuming a model structure as presented below.

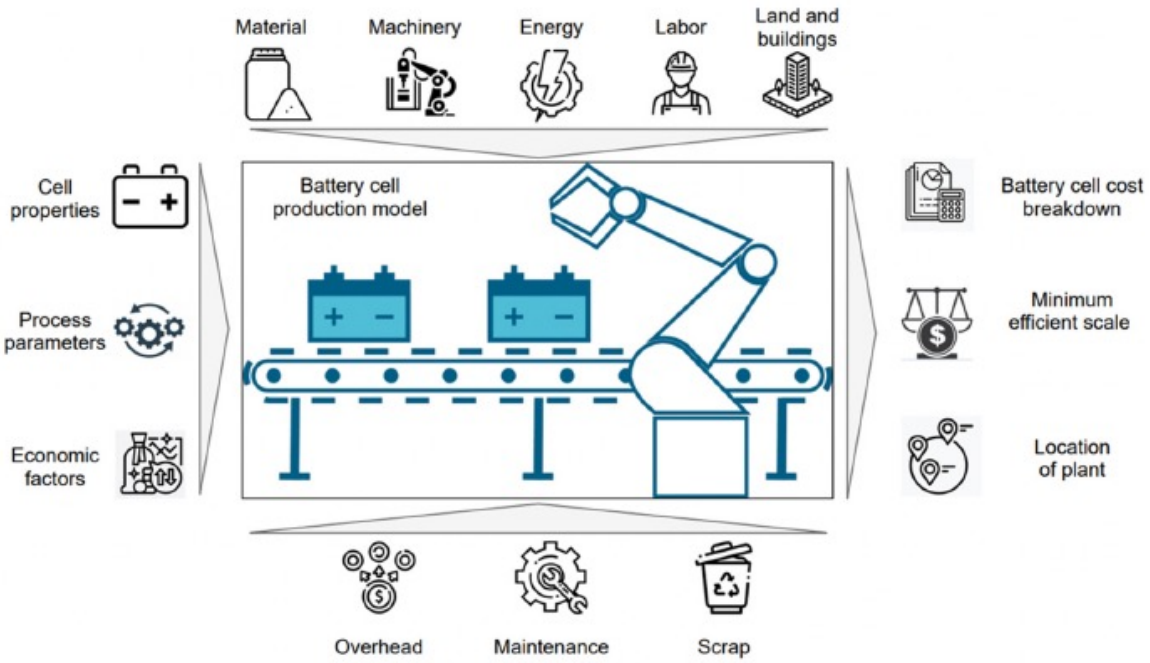


Figure 25: Prismatic Cell Model Structure

The below graphical cell cost breakdown reflects the outcome for the 5.3 GWh NMC111-G battery cell for 9 different locations around the world.

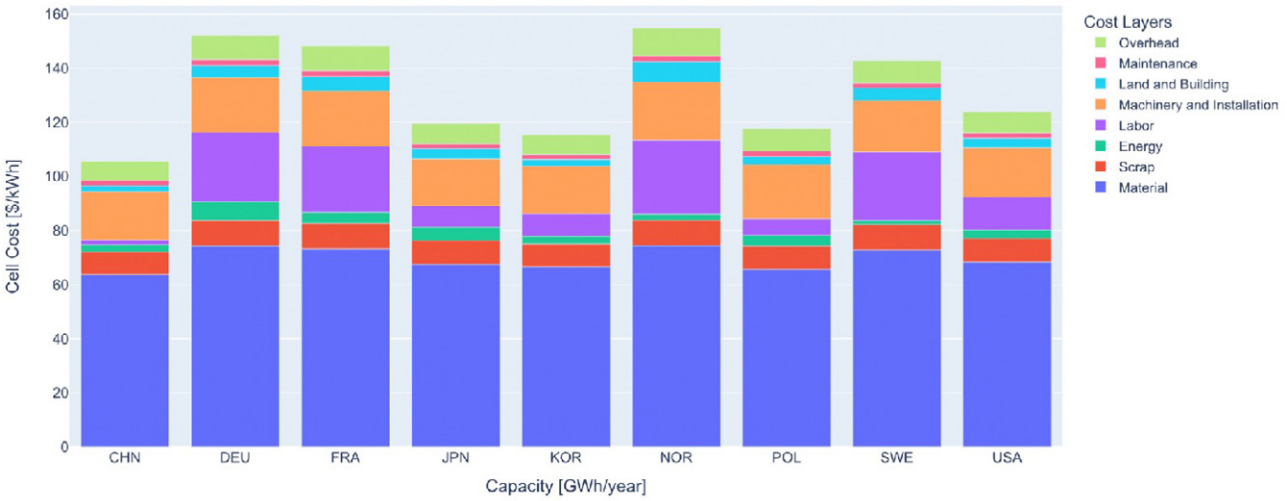


Figure 26: Cell Cost Breakdown

Furthermore, below is a graphical representation of how the costs vary for difference chemistries. This reflects envisaged LFP chemistries for South Africa on the lower end of the cost curve.

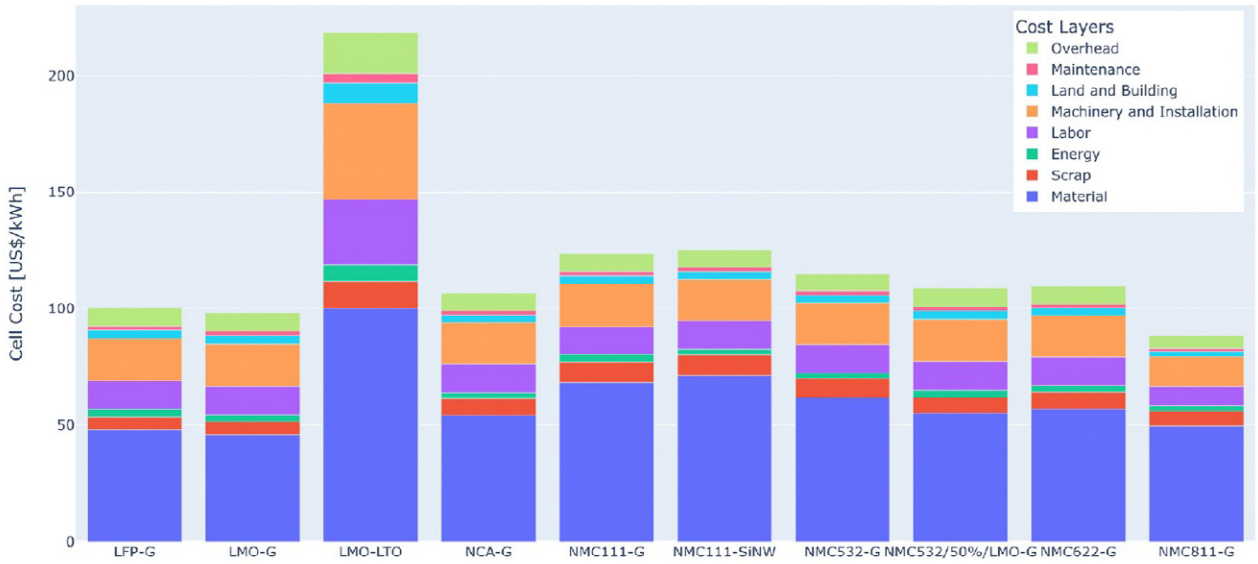


Figure 27: Cost Breakdown for Different Chemistries

The expanding production volume is one of the strategies which is used to reduce the manufacturing cost of the cell. The economics of scale must be maximally materialised to reach a minimum efficient scale corresponding to the lowest point on the cost curve.

Below is stacked diagram of applied cost layers for the production of NMC111-G prismatic cells in US$ (black dashed line tracks the lowest price of the total battery cell cost).

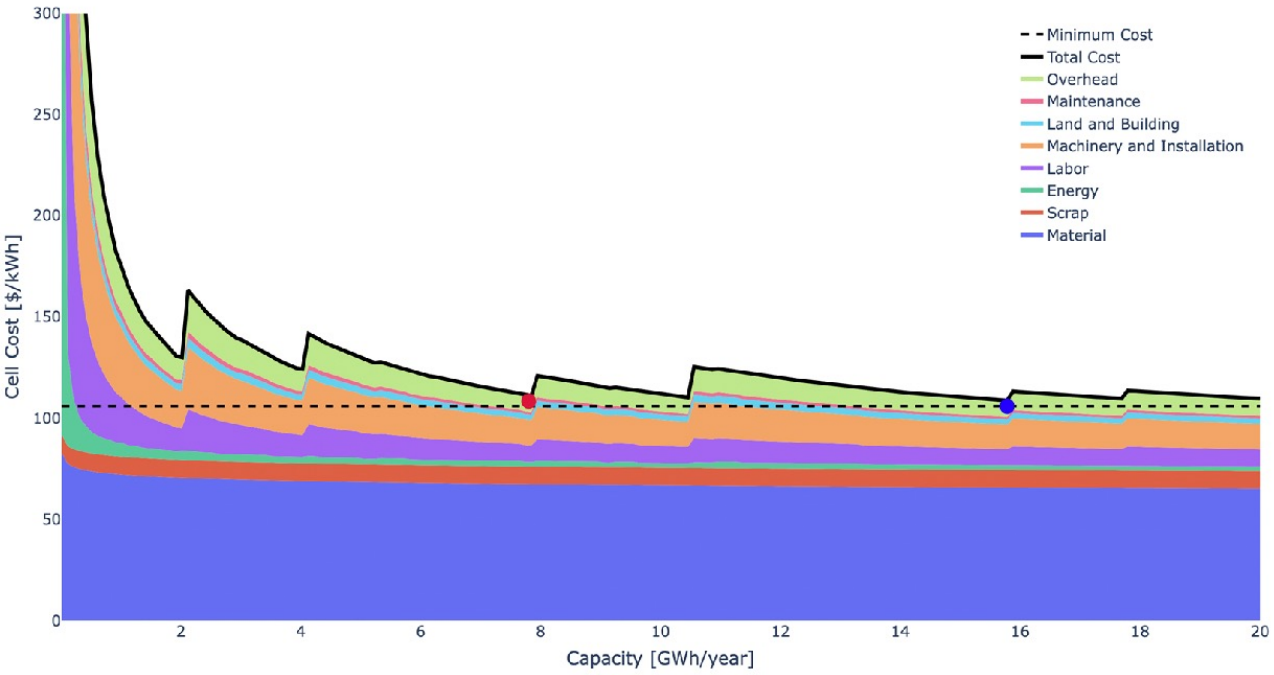


Figure 28: Cost Layers for Production of NMC111-G Prismatic Cell

5.3 Benchmarking with Announced Projects

To derive a reasonable assumption for the costs associated with a gigafactory for battery cell production, the above costs were benchmarked against the costs highlighted earlier.

Table 2: Costs Associated with a Gigafactory for Battery Cell Production

Project	Cost	Capacity	Cost per GWh
CATL Henan	$1,9 bn	26 GWh	$73 m
Sunwoda Hefei and Zhejiang (2 factories)	$4,7 bn	Approximately 60 GWh	$78 m
LG Energy Solution's Arizaona USA	$1.3 bn	-	$127 m in USA
China's average cost per GWh	-	-	$72 m however some plants are around $55 m per GWh
Ultium Cells Spring Hill expansion	$275 m	15 GWh	$18,34 m
Tesla Nevada	$4,5 bn	35 GWh	$128m
Ford previously (LFP) cell production capacity in North America	$2,5 bn	21 GWh	$119 m

5.4 Conclusion of Costs

The modelling versus the actual costs of the announced project shows a large variation depending on size, level of automation and location. In addition, comparing the above with the work of Sina Orangi and Anders Hammer Strømman, a battery cell plant cost of around $125m per GWh is considered realistic for a South African environment, and could be even higher based on South Africa's location. Factors that could increase the costs include:

South Africa's ability to secure a reputable international partner with experience in the establishment and operation of such a gigafactory. If not, the learning curve, time to full operation, etc. will increase the costs.

The availability of manufacturing equipment and associated shipping, installation and commissioning costs for such a plant in South Africa, being outside of the dominant cell production regions.

Local costs structures such as energy, labour, etc compared to the dominant regions.

6. PRECURSOR MATERIAL PRODUCTION AND RAW MATERIAL PROCESSING COSTS

6.1 Bloomberg NEF

BloombergNEF released a study on the production of battery precursors in the DRC in November 2021 for the Africa Export-Import Bank (Afreximbank), United Nations Economic Commission for Africa (UNECA), African Development Bank (AfDB), Africa Finance Corporation (AFC), Arab Bank for Economic Development in Africa (BADEA) and African Legal Support Facility (ALSF). This report is considered the latest report reflecting the associated information and costs for an African environment.

The report determined the cost of producing lithium-ion battery precursors in the DRC and benchmark the cost to that in the USA, China and Poland.

The report concluded that building a 10 000 metric-ton precursor facility in the DRC could cost $39 million. This is three times cheaper than what it would cost for a similar plant in the USA, while a similar project in China and Poland will cost $112 million and $65 million, respectively. This conclusion was derived on the basis that the capital cost in the DRC is cheaper than all three countries mainly due to the lower cost of land and construction of the project.

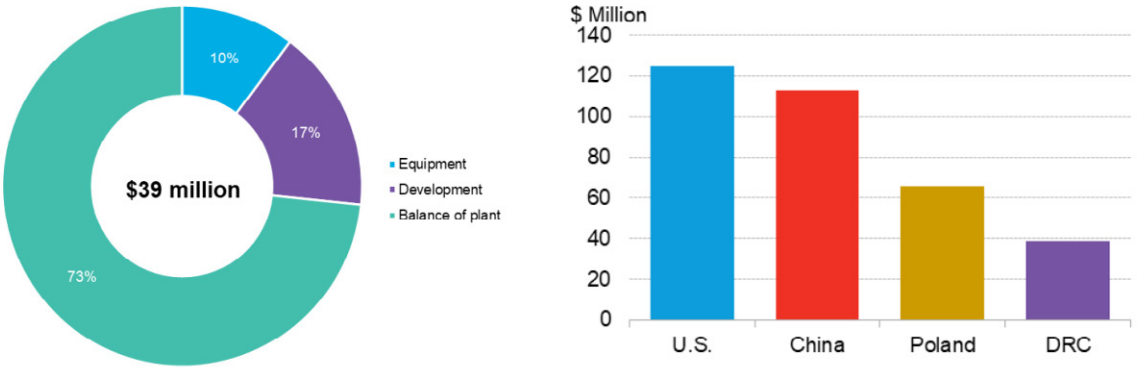
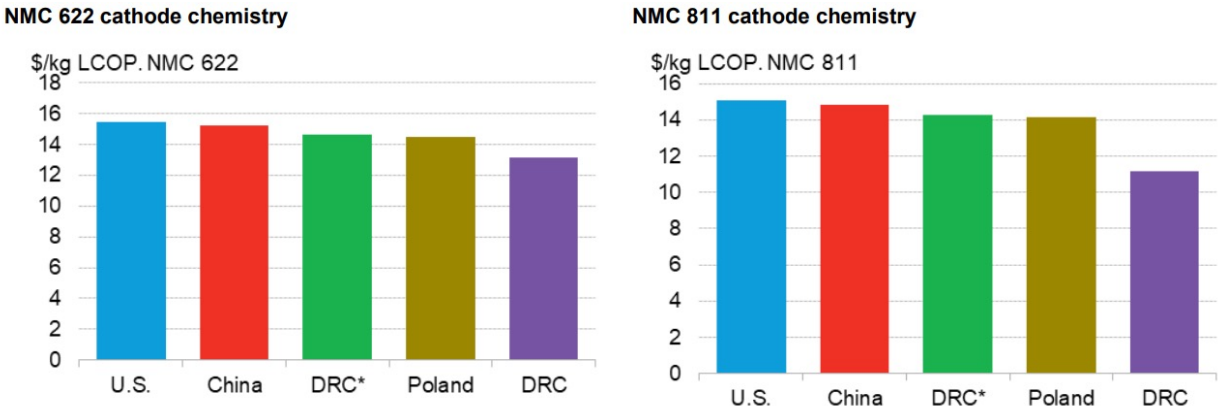


Figure 29: Capital Cost for Production of Battery Precursors

Furthermore, operating a 10 000 metric tons precursor facility in the DRC that procures cobalt at cost (integrated scenario) from a captive mine is the most cost-competitive, compared to a similar plant in the USA, China and Poland. Operating costs in the DRC are however more expensive than Poland once the plant must procure its cobalt at spot prices (non-integrated).



Source: BloombergNEF. Note: The asterix (DRC) indicates a non-integrated scenario for the D.R.C.*

Figure 30: Operating Cost for Production of Battery Precursors

The model used by Bloomberg NEF was based on:

- A top-down approach to estimate the capex of an existing plant and split it across land, construction and equipment.
- Considered operating costs included costs such as labour, electricity, water, maintenance, reagents and feedstock to determine the levelised cost precursor production (LCOP).
- Obtaining project-specific data from battery manufacturers around the world.
- Used project data from the mining and manufacturing industries in the DRC to estimate the cost of project development in the DRC.
- Bloomberg Terminal for finance data.
- The DRC government facilitated the acquisition of local cost data on transport, labour, water and electricity in conjunction with the utility providers and other private companies.

An illustration of the cost model is presented below:

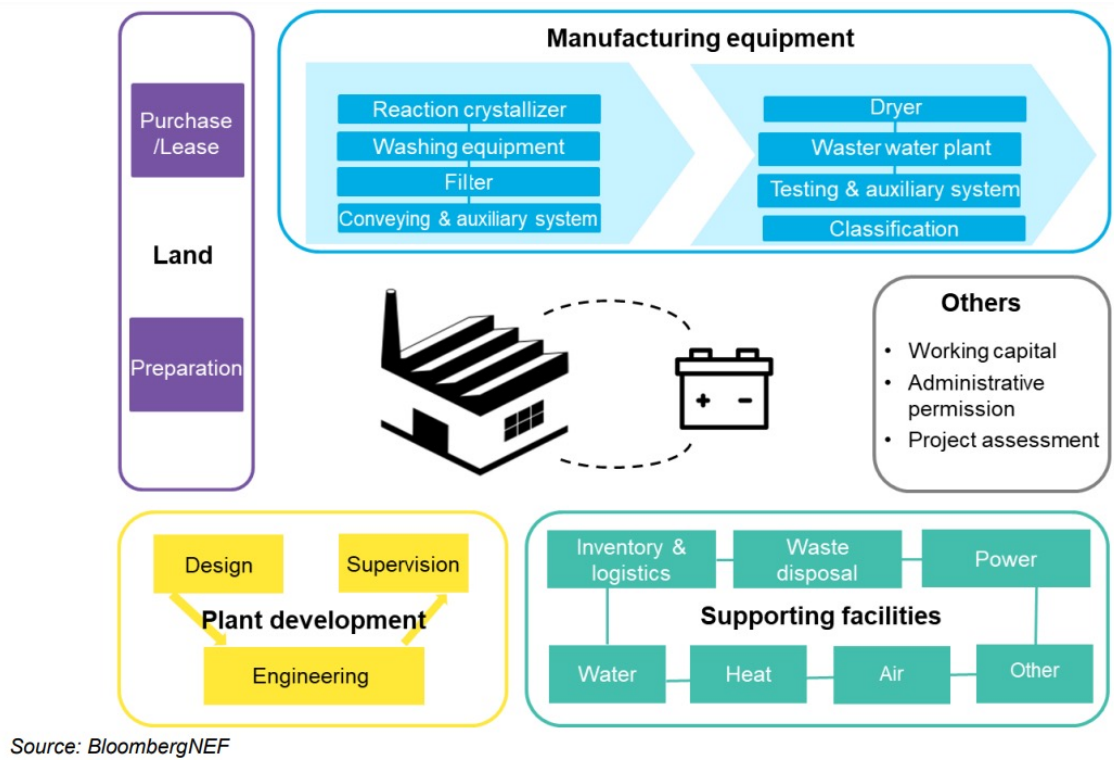


Figure 31: Cost Model for Production of Battery Precursors

Based on engagements with equipment manufacturers and benchmarking with existing plants, Bloomberg NEF concluded that scaling a 10 000 tons plant to 100 000 tons in the DRC would increase the capital required for equipment by 7.5 times. Similarly, development costs and balance of plant expenditure increase by 6.5 and 8 times, respectively. Using BloombergNEF's top-down approach, it was estimated that a 100 000 metric tons precursor plant built in the DRC could cost $301 million.

6.2 Benchmarking

Benchmarking by Bloomberg NEF and other sources to compare the capital expenditure, revealed the following:

Table 3: Benchmarking of Capital Expenditure

Project	Cost	Capacity	Cost per 100 000 tons/annum
GEM in China's Hubei province	$431 million	80 000 tons per annum	$53,88 million
Umicore in Canada	$1,4 billion (€1,27 billion)	35GWh (calculated about 87 000 tons/ annum)	$160,92 million
Confidential	R2,5bn ($132,28m)	10 000 tons per annum	$132,28 million
Bloomberg China benchmark	$112 million	10 000 tons per annum	$112 million
Bloomberg Poland benchmark	$65 million	10 000 tons per annum	$65 million
Austvolt – Western Australia	AUD 300 million ($201m)	40 000 tons per annum	$50,25million

6.3 Conclusion

Based on the above, it is again clear that there is wide fluctuation in the prices of precursor plants and it varies from country to country. From the limited available data and information released, it is very difficult to distinguish between the different types of plants, chemistries, etc.

The Estimated price of $39 million for 10 000 tons per annum is accordingly considered low while others are very mixed. It is therefore challenging to indicate a realistic price but the $132,28 million for a South African plant was obtained in 2019/20. This price could be different now.

Note that these precursor plant costs exclude the processing plant costs for producing the required nickel, cobalt, manganese sulphates and lithium hydroxide.

Indicative associated costs for such plants are indicated below. Due to the confidential nature of the information obtained, the sources and associated projects cannot be disclosed.

Table 4: Indicative Associates Costs for Gigafactories

Estimates	tpa	Capex ($)
Nickel hydroxide to nickel sulphate	30 000	25
Cobalt hydroxide to cobalt sulphate	500	27
Manganese oxide to Manganese sulphate	1 000	28
Graphite	15 000	26

6.4 Operational costs

The operation costs associated with the value chain components is a challenging exercise given there are many variable components that need to be considered to derive any costs. The following is a non-exhaustive list of variables that influence the costs:

- Location of the facility.
- Size of the facility.
- Battery chemistry.
- Commodity cycles of the various metals.
- Terms of contract for the supply of the raw material in terms duration, volumes, price.
- Origin of the raw material and associated transport-in costs.
- Quality of the raw material and level of contaminants that need to be removed if the process commences at a hydroxide level and needs to produce sulphates.
- Quality of the sulphates if the process commences at producing directly a precursor material.
- Raw material wastage and recovery rates.
- Overhead costs in the specific location such as labour, water, electricity, etc.
- Off-taker price from the battery manufacturer for the precursor material.
- Quality of the precursor product.
- Transport-out for the precursor product

To achieve a reasonable operation cost price, it requires effectively a separate pre-feasibility study that involves the understanding of the cell manufacturer's specifications, the compilation of raw material specifications, engagements with raw material suppliers based on volumes, duration and some level of indicative pricing. In addition, the plant concept design needs to be done as that will influence contamination removal requirements, water consumption, the extent of water recovery and recycling facilities, electrical consumption, etc.

6.4.1 Value chain price solving

Normally pricing of the specific element is based on a backwards cost-solving exercise. It starts at the cell manufacturers, the precursor material manufacturers' respective off-take prices, then sulphate- and hydroxide producers' respective off-take prices and linking that to commodity cycles and raw material suppliers' prices. Across the value chain, each element needs to demonstrate financial viability and provide a required return considering the capital- and operation costs versus the next off-taker price.

Note that the respective manufacturers and producers' costs are confidential cannot be obtained, as that becomes the intellectual property and competitive advantage versus competitors.

What is known is that if you back-solve, it results in the raw material supply contracts needing to be concluded on a long-term basis to mitigate commodity cycle risks, at a substantial discount to the London Metal Exchange ("LME") price for metal content, and to ensure security of supply in terms of volumes and quality.

6.4.2 Metal prices

The growing demand for battery energy storage, both stationery and mobility (EVs), as well as Covid-19, shipping costs, etc. impacted the prices for battery storage materials as depicted in the following graphs extracted from Trading Economics[15].

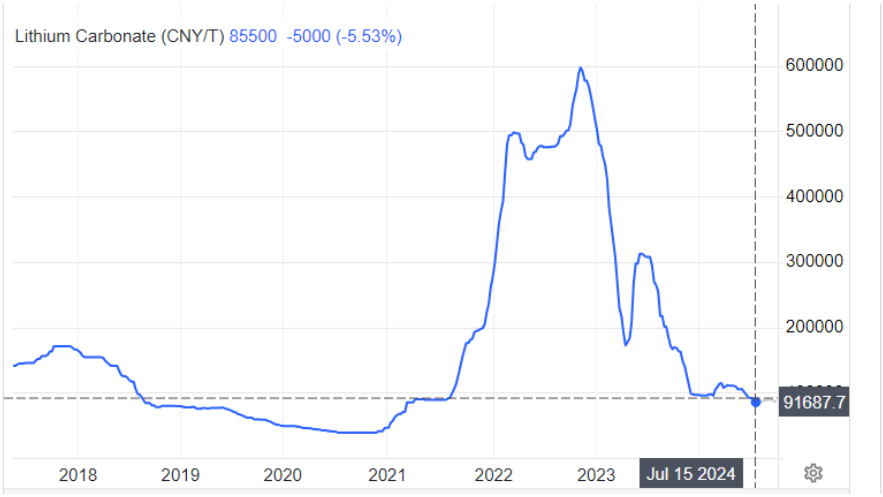


Figure 32: Lithium Carbonate Prices Over The Last 10 Years

Lithium prices are currently forecasted to stay fairly stable (light blue line at the end of the graph).



Figure 33: Nickel Prices Over Last 30 Years

Nickel prices are currently forecasted to stay fairly stable (light blue line at the end of the graph).

[15] https://tradingeconomics.com/



Figure 34: Cobalt Prices Over Last 5 Years

Cobalt prices are currently forecasted to stay fairly stable (light blue line at the end of the graph).



Figure 35: Manganese Prices Over Last 10 Years

Cobalt prices are currently forecasted to increase fairly stable (light blue line at the end of the graph).

The trends shown above for the pricing of essential battery minerals place upward price pressure on battery prices.

6.4.3 Battery price trajectory

Battery energy storage prices are currently still high, yet battery prices are on a downward trend across all technologies, and it is envisaged that battery producers will continue to experience a profit margin squeeze due to the market desire for reduced battery prices, even though battery material costs are stable or increasing.

It has been seen that lithium-ion battery prices have decreased by about 10% over the past 24 months. If raw material costs drastically increase, this will put severe price pressure on manufacturers/producers and emphasise the essentiality of long-term contracting and pricing.

6.4.4 Price sensitivities

Nickel and cobalt price swings have the largest effect on the cost of both NMC (811) and NMC (622) packs. Based on Bloomberg NEF's battery price sensitivity (for the DRC) to estimate the impact of volatile raw material prices on NMC 811 battery packs, versus volumes, the following results were revealed:

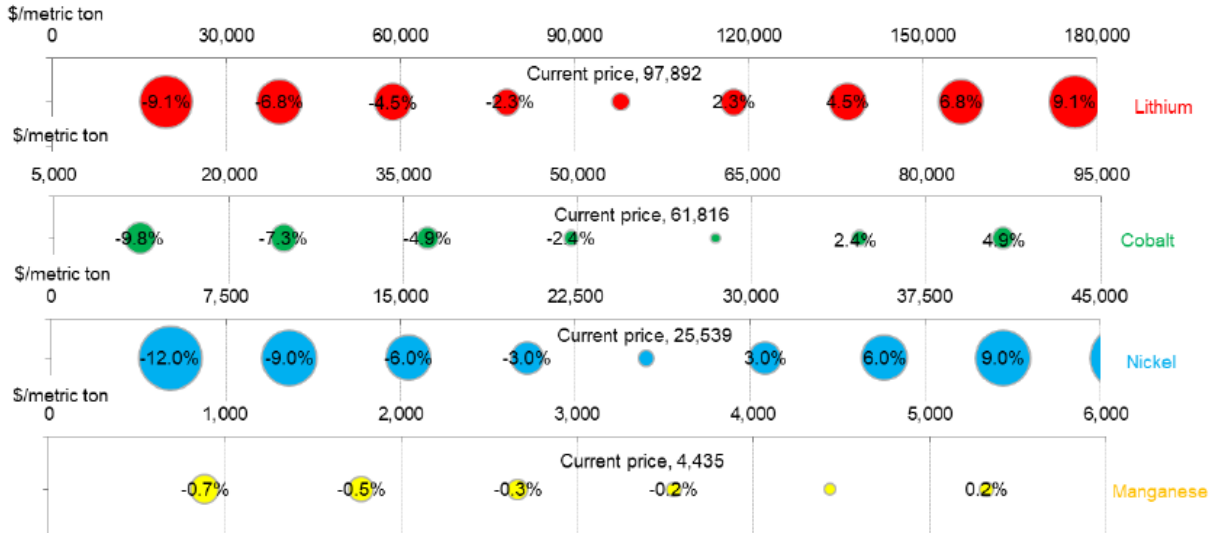


Figure 36: Impact of Material Price Changes on NMC 811 Battery Pack Price

**Prices reflected was Nov 2021*

Doubling of cobalt prices for an NMC 811 battery will increase battery pack cost by 6% only. Doubling of lithium hydroxide prices increases the battery cost by 9%. Nickel price volatility has the highest impact on the battery.

Given current price is a bit lower than November 2021, the variances may be smaller, however, it demonstrates the impact of volumes and a sweet spot for local facilities must be determined through a detailed study.

6.4.5 Cost structures

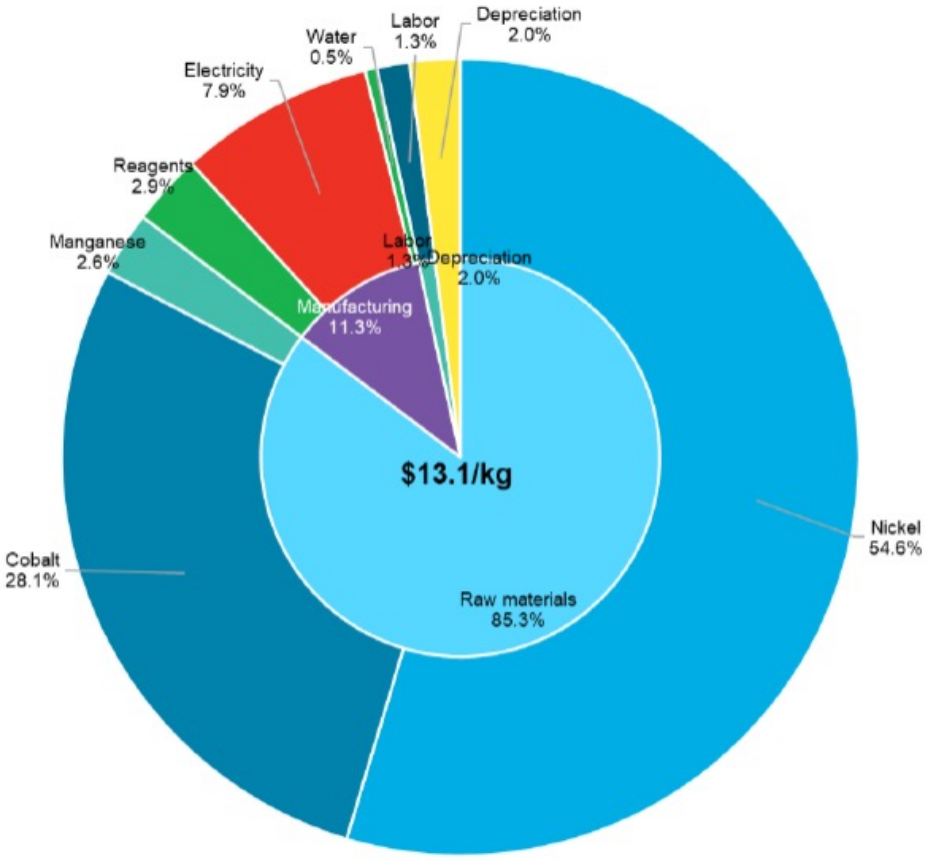
The only cost structure that could be obtained to-date in the public domain is from the Bloomberg NEF study on precursor material in the DRC. Given from the previous that the capital cost estimates were well below the market trend.

The cost of operating a 10 000 metric-ton integrated precursor facility in the DRC is $13.1/kg (2020 real) as shown below in Figure 36. The breakdown of the costs for running the facility includes raw materials (cobalt, manganese, nickel), reagents, water, labour, electricity and the cost of plant and equipment depreciation.

Procuring nickel is the highest operation cost for the precursor plant. This is 55% of the total levelised cost of production. Cobalt comes in next at 28.1% of the levelised cost.

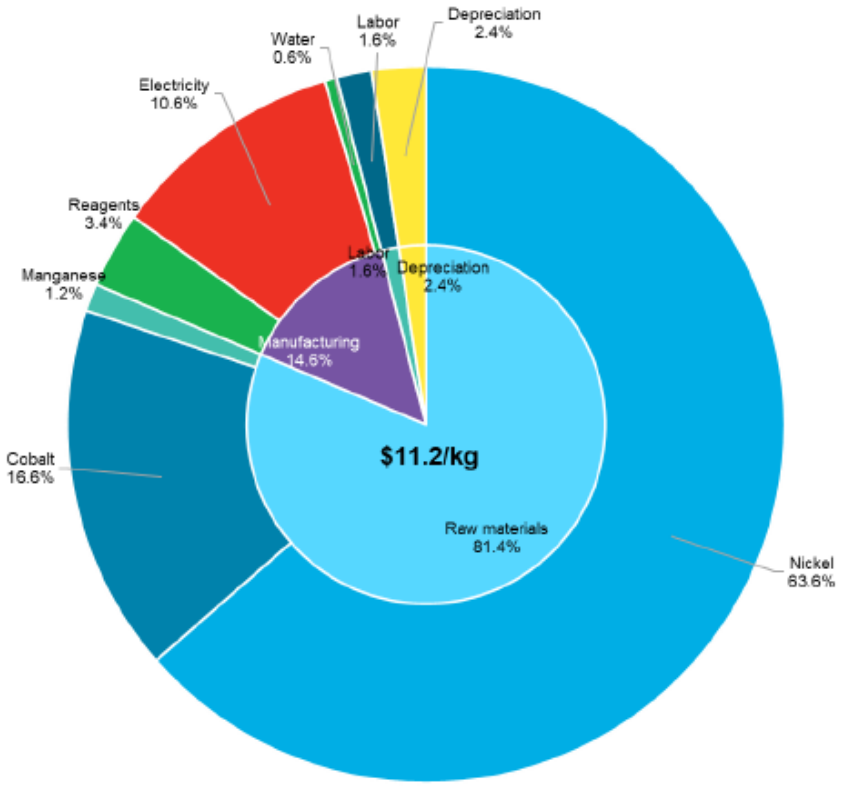
Overall, raw materials make up 85% of the total cost of operation. Next is manufacturing costs at 11%, which includes procuring reagents, electricity and water. In addition to determining the cost of operation at an

integrated facility in DRC, costs for a non-integrated precursor facility scenario in the DRC are included (the company will procure its cobalt at the assumed spot price just like other countries.) It is very difficult to relate these cost structure to a South African environment.



Source: BloombergNEF. Note: The cost is for a 10,000 metric-ton precursor facility and does not include any government subsidy.

Figure 37: Cost of Operating a Precursor Plant for NMC Hydroxide 622 in the DRC



Source: BloombergNEF. Note: The cost is for a 10,000 metric-ton precursor facility and does not include any government subsidy.

Figure 38: Cost of Operating a Precursor Plant for NMC Hydroxide 811 in the DRC

6.4.6 Benchmarking

Based on the Bloomberg NEF benchmarking refers in section 7.4.5, the outcomes is reflected below (based on 2020 real costs):

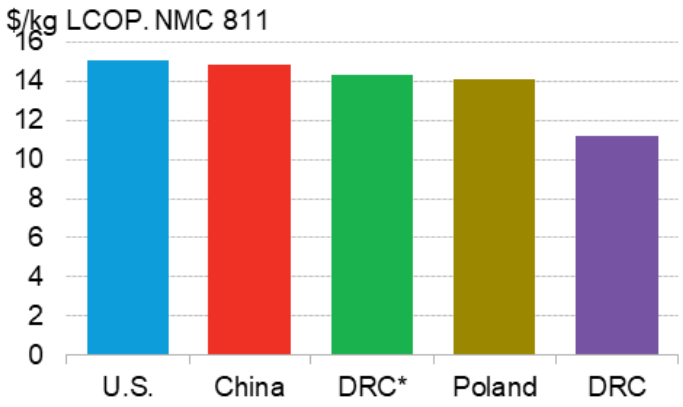


Figure 39: Cost of Operating a Precursor Plant for NMC Hydroxide 811 in the DRC

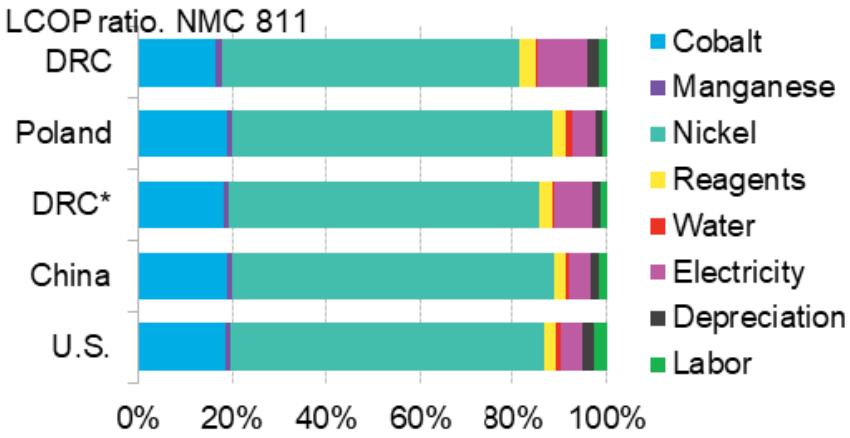


Figure 40: Cost of Operating a Precursor Plant for NMC Hydroxide 811 in the DRC

As expected, the DRC cost is lower compared to the rest of the benchmarked countries and therefore **conservatively a cost of $14/kg** should be assumed for a 10 000 tons per annum precursor plant. In real terms, this should compensate for inflation as well as raw material price reductions between 2021 and current.

6.4.7 Cell plant operating costs

Research has very limited information relating to the operational costs for gigafactories on an independent basis, given many of these companies have integrated business and consolidated financial reporting.

An analysis of the reporting information in their annual financial statements does not provide enough details to isolate the battery production. As an example, Tesla Nevada reports Energy solutions and batteries which include production and assembly, as well as other products such as solar, storage leases etc. A reflection of available and disclosed Tesla data is depicted below, however, the costs per GWh are considered way too high to be realistic.

Table 5: Tesla Reported Data Analysis for Energy Solutions and Storage

TESLA	Dec-23	Dec-22
Revenue (USD'm)	3 909	2 789
Cost of revenue (USD'm)	3 621	2 918
GWh capacity GWh	14,7	6,5
Cost per GWh (USD'm)	246	449
USD / ZAR	18,30	17,02
Cost per GWh (ZAR'm)	4 500	7 641

Analyses of more battery specific companies like CATL and CALB revealed more realistic data as reflected below:

Table 6: CATL Reported Data Analysis

CATL	Dec-23	Dec-22
Revenue (CNY'm)	400 917	325 594
Cost of revenue (CNY'm)	309 070	262 050
GWh capacity GWh	705,5	433,2
Cost per GWh (CNY'm)	438	605
CNY / ZAR	2,64	2,47
Cost per GWh (ZAR'm)	1 157	1 494

Table 7: CALB Reported Data Analysis

CALB	Dec-23	Dec-22
Revenue (RBM'm)	12 294	9 167
Cost of revenue (RMB'm)	11 116	8 297
GWh capacity GWh	50,0	50,0
Cost per GWh (RMB'm)	222	166
USD / ZAR	2,64	2,47
Cost per GWh (ZAR'm)	587	410

The assessment reveals that CATL operates from multiple sites with a large installed capacity, including various battery types/chemistries while CALB mainly operates from a single site, producing Lithium-ion phosphate batteries. This again reveals the impact of diversification, size and chemistry on operating costs. It is not clear how much value add into final product is included the CATL numbers.

It is also clear that operating costs are increasing year-on-year while batteries price is on a downward trend. This confirms the squeeze and margins are reducing year-on-year.

It is therefore proposed to assume at least operational costs from between R600k to R1 150 with the understanding that these are based on Chinese production costs and information. It is recommended that some adjustment factors be included for South African conditions.

6.4.8 Sulphate production costs

After an extensive literature search, no specific operational costs could be derived for hydroxides to sulphates for nickel, cobalt or manganese.

The only basis for extracting some level of operation costs for sulphate production was to utilise available selling price data for sulphates to determine indicative operation costs. It needs to be recognised that the value used includes profits, and other non-production overheads and therefore does not represent true operating costs. Furthermore, prices are based on Chinese production and are not representative of an SA environment.

Sales values were obtained from the S&P Markets IO Platts Battery Metals report and based on prices as of 16 August 2024. Similar exchange rates for the same date were applied.

6.4.9 Cobalt sulphate

The S&P Markets IO Platts Battery Metals report quotes the following prices:

Table 8: Cobalt hydroxide and Cobalt sulphate prices

		CIF China	Exchange		CIF China
Cobalt Hydroxide	$/mt	13889,11	17,933	ZAR/mt	249073,41
		DDP China			DDP China
Cobalt Sulphate	CNY/mt	28200	2,51405	ZAR/mt	70896,21
		CIF North Asia	Exchange		CIF North Asia
Cobalt Hydroxide	$/mt	13889,11	17,933	ZAR/mt	249073,41
		CIF China			CIF China
Cobalt Sulphate	$/mt	4800	17,933	ZAR/mt	86078,40

The Cobalt content has been determined using the molecular mass of cobalt relative to the molecular mass of cobalt hydroxide and cobalt sulphate (Cobalt hydroxide 92.948 g/mol and Cobalt sulphate 154.996 g/mol while the molecular mass of cobalt is 58,933 grams).

A key assessment from the calculation below is that sulphate prices are lower that cobalt prices when using the current prevailing commodity prices. This confirms a previous assessment that raw materials need to be secured at a discount to the prevailing commodity prices for cobalt sulphate production to be profitable and viable - difference highlighted in green below.

Table 9: Cobalt sulphate operational cost calculation

MATERIAL			**Pricing tons**	**Adjusted Princing for capacity**
COBALT HYDROXIDE				
Cobalt Hydroxide	gram/mol	92,95		
Metric ton	gram	1 000 000,00		
Cobalt content	%	63,4%		
Cobalt content per ton	gram	634 000,00		
Cobalt content per ton	kg	634,00		
Cobalt Hydroxide	R/mt		249 073,410	
Cobalt price	$/ton		25 279,6	
Cobalt price	R/ton		453 339,067	
Cobalt equivalent cost	R/mt		287 416,968	
Cobalt equivalent cost	$/mt		16 027,266	
In order to be profitable, the Cobalt Hydroxide should be purchased at a discount to the Cobalt LME prices				
COBALT SULPHATE				
Cobalt Sulphate	gram/mol	155,00		
Metric ton	gram	1 000 000,00		
Cobalt content	gram/mol	38%		
Cobalt content per ton	gram	380 200,00		
Cobalt content per ton	kg	380,20		
Cobalt Sulphate	R/mt		86 078,400	
Cobalt price	$/ton		25 279,6	
Cobalt price	R/ton		453 339,067	
Cobalt equivalent cost	R/mt		172 359,513	
Cobalt equivalent cost	$/mt		9 611,304	
In order to be profitable, the Cobalt Sulphate should be purchased at a discount to the Cobalt LME prices				
Project Cobalt sulphate plant	ton			778
Cost as per material prices	R'm			67
Number of cells	Number			57 803 468
Cell plant capacity	kWh			1 000 000
Cost per cell	R			1,16
This is not a true reflection but indicative based on the Cobalt sulphate selling prices as per 16 Aug 2024				

6.4.10 Nickel sulphate

The S&P Markets IO Platts Battery Metals report quotes the following prices:

Table 10: Nickel sulphate prices

		CIF Northern Asia	Exchange		CIF Northern Asia
Nickel Sulphate	$/mt	3826	17,933	ZAR/mt	68611,66

The Nickel content has been determined using the molecular mass of nickel relative to the molecular mass of nickel sulphate (Nickel sulphate 154.75 g/mol while the molecular mass of nickel is 58,693 grams).

A key assessment from the calculation below is that again sulphate prices are lower that the nickel prices when using the current prevailing commodity prices. This again confirms that also for nickel raw materials need to be secured at a discount to the prevailing commodity prices for nickel sulphate production to be profitable and viable - difference highlighted in green below.

Table 11: Nickel sulphate operational cost calculation

MATERIAL			**Pricing tons**	**Adjusted Princing for capacity**
NICKEL SULPHATE				
Nickel Sulphate	gram/mol	154,75		
Metric ton	gram	1 000 000,00		
Nickel content	gram/mol	37,9%		
Nickel content per ton	gram	379 278,84		
Nickel content per ton	kg	379,28		
Nickel Sulphate	R/mt		68 611,658	
Nickel price	$/ton		16 352,100	
Nickel price	R/ton		293 242,209	
Nickel equivalent cost	R/mt		111 220,564	
Nickel equivalent cost	$/mt		6 202,005	
In order to be profitable, the Nickel Sulphate should be purchased at a discount to the Nickel LME prices				
Project Nickel sulphate plant	ton			1 831
Cost as per material prices	R'm			126
Number of cells	Number			57 803 468
Cell plant capacity	kWh			1 000 000
Cost per cell	R			2,17
This is not a true reflection but indicative based on the Nickel sulphate selling prices as per 16 Aug 2024				

6.4.11 Manganese sulphate

The S&P Markets IO Platts Battery Metals report quotes the following prices:

Table 12: Manganese sulphate prices

		DDP China	Exchange		DDP China
Manganese Sulphate	$/mt	892	17,933	ZAR/mt	15996,24

The Manganese content has been determined using the molecular mass of manganese relative to the molecular mass of manganese sulphate (Manganese sulphate 151.001 g/mol while the molecular mass of nickel is 54,938 grams).

Table 13: Nickel sulphate operational cost calculation

MATERIAL			Pricing tons	Adjusted Princing for capacity
MANGANESE SULPHATE				
Manganese Sulphate	gram/mol	151,00		
Metric ton	gram	1 000 000,00		
Manganese content	gram/mol	36,4%		
Manganese content per ton	gram	363 825,41		
Manganese content per ton	kg	363,83		
Manganese Sulphate	R/mt		15 996,236	
Manganese ore price	$/ton		3,020	
Manganese price	R/ton		54,158	
Manganese equivalent cost	R/mt		19,704	
Manganese equivalent cost	$/mt		1,099	
Project Manganese sulphate pl	ton			702
Cost as per material prices	R'm			11
Number of cells	Number			57 803 468
Cell plant capacity	kWh			1 000 000
Cost per cell	R			0,19
This is not a true reflection but indicative based on the Manganese sulphate selling prices as per 16 Aug 2024				

6.5 Cost Example for a 1GWh Gigafactory

The table below shows a cost example of a 1GWh gigafactory and supported sulphate and lithium hydroxide production.

Table 14: Costing: 1GWh Gigafactory with Sulphate and Lithium Hydroxide Production

INDICATIVE MODEL TO CALCULATE NMC BATTERY VALUE CHAIN COSTS
(This model excludes raw material prices)

Legend
Inputs
Calculated

ASSUMED kWh FORM PLANT REQUIRED	1 000 000

ASSUMPTIONS	**Value**	
Cell type	2170	
Energy density	247	Wh/kg
Cell energy	17,3	Wh
Cell weight	70	g
Cathode materials % of weight	31%	%
Anode material % of weight	22%	%
Cells per vehicle powerpack for EV(large)	6830	Cells
Cell plant capacity	57 803 468	Cells

ESTIMATES NMC value chain	**tpa**	**Indicative capex ($m)**	**Indicative capex (Rm)**
Nickel hydroxide to nickel sulphate	30 000	25	473
Cobalt hydroxide to cobalt sulphate	500	27	510
Manganese oxide to Manganese sulphate	1 000	28	529
Graphite	15 000	26	491
Lithiation plant	10 000	116	2 192
Precursor plant	10 000	132	2 495

CELL PLANT COSTS	**Units**	**Capex ($m)**	**Split**
1GWh plant cost		125	
Pack assembly plant nameplate	8 463	13	10%
Cell manufacturing plant nameplate	57 803 468	113	90%

ESTIMATION (example based on Li-ion NMC 532) (1 GWh)	**Volume**	**Weighted Capex Cost (R million)**	**Capex per cell (one year discounted) (R/cell)**	**Capex excluding cell manufacturing (R million)**	**Capex per cell (one year discounted) (R/cell)**
Cell plant	57 803 468	2 126	36,78		
Cell assembly/packs	8 463	236	4,09	236	4,09
Sub Total		2 363	40,87	236	4,09
Material Required for Cell Plant					
Precursor material cathode (tpa)	1 254	313	5,41	313	5,41
Precurcor lithiation (tpa)	1 659	364	6,29	364	6,29
Nickel sulphate (tpa)	1 831	29	0,50	29	0,50
Cobalt sulphate (tpa)	778	794	13,73	794	13,73
Manganese sulphate (tpa)	702	412	7,12	412	7,12
Sub Total		**1 911**	**33,06**	**1 911**	**33,06**
Total		**4 273**	**73,93**	**2 147**	**37,14**

ESTIMATION (example based on Li-ion NMC 532) (1 GWh)	**Avg volume**	**Operation cost adjusted (R million)**	**Operational cost per cell (one year discounted) (R/cell)**
Cell plant	57 803 468	1 150	19,90
Precursor material cathode (tpa)	1 254	325	5,62
Nickel sulphate (tpa)	1 831	126	2,17
Cobalt sulphate (tpa)	778	67	1,16
Manganese sulphate (tpa)	702	11	0,19
Total		**1 679**	**29,04**

Putting the above in context for South Africa, the investment strategy for electric two-wheelers indicates that a pool of 39 446 batteries is needed to be in circulation by 2034. Based on the assumption that each of these batteries' capacity is 5kWh (two batteries of 2,5kWh each), this represents a cumulative total capacity in circulation of 192 230 kWh which is only 19,7% of a 1GWh gigafactory's capacity for one year and cannot be the main driver to decide on the establishment of such battery gigafactory.

7. CONCLUSION

It is clear from the assessment that:

- The establishment of a battery gigafactory and associated material processing facilities are very capital intensive and an intensive growth internationally if experienced;
- A battery gigafactory for only two-, three- and 4-wheelers cannot be justified for only the segments. Battery manufacturing for two-, three- and 4-wheelers should be a subset of a much bigger picture inclusive of passenger EVs, E-buses, mining equipment, stationary applications, etc. in order the justify the capital investment;
- If two-, three- and 4-wheelers are considered in isolation, the best option will be the importation of battery cells, but investing in the South African industry to advance the assembly with local value-adding elements such as the battery management systems, packaging, testing, battery swapping infrastructure, etc.; and
- If a gigafactory becomes an option within the biggest market segment, it is essential that this be done with a reputable international partner(s) to avoid the need for having to go through an extensive learning curve. Furthermore, for such international partner(s), an attractive value proposition is key and at least must be based on the partner(s) providing technology and expertise as a minimum while the South African partners contribute market, infrastructure and capital.

In this context it is clear that South African and African battery manufacturing needs to be considered in a broader context due to the high capital investment requirements, which requires economies of scale to achieve financial viability.

As far a raw material processing is concerned, South African supply could form part of the global battery raw material supply chain, as the mineral resources are present and currently being mined for the battery market and other applications, with primary mineral processing also being undertaken.

Both the battery minerals mining and battery mineral processing, or beneficiation, could be expanded in the various value chains indicated in this report.

8. PROJECT TEAM

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