The Cost of Producing Battery Precursors in the DRC

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BloombergNEF

United Nations
Economic Commission for Africa

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Section 1. Overview

$39 million

Cost of building a 10,000 metric tons precursor plant in the DRC for NMC cathodes

$11/kg

Levelized cost of producing precursors for NMC 811 in the DRC

$13/kg

Levelized cost of producing precursors for NMC 622 in the DRC

Project background

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) have asked BloombergNEF to conduct a study on the production of battery precursors in the lead up to the DRC-Africa Business Forum.

The objective of this study is to determine the cost of producing lithium-ion battery precursors in the Democratic Republic of Congo (DRC) and benchmark the cost to that of the U.S., China and Poland. In addition to the cost, the study assesses the emissions associated with the production of precursors in the DRC for the global electric vehicle market compared with producing them in China and Poland.

This report details the key findings of the study as well as the policy implications that could harness Africa's electric vehicle potential.

Lithium-ion batteries: A primer

Lithium-ion batteries were commercialized in 1991. They have since been predominantly used in consumer electronics such as mobile phones and laptops. Demand for these batteries in electric vehicles has significantly increased in the last decade. Batteries for electric vehicles overtook consumer electronics as the largest annual market for lithium-ion batteries in 2018.

The five main raw materials used in the current lithium-ion batteries are lithium, cobalt, nickel, manganese and graphite. Other materials include copper, aluminum and iron. The movement of charged lithium particles, known as ions, between the two electrodes of a battery enable energy to be stored or released. Cobalt is a key material for high energy-density lithium-ion batteries as it provides stability to the structure of the active material. By reducing the cobalt content and replacing it with metals such as nickel or manganese, energy density can be further increased but often at the expense of cycle life and safety.

The feedstocks used in the production of lithium-ion batteries are in the form of metal salts, predominantly sulfates. The sulfates for cobalt, nickel and manganese are combined in various ratios depending on the chemistry type to form the precursor cathode active material (precursors). The precursors are then combined with either lithium carbonate or lithium hydroxide, depending on battery chemistry, to form the cathode active material. The cathode active materials are then combined with the anode material, predominantly graphite, to form the battery cells. The cells are finally assembled into a battery pack, which then goes into an electric vehicle.

The performance and price of the battery is largely determined by the materials used for the anode and the cathode. There are five main characteristics of a battery that determine its suitability and attractiveness for different applications. In no particular order:

Cycle life: The number of times a cell can be cycled determines its useful life in an electric vehicle or stationary storage project.

Energy density: This can be expressed based on either the volume of the material or the weight of the material. Volumetric energy density impacts manufacturing costs, while gravimetric energy density has a bigger impact on the driving range of vehicles.

Discharge/charge rate: The discharge rate refers to how quickly a battery using a specific chemistry can be charged or discharged. This impacts how long it takes an electric vehicle to charge and can affect the acceleration of an electric vehicle.

Safety: Lithium-ion batteries store a large amount of energy. If things go wrong, this energy can be released quickly and that in turn can lead to fires or even explosions. The safety of a battery is dependent on the material, cell and the pack used. There are multiple layers of safety mechanism in place in most batteries, focused on fire prevention and control.

Cost: The cost of a lithium-ion battery is hugely important in determining its viability in different applications. This is largely dependent on the cell and pack design, and the cathode chemistry.

Multiple cathode chemistries remain in common use, each with different characteristics. The cathode chemistries are named based on the specific materials used in each type. Lithium-iron-phosphate batteries, for example, are typically known as LFP. A nickel-manganese-cobalt oxide (NMC) battery is further identified by the proportion of those materials to each other. An NMC (811) battery has 8 parts nickel to 1 part of manganese and cobalt. Likewise, an NMC (622) battery has 6 parts nickel to 2 part of manganese and cobalt.

The market has not yet converged around a single cathode chemistry because each involves tradeoffs. Current iterations of an NMC (811) battery for instance have very high energy densities but have a short cycle life and are comparatively unstable, needing more thermal management in place at the pack level.

Key findings

African countries could play a key role in the lithium-ion battery supply chain. Electric vehicles represent a $7 trillion market opportunity between today and 2030, and $46 trillion between today and 2050. While there are notable leading electric vehicles and cell manufacturers today, the sheer scale of growth expected in the coming decades means that there is inherent uncertainty over which companies and countries may come to dominate this new value chain.

Electrification of two-and three-wheelers could be a big opportunity for Africa. Two-and three-wheeler sales are growing rapidly in countries such as India, Vietnam and Indonesia. Increasing population, GDP per capita and urbanization in Africa and other parts of the world will help drive global sales of two-and three-wheeler sales up from 88 million in 2020 to 114 million in 2040 in BloombergNEF's long-term outlook. Electric vehicle adoption is also growing fast in this segment, where some 44% of new two-and three-wheelers sold globally in 2020 were electric models.

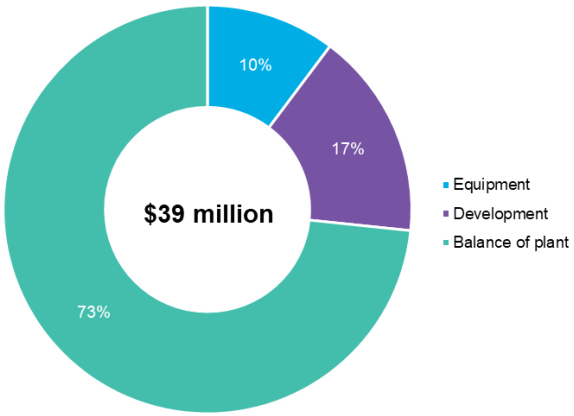
Annual lithium-battery demand will grow rapidly, topping 4.5 terawatt-hours (TWh) annually by 2035. Meeting this demand requires unprecedented but achievable increases in metals, precursor and cell production. By 2025, there will be over 3TWh of nameplate cell manufacturing capacity, if manufacturers successfully execute their growth plans.

Total metals demand from lithium-ion batteries will reach 13.5 million metric tons by 2030. Overall cobalt demand from the lithium-ion industry will grow 1.5 times between 2021 and 2030. Nickel, used in the cathode, will see demand grow to about 1.4 million metric tons by 2030, five times that of 2021. Annual demand from the lithium-ion battery industry for copper will reach 3.9 million tons by 2030 while aluminum will reach 3.1 million tons, with market size for both metals growing six times over that period.

BloombergNEF expects the nickel-manganese-cobalt oxide (NMC) 622 and NMC 811 battery chemistries to be prevalent 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 lithium-iron-phosphate (LFP) for low-cost entry-level vehicles. It would be more practical for the DRC. to produce precursors that would ultimately have commercial value in its most dependent market, Europe, as Africa works toward building its domestic demand.

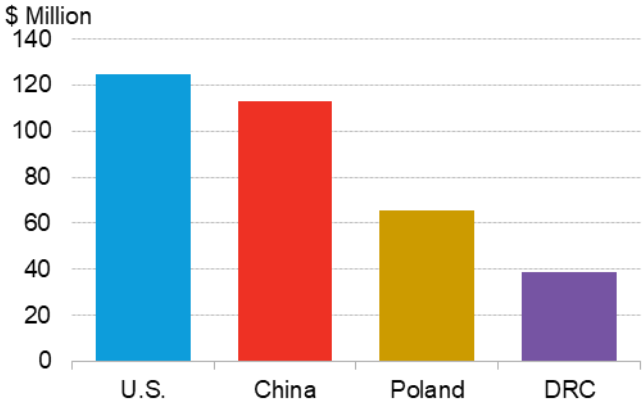
Building a 10,000 metric-ton precursor facility in the DRC could cost $39 million. This is three times cheaper than what it would cost for a similar plant in the U.S. A similar project in China and Poland will cost $112 million and $65 million, respectively. The capital cost in the DRC is cheaper than all three countries mainly due to the lower cost of land and construction of the project (Figure 1 and Figure 2).

Figure 1: Capital cost of a 10,000 metric tons precursor plant in the DRC



Source: BloombergNEF. Note: Balance of plant include auxiliary services such as water and heat.

Figure 2: Capital cost of a 10,000 metric tons precursor plant



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

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 U.S., China and Poland. Operating in the DRC becomes more expensive than Poland once the plant has to procure its cobalt at spot prices (non-integrated) (Figure 3 and Figure 4).

Figure 3: Levelized cost of precursor production (LCOP) for NMC 622 cathode chemistry

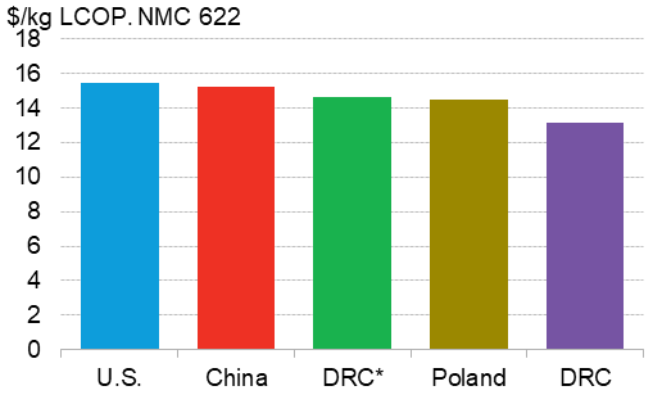
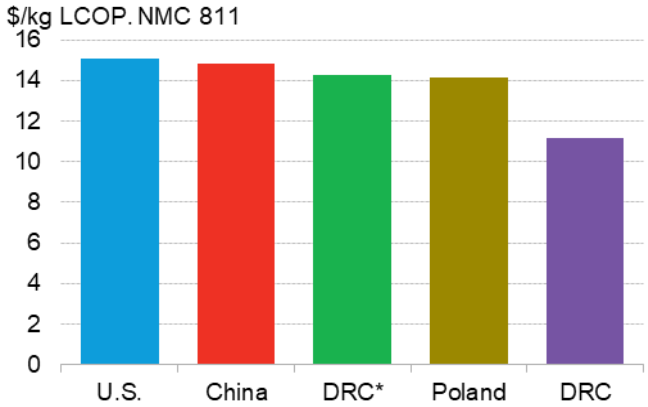


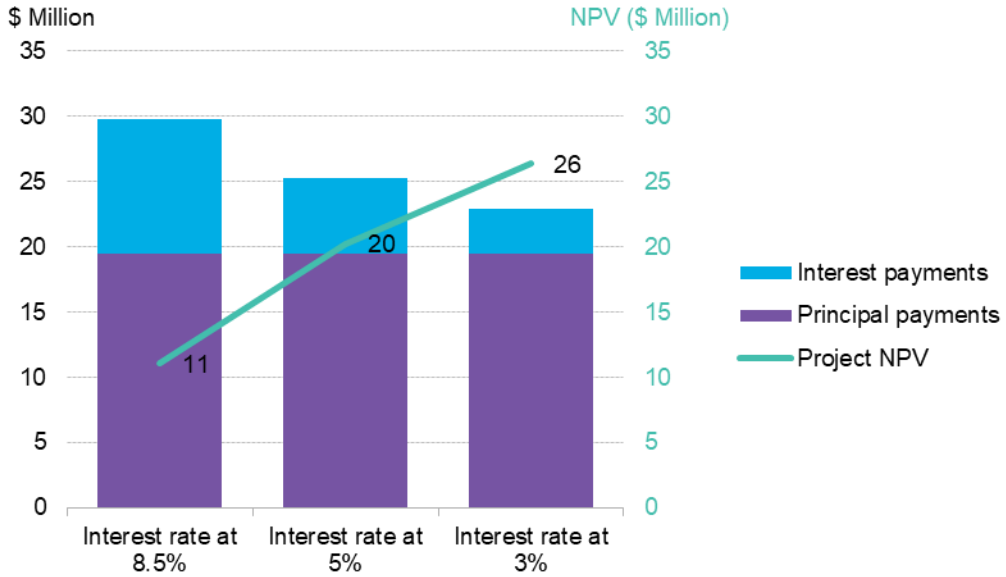
Figure 4: Levelized cost of precursor production (LCOP) for NMC 811 cathode chemistry



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

An optimal mix of concessional loans, development funds, private debt and equity could maximize the project net present value (NPV). At an interest rate of 8.5% and a theoretical precursor price of $32/kg, the project NPV is $11 million, as shown in Figure 5. The project NPV increases to $20 million at a 5% interest and rises further to $26 million at a 3% interest rate. This shows that high interest rates could increase total project cost. Working with development finance institutions on adding a tranche of concessional financing – debt at a discounted rate compared to typical market rates – could significantly reduce the cost of borrowing. However, over-reliance on concessional loans could crowd out investment from private lenders.

Figure 5: Total debt repayment and project NPV based on three interest rates



Source: BloombergNEF. Note: We assumed a 10% post-tax equity return, a principal of $19.5 million and a project-life of 20 years. Project financing is in U.S. dollars and a 50% debt-to-equity ratio. Repayment period is 12 years and tax rate was assumed to be 30% and inflation at 2.5%.

The project partners indicated their interest in developing a 100,000 metric-ton capacity precursor plant in the DRC **using BloombergNEF's top-down approach, we estimate a 100,000 metric tons precursor plant built in the DRC could cost $301 million**. A 100,000 metric-tons-per-annum NMC (622) precursor plant will require 16,000 metric tons of cobalt annually as well as 48,000 metric tons and 15,000 metric tons of nickel and manganese, respectively.

Producing the precursors in the DRC for packs assembled in Salzgitter, Germany, and cells manufactured in Nysa, Poland will reduce the life-cycle emissions of cells by 30% compared to making the precursors in China, and 9% compared to making them in Poland. This is due to the DRC's proximity to some cathode raw materials and relatively clean grid.

Policy implications

Countries in Africa must create a diversified capital market that supports battery research, early-stage products and the scale-up of manufacturing for the electric vehicle industry*. Development finance institutions such as the AfDB and BADEA can support research and early-stage projects through grants. Also, institutions such as the Afreximbank and the AFC can complement commercial banks by providing loans to mature companies to support expansion, whilst the ALSF can provide legal support for business transactions.*

African countries must formulate policies such as zero-emissions vehicle subsidies, emissions regulations and consumer incentives to boost demand for electric vehicles *in order to attract cell manufacturing capacity to the continent.*

The DRC must upgrade its infrastructure, from electricity, roads, ports, and rail to electric vehicle charging ports, *to support low-cost manufacturing and integration of electric vehicles.*

In line with setting up the precursor manufacturing plant, ***the DRC must also develop a research center to invest in next-generation battery technology*** *to support the budding industry and to also train the local workforce.*

Government must promote fiscal certainty through the provision of laws and regulations that support local businesses*. The government could also create specialized economic zones with a focus on the electric-vehicle industry, with a clear mandate to protect investment capital, guarantee business continuity and lower the risk of operating business in the country.*

The government could set up a one-stop-shop to coordinate and streamline engagement with third-party organizations*. This will improve transparency and reduce red tape associated with activities such as licensing, permitting and intellectual property negotiations. This could either be through a joint venture between the state and its strategic partners or a special purpose vehicle.*

Section 2. Introduction

The global electric vehicle market

Near-term

The outlook for electric vehicle adoption remains high due to a combination of more policy support globally, improvements in battery performance and cost, build out of charging infrastructure, and rising commitments from automakers.

BloombergNEF Economic Transition Scenario

BloombergNEF's Long-Term Electric Vehicle Outlook combines near-term forecasts with a long-term scenario. From 2021 to 2025 it includes a bottom-up forecast for each vehicle segment and country. This takes into account factors like current and upcoming electric vehicle models available, policy and incentive frameworks, historical growth rates, consumer adoption patterns and other factors.

From 2026 onward, our outlook splits into two long-term scenarios:

Economic Transition Scenario (ETS): This is the main scenario described in this report. It assumes no new policies or regulations are enacted that impact the market. It also does not assume any long-term climate targets are hit, or that any combustion vehicle phase-out targets that have been announced by countries, states, cities or companies are achieved. Instead, adoption is primarily driven by techno-economic trends and market forces.

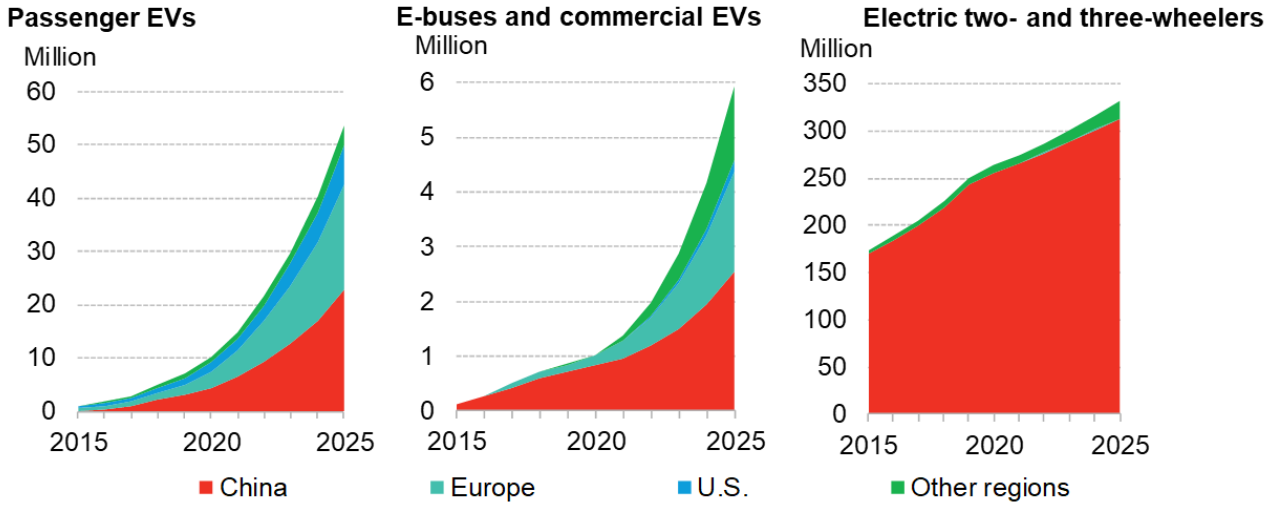
Net Zero Scenario (NZS): This scenario investigates what a potential route to net-zero emissions might look like for the road transport sector by 2050. This scenario looks primarily at economics as the deciding factor for which drivetrain technologies are implemented to hit the 2050 target.

Annual passenger electric vehicle (cars and light-duty vehicles) sales are set to increase sharply in the next five years, rising from 3.1 million in 2020 to 14 million in 2025 in BloombergNEF's economic transition scenario. Globally, this represents around 16% of new passenger vehicle sales in 2025, but some countries achieve much higher shares. In Germany, for example, BloombergNEF expects electric vehicles to represent nearly 40% of total passenger vehicle sales by 2025, while in China – the world's largest auto market – electric vehicle sales will account for 25% of new passenger vehicle sales in the same year.

China and Europe continue to be the dominant electric vehicle markets out to 2025, driven primarily by Europe's vehicle CO2 regulations, China's fuel economy regulations and new-energy-vehicle credit system. By 2025, the global auto market will be fragmented, with electrification of transport further ahead in China, Europe, and some smaller markets. This presents challenges for automakers with global portfolios. Low levels of adoption in emerging economies such as Africa limit the global adoption rate, as automakers focus their passenger electric vehicle efforts on the markets with the most stringent regulations.

There are currently 12 million passenger electric vehicles on the road, representing 1% of the global fleet. This will rise to 54 million by 2025 as shown in Figure 6. Other segments of road transport are already much further along on electric vehicle adoption. Some 44% of global two- and three-wheeler sales annually and 25% of the existing fleet are already electric. China accounts for the bulk of two-wheeler electrification to date, but sales are growing rapidly in markets like Taiwan, Vietnam and India.

Figure 6: Global electric vehicle fleet sizes by segment and market



Source: BloombergNEF. Note: Two-wheelers includes mopeds, scooters and motorcycles, excludes e-bikes.

Direct electrification via batteries is the most economically attractive and efficient approach to decarbonizing road transport and should be pursued wherever possible. Hydrogen fuel cell vehicles can help fill the small gaps left by electrification in some heavy vehicles, in regions or duty cycles where batteries struggle.

Electric vehicles take longer to spread in Africa, where policy support is limited, and low-cost internal combustion vehicles are hard to beat on price

Long-term

After increasing rapidly over the next 15 years, electric vehicle sales growth begins to slow down slightly in the late 2030s in the main electric vehicle markets, like Europe, China or the U.S., as they begin to saturate (Figure 8). Electric vehicles take longer to spread in Africa, where policy support is limited, and where low-cost internal combustion vehicles are hard to beat on price. However, sales grow rapidly in the 2030s as the economics improve in these price-sensitive markets.

The fleet of internal combustion passenger vehicles keeps growing until 2027 in the Economic Transition Scenario, before declining steadily. Despite the relatively rapid growth of electric vehicle sales, this takes time to flow through to the fleet and there are still over 900 million internal combustion engine vehicles on the road in 2040 – more than half the fleet (Figure 7).

Fuel cell vehicles start to be sold at volume in a few markets in the 2030s, but with just 8.6 million on the road in 2040 (up from only 30,000 today), this is well below 1% of the global passenger vehicle fleet. Plug-in hybrids take a slightly larger share but are quickly surpassed by battery electric vehicles on price, performance and overall consumer appeal.

Figure 7: Global passenger vehicle sales outlook by drivetrain – Economic Transition Scenario

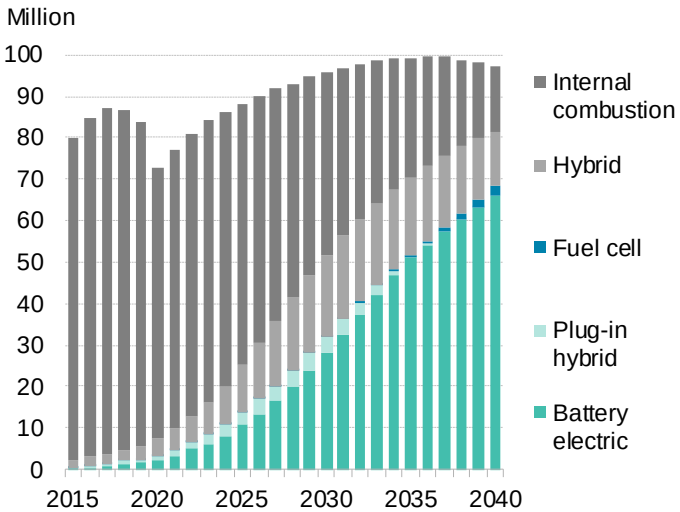
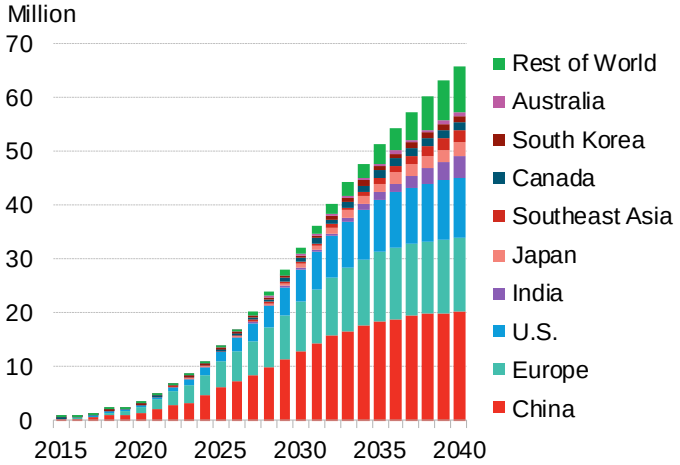


Figure 8: Global passenger electric vehicle sales outlook by market – Economic Transition Scenario



Source: BNEF. Note: Electric vehicles include battery-electric and plug-in hybrid electric vehicles. Europe includes the EU, the U.K. and EFTA countries.

Electric vehicles represent a $7 trillion market opportunity between today and 2030, and $46 trillion between today and 2050

Electric vehicles represent a $7 trillion market opportunity between today and 2030, and $46 trillion between today and 2050. While there are notable leading electric vehicle and cell manufacturers today, the sheer scale of growth expected in the coming decades means there is inherent uncertainty over which companies and countries may come to dominate this new value chain. Countries should be giving serious consideration to how they can create economic value-add and domestic jobs from this growth.

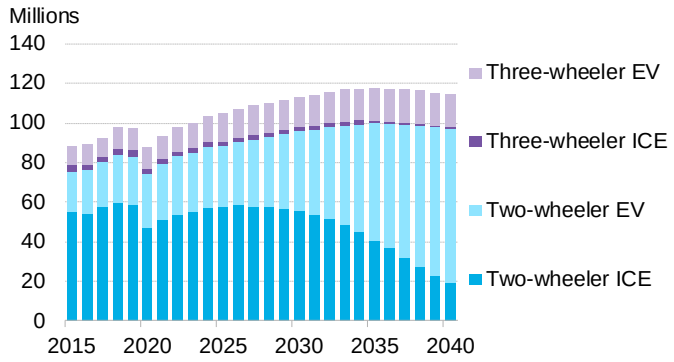
Today's leading markets (China, Europe, North America and South Korea) have invested significant sums from both private and public funds into enabling the electric vehicle transition, but tomorrow's growth markets, such as Africa, will require much lower investment. The scale, driven by today's leading markets will push down battery and infrastructure costs such that the 'cost of going electric' for the next wave of countries should be far less than the early adopters. Countries in Africa should ready themselves to take advantage of this trend within the next five years.

Africa's electric vehicle potential

Two-and three-wheeler sales are growing rapidly in markets such as India and Vietnam. Increasing population, GDP per capita and urbanization in these countries help drive two-and three-wheeler sales up from 88 million in 2020 to 114 million in 2040 in our long-term outlook (Figure 9). Electric vehicle adoption is also growing fast in this segment, where some 44% of new two- and three-wheelers sold globally in 2020 were electric models. Policy pressure, improving economics and rising competition will accelerate electric-vehicle adoption in these segments. Rising manufacturer interest in high-powered models, and rapidly improving economics will push two-and three-wheeler electrification significantly higher. The global electric vehicle adoption rate in the two- and three-wheeler segment slows over the next 3-4 years as the Chinese market saturates, but then starts rising quickly from 2025 as sales pick up in other markets.

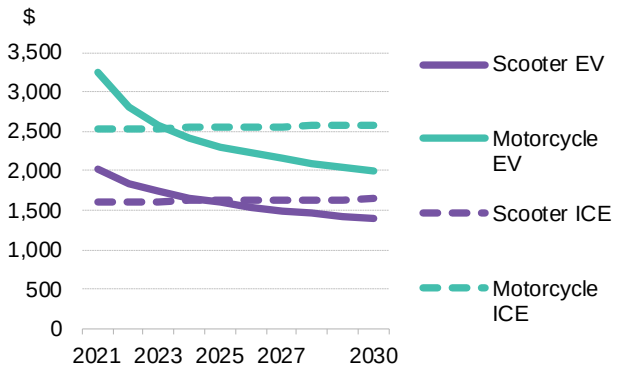
BloombergNEF expects lithium-ion battery pack prices to fall to $58/kWh by 2030 from $137/kWh in 2020. This can help electric scooters and motorcycles achieve upfront purchase price parity with comparable internal combustion vehicles by the mid-2020s in the largest markets. In Southeast Asia, high-speed electric scooters and motorcycles could achieve upfront purchase price parity with internal combustion engine (ICE) models during 2023-25, as shown in Figure 10. We assume that scooters and motorcycles have an electric range of 150 kilometers and 200 kilometers, respectively, for this analysis.

Figure 9: Global outlook for two- and three-wheeler sales by drivetrain



Source: BloombergNEF. Note: ICE –internal combustion vehicle, EV –electric vehicle.

Figure 10: Theoretical upfront price parity outlook for electric vehicle and ICE two-wheelers in Southeast Asia



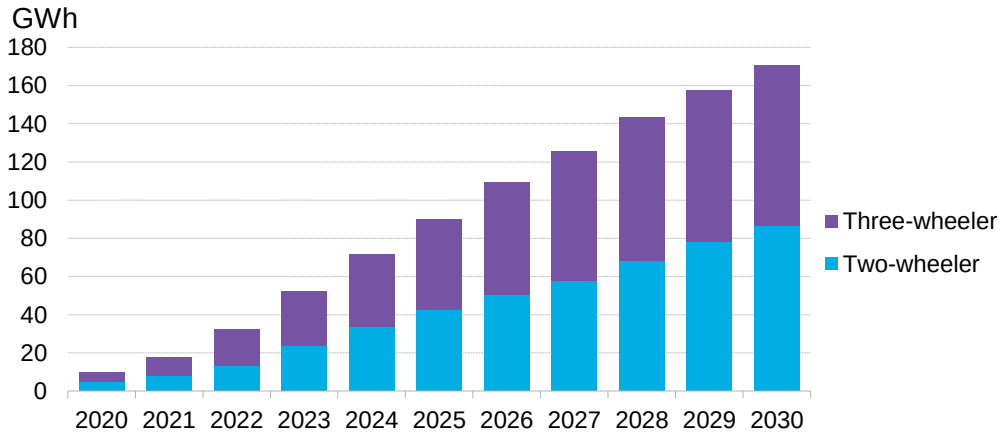
Source: BloombergNEF. Note: Scooter EV range –150 kilometers, Motorcycle EV range –200 kilometers.

BloombergNEF sees two- and three-wheeler electrification being a big opportunity for African markets

BloombergNEF sees two-and three-wheeler electrification being 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, the last five years, are in Africa. This low demand hinders 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 (Figure 11). 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 11: Lithium-ion battery demand from two- and three-wheeler segment



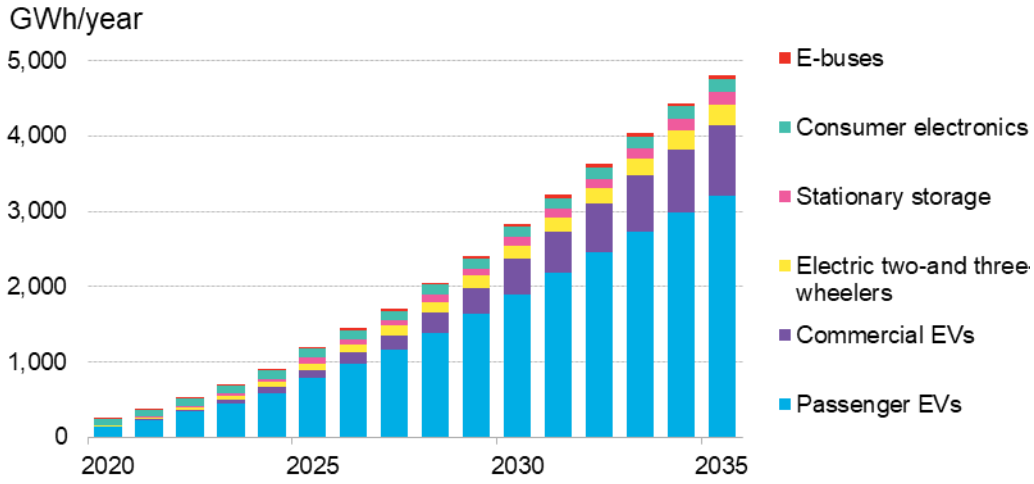
Source: BloombergNEF

Section 3. Battery raw materials

3.1. Battery demand

Annual lithium-battery demand will grow rapidly, topping 4.5TWh annually by 2035 in BloombergNEF's Economic Transition Scenario (Figure 12). Meeting this demand requires unprecedented but achievable increases in metals, precursor and cell production. By 2025, there will be over 3TWh of nameplate cell manufacturing capacity, if manufacturers successfully execute their growth plans. Sustained growth will be required in the second half of the decade to keep up with demand. China remains the market leader in manufacturing. Europe is emerging as the second-largest region for cell manufacturing. High-nickel battery chemistries take a growing share of the market over the next 10 years. Africa's proximity to Europe could provide a market opportunity as European companies seek to reduce both its supply-chain dependency on Asia and the associated supply-chain emissions.

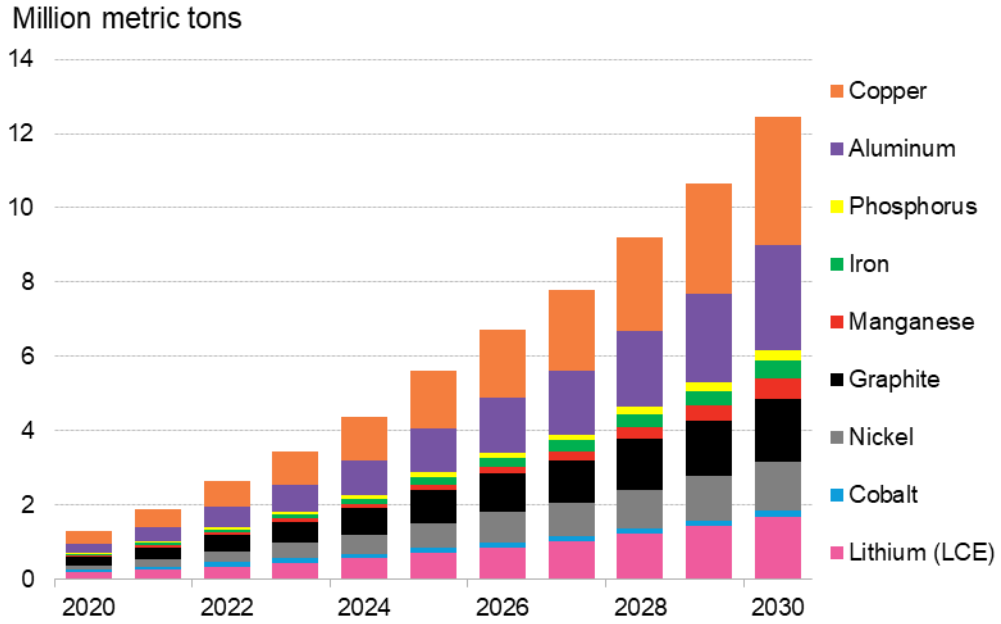
Figure 12: Lithium-ion battery demand outlook



Source: BloombergNEF

Total metals demand from lithium-ion batteries, under BloombergNEF's least-cost Economic Transition Scenario, will reach 13.5 million metric tons by 2030 (Figure 13). In our modeling, we assume metals demand occurs at mine mouth, one-year before batteries are deployed on the market. Cobalt used in the cathode per annum will grow 1.5 times between 2021 and 2030. Nickel, used in the cathode, annually, will be about 1.4 million metric tons in 2030, five times the demand in 2021. Annual demand for copper used as current collectors, bus bars and connecting wiring will reach 3.9 million tons by 2030, while aluminum used as current collectors and housing will reach 3.1 million tons.

Figure 13: Metals demand from lithium-ion batteries



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).

3.2. Battery metals supply

The DRC produced about 70% of global cobalt supply in 2020

The DRC produced about 70% of global cobalt supply in 2020, as shown in Figure 14. 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. It plans to produce about 16,500 to 20,000 tons in 2021. In April, leading battery manufacturer, Contemporary Amperex Technology (CATL) announced it will acquire 25% of CMOC's stake in the Kisanfu mine in the DRC. The project is sandwiched between CMOC's Tenke Fungurume and Glencore's Mutanda mines. The Kisanfu project is estimated to hold a resource of about 3.1 million tons of cobalt but is still under development. The company wants to process the ore at the nearby Tenke Fugurume mine. Eurasian Resources Group (ERG), a mining company, is developing the phase 2 of its Meltakol Tailings Reclamation project. This will result in production capacity at the mine increasing to 24,000 tons by mid-decade.

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 fueled 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

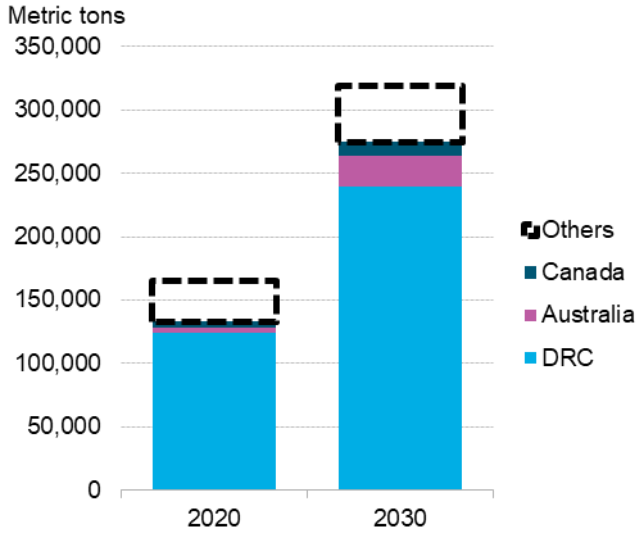
global supply by 2030, partly due to the quality of its deposits and the lower cost of extraction and processing.

South Africa and Gabon account for about 43% of global manganese ore production

Manganese is used in lithium-ion battery cathodes. It 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.

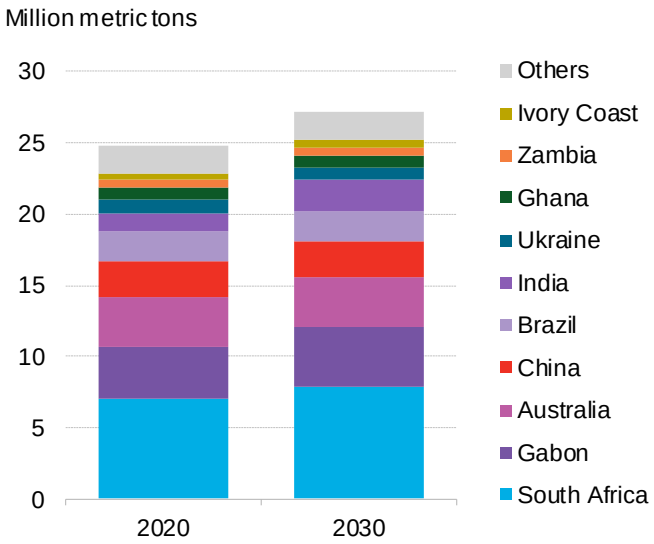
According to BloombergNEF, manganese ore mining capacity will grow to 26.7 million tons in 2030 from about 22 million tons in 2020. South Africa will add about only 800,000 tons of new capacity by 2030 due to companies holding back on new investment because of legacy challenges associated with rail capacity, 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.

Figure 14: Mined cobalt capacity by country



Source: BloombergNEF

Figure 15: Mined manganese capacity by country



Source: BloombergNEF

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 by-products 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.

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 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.

Section 4. Global precursor market

The precursor market will grow significantly over the coming decades as battery demand from electric vehicles grows. Global players include Fuijan, Evergreen New Energy Technology, Umicore and Huayou. 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.

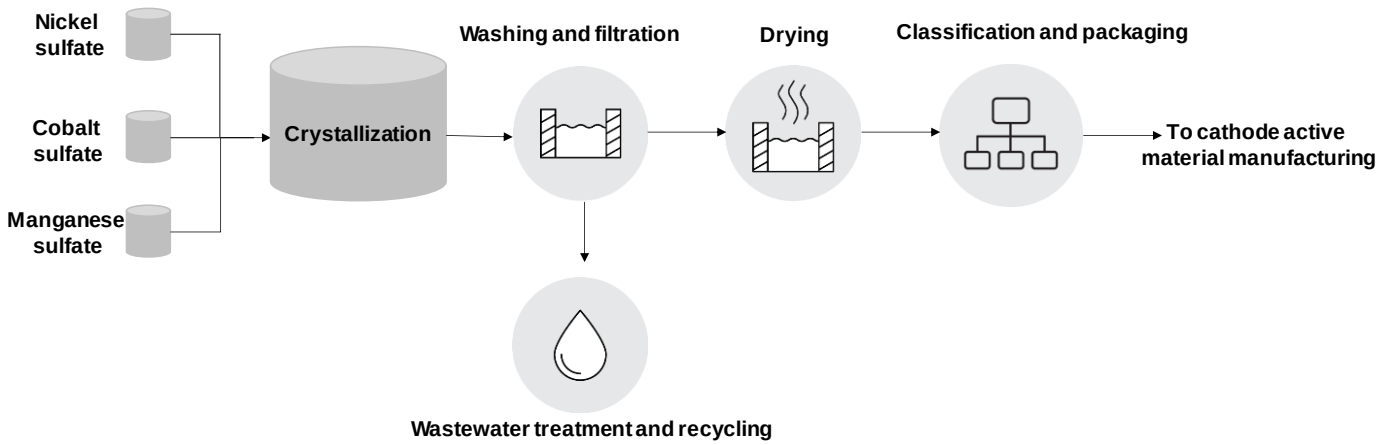
In 2020, Eurasian Resource Group (ERG) announced plans to build a nickel manganese cobalt (NMC) battery precursor plant to produce 90,000 metric tons of materials annually. The company said it will source its cobalt from ERG's Metakol RTR project in the DRC and nickel sulfate from third-party sources. The company has not confirmed where it will site the precursor plant.

Producing precursors for NMC cathode chemistries requires three main raw materials – nickel sulfate, cobalt sulfate and manganese sulfate – as shown in Figure 16. 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 in order to achieve different performance. When first introduced onto 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.

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 in close proximity to electric vehicle manufacturing in order to fit into the 'just-in-time' manufacturing model of the auto industry. Precursor material are not as complicated to transport over long distances, compared to cathode active materials, so building a precursor facility in the DRC could be feasible, if it can benefit from low material and manufacturing costs.

Figure 16: Simple flowsheet of precursor manufacturing process



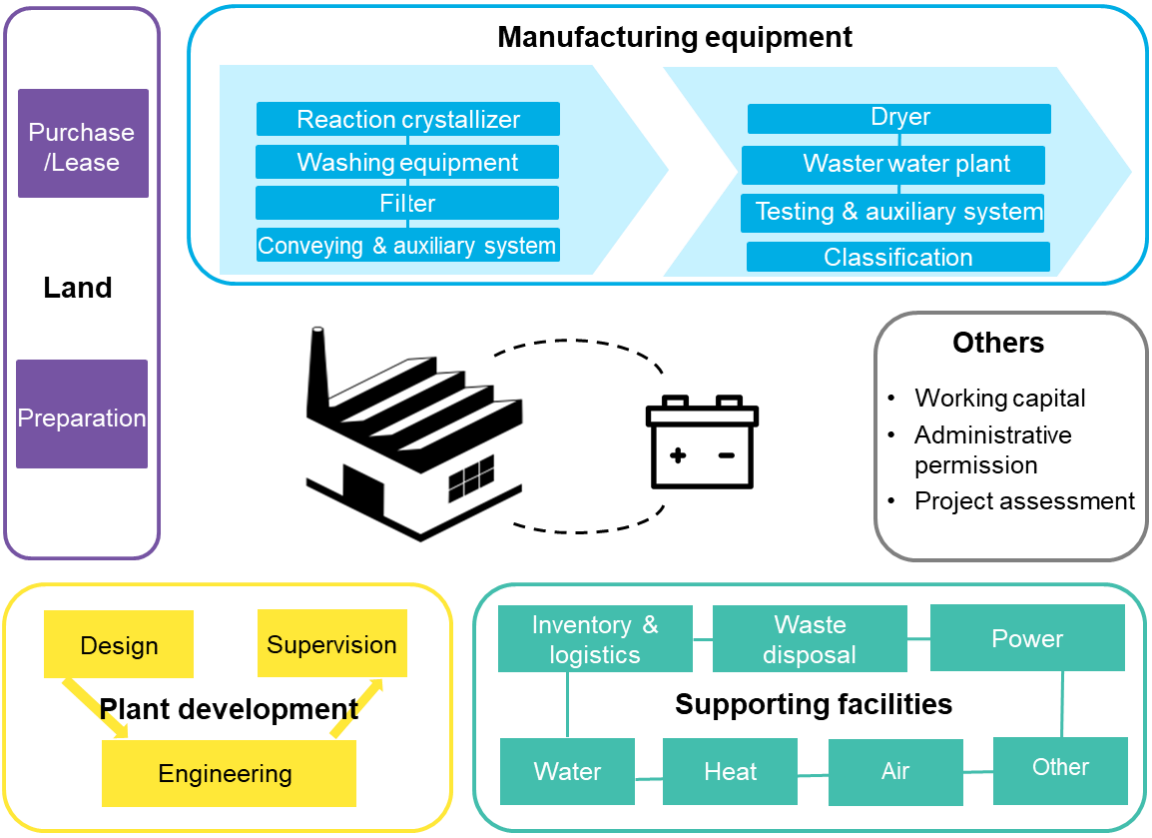
Source: BloombergNEF

4.1. Methodology

This section describes the proposed methodology for BloombergNEF's proprietary precursor model used to assess the economics of producing precursors in the DRC and other benchmarked countries. The model uses a top-down approach to estimate the capex of an existing plant and split them across land, construction and equipment, as shown in Figure 17 For operating cost, we considered costs such as labor, electricity, water, maintenance, reagents and feedstock to determine the levelized cost precursor production (LCOP).

BloombergNEF obtained project-specific data from battery manufacturers around the world. In the DRC we used project data from the mining and manufacturing industries to estimate the cost of project development. For finance data, we used the Bloomberg Terminal. The DRC government facilitated the acquisition of local cost data on transport, labor, water and electricity in conjunction with the utility providers and other private companies.

Figure 17: Capital cost framework



Source: BloombergNEF

Precursor plant investment (capex): To calculate the plant capital investment, we review major expenditures related to land, equipment and construction. Other investments for the company as a whole, such as office buildings and R&D centers, are excluded. In practice, a plant location and supplier relationships could lead to different equipment pricing as well. We also exclude subsidies from the direct plant investment.

The plant location and manufacturing capacity are major variables that affect the model's plant investment outputs.

- As the capacity of a plant increases, operators will benefit from economies of scale in equipment purchasing and falling construction costs compared to the total project size.
- Location matters due to different land pricing and construction cost across regions. These location-related costs vary greatly, especially across different provinces in the DRC. The model output, therefore, is representative of required investment for an individual plant based in the cobalt-rich province of Haut-Katanga, rather than the average level for the DRC market.

Supporting facilities

Six main types of supporting facilities are essential for a plant. They are the inventory & logistics system, waste-disposal facilities, power system, heating system, water system and air system.

The supporting-system proportion to the plant's total capital investment diminishes as a plant scales in size. This is because infrastructure development and installation at the early stage require more effort than further capacity expansion.

Manufacturers aiming for an advanced and environment-friendly factory also need to invest more in supporting facilities. Stricter regional environment standards on hazardous-substance management require comprehensive waste-disposal systems.

Plant construction

Plant construction costs vary greatly across regions. Construction speed and makers' experiences in engineering project management also have indirect impacts. In terms of the construction expenditure per ton, scaling up the plant could reduce the unit cost per square meter.

Land

Land acquisition and preparation costs contribute to total land expenditure. The land area covers manufacturing plants, warehouses, supporting facilities, offices and other features such as roads and green spaces.

The land price is the most variable and uncertain factor in plant investment. There is a big discrepancy in land price even within a single country. It is also susceptible to local incentive policies. Subsidized land is a common way for local governments to woo manufacturers. Another strategy is to lease an existing factory at a discount or even for free, saving time and reducing construction costs. We, however, did not include subsidies in our modeling.

Others

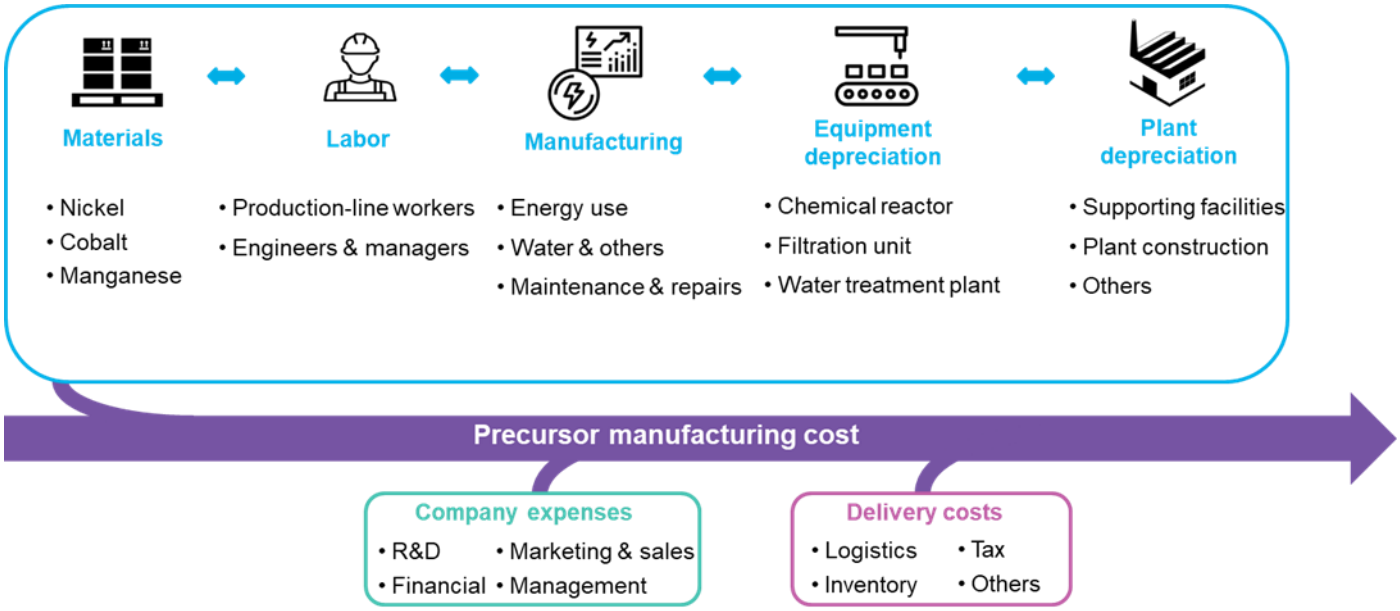
In the model, other capital expenditures associated with plant development include working capital, expenses for administrative permission and project assessment. These expenditures could fluctuate, depending on how well the project progresses. Simplified administrative permission procedures and closer partnerships with various stakeholders also contribute to cost savings.

Precursor manufacturing cost (LCOP): To determine the precursor manufacturing costs, we review the required inputs across the production process, including materials, labor, energy, and maintenance as shown in Figure 18. The cost at each stage is dependent on its usage amount. The model first calculates a plant's total annual operating cost, and then converts it to its levelized cost of precursor production (LCOP), which enables us to account for equipment and plant depreciation.

The model does not account for a company's core competencies and assumes the same level of know-how on large-scale production and management across facilities. However, in the DRC, we assumed the initial stages of plant development and production will require skilled expertise from other countries. We have not accounted for any differences across plants in terms of workers' manufacturing proficiency and level of experience at the production-line level.

The cost structure is dependent on component materials, labor, manufacturing, equipment depreciation and plant depreciation.

Figure 18: Manufacturing cost-calculation methodology



Source: BloombergNEF

Labor

To calculate the labor cost, we divide factory workers into two groups based on their role in a plant's operation – operation managers and production-line workers. We intend to use average wages in the DRC as labor-cost defaults for these two positions.

The plant location and the stage of development of the battery industry in the country has an impact on the labor-cost calculation. In countries with a strong battery industrial base, salaries for workers are in line with the average across the manufacturing industry. In less-established markets, like the DRC, the lack of experienced workers and the required additional training for new hires will increase labor costs due to the reliance on expatriates at the initial stages of production. It is common that new entrants hire experienced people, often from overseas, to build their know-how on mass production and plant management.

Manufacturing

This segment includes plant maintenance and repair costs as well as other resource usage.

A plant's mass production know-how and energy efficiency know-how are important factors. Experienced operations management helps minimize the requirements and expenses for maintenance, repairs and debugging facilities, while maximizing a plant's throughput. They do this while maintaining stringent quality standards.

Equipment depreciation

We use the straight-line depreciation method. Once the depreciation period ends, the equipment is no longer included in the final product cost, contributing to falling precursor costs.

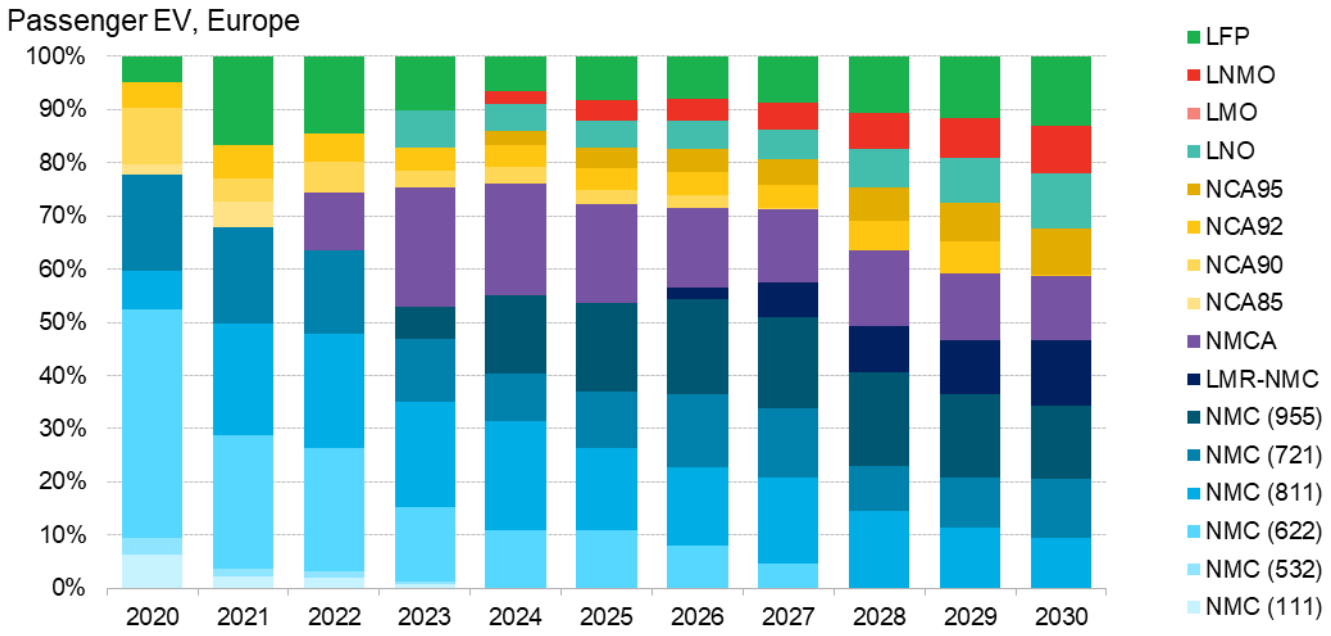
4.2. Cost of precursor facility

To determine the cost of building and running a precursor plant in the DRC, we made key assumptions on the battery chemistry, commodity prices, business model for the plant, sourcing of raw materials, cost and finally benchmarked it with other countries to determine the country's competitiveness.

Battery chemistry

The battery chemistry type determines the precursor that would be produced. We relied on BloombergNEF's battery chemistry forecast to assess three main factors that would influence the choice of material produced at a precursor plant in the DRC. First, the driver behind building a precursor facility in the DRC would be to take advantage of the country's cobalt resources, so any material produced at the plant would need to contain cobalt. Secondly, demand for the chemistry will need to be sustained throughout this decade. Finally, given Europe is the expected end-market for the material, it should be a chemistry that is used in the region.

Figure 19: Evolution of battery cathode chemistry in Europe



Source: BloombergNEF

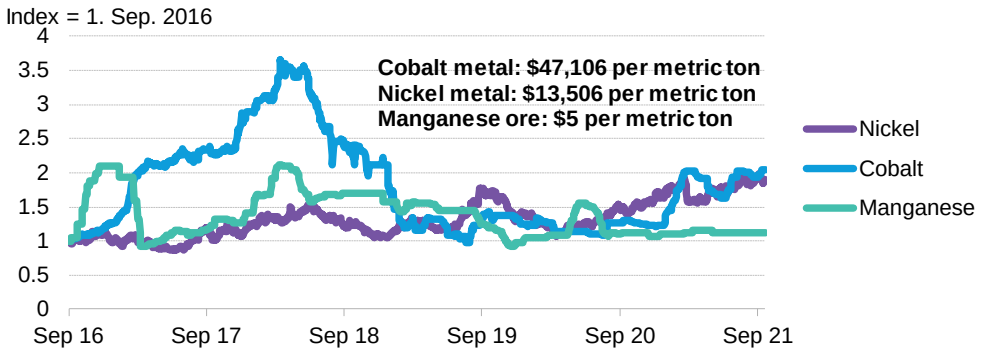
BloombergNEF expects NMC 622 and NMC 811 to be commonly used in passenger electric vehicles in Europe this decade (Figure 19). Most European original equipment manufacturers (OEMs) have announced their reliance on high-nickel chemistry batteries, for performance applications, although they will use LFP for low-cost entry-level vehicles. It would be more practical for the DRC to produce precursors that would ultimately have commercial value in its most dependent market as Africa works toward building its domestic demand.

In practice, a precursor production facility would be able to switch between producing NMC (622), NMC (811) or future high-nickel chemistries like NMC (955).

Commodity price

Raw materials such as manganese, nickel and cobalt serve as inputs to produce precursors. To determine the cost of manufacturing the precursors, we had to first assume the prices of the input raw materials. Commodity prices have been rising significantly the last 12 months. To ensure that the prices capture the boom-and-bust cycle of the commodity market we used the five-year average of the three commodities. Using the five-year average for the prices ensures that our estimates capture the pre-2018 era, when prices rose to record high before crashing to a record low due to the pandemic, and the post-pandemic era, when prices have reacted to heightened supply chain constraints. Future prices could either rise above or fall below our average used in the modeling.

Figure 20: Five-year movement of commodity prices, indexed at September 2016



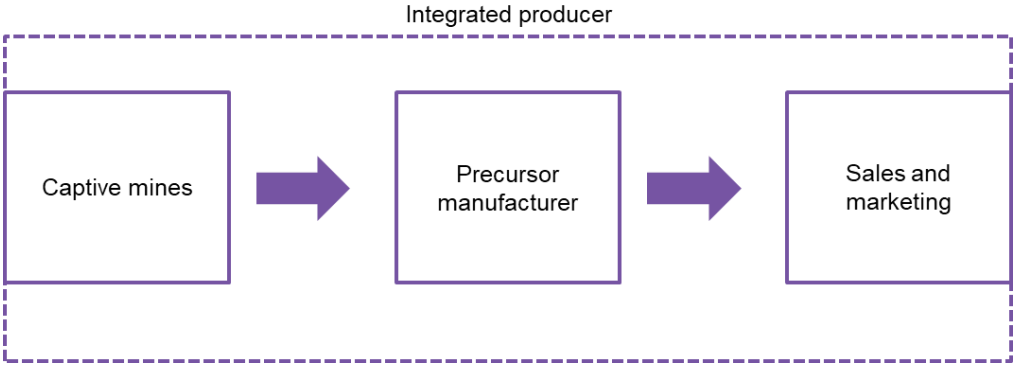
Source: Bloomberg

Business model

The type of business model chosen will have an impact on the final cost of operation. For this project, we presented two options. The integrated and non-integrated business models.

An integrated project is where the precursor company has direct offtake to a captive cobalt mine in the country. Under this model, the DRC can build an integrated plant by incentivizing an experienced third-party precursor manufacturer to invest resources and talent in the project through a joint venture (JV). The integrated producer can acquire raw materials feedstock at the cost of production, generally between 15% to 30% discount to the prevailing spot prices, since it comes directly from an affiliated mine. By working with an experienced manufacturer in a JV, the DRC will avoid the difficulties of developing the required intellectual property to develop the plant and produce precursors. An integrated JV approach will also reduce the project risk associated with capital raising, product sales and project continuity.

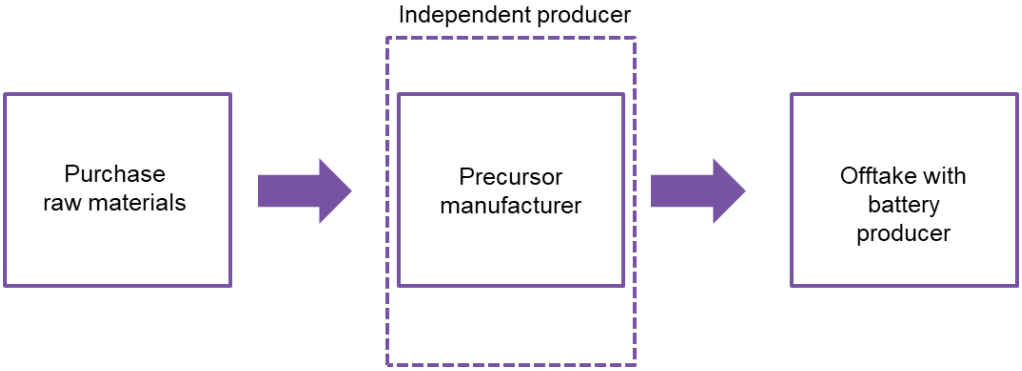
Figure 21: Integrated producer



Source: BloombergNEF

The non-integrated model will require the precursor company to purchase its cobalt on the market at the prevailing spot price. Through this arrangement, the company can purchase cobalt from any miner. On the downside, it will be exposed to the volatility in cobalt prices.

Figure 22: Non-integrated producer

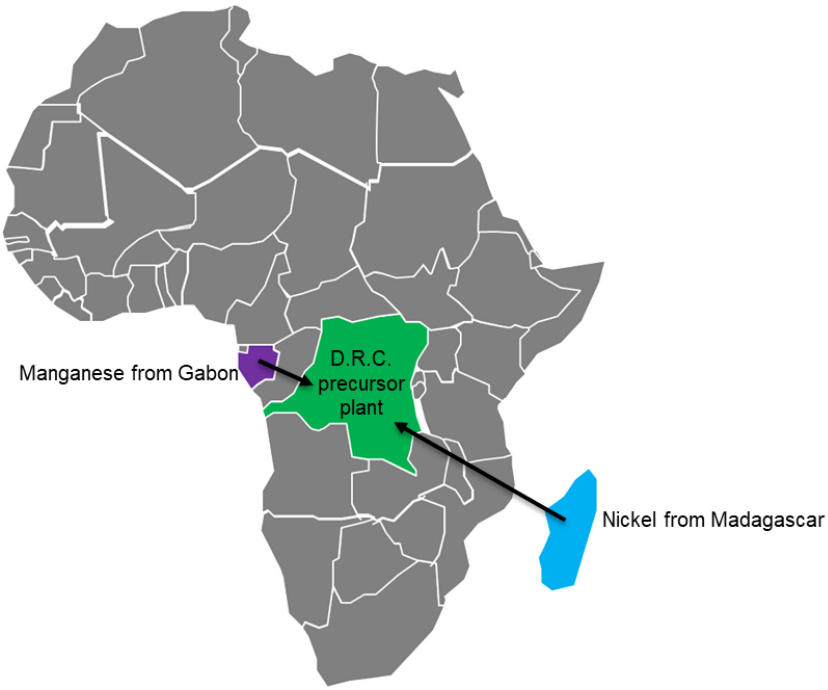


Source: BloombergNEF

Supply chain

The DRC produces only cobalt out of the three main raw materials needed to produce battery precursors. We excluded artisanal mine production from our modelling. In our cost modeling, we assumed the plant will procure its nickel from Madagascar's Ambatovy mine and get it shipped through Tanzania or Mozambique into the country. For manganese, we assumed it will be procured from Gabon and transported into the DRC, as shown in Figure 23. The DRC has manganese deposits that could benefit from the potential demand from the precursor plant should it be established.

Figure 23: Raw materials supply chain



Source: BloombergNEF

Benchmark

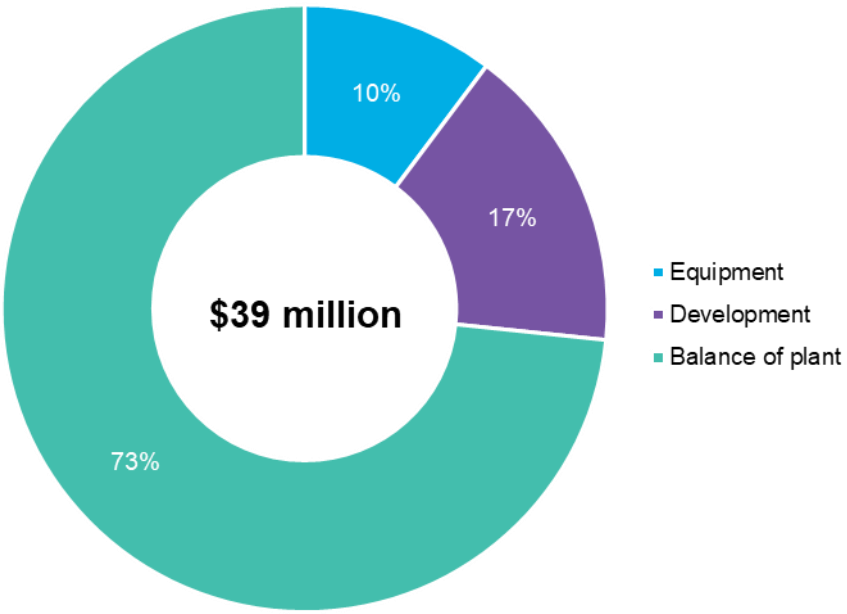
The cost of producing precursors in the DRC is benchmarked with production costs in China, Poland and the U.S. to determine their competitiveness. The three countries were selected for the reasons stated.

- **China**: The country is the biggest producer of precursors currently. Most of the battery raw materials produced in Africa are exported to China as intermediary products and further processed into precursors and cells. The precursors and cells are then exported to Europe. Including China in the benchmark will enable market participants to compare the cost of producing these precursors in DRC instead and its impact on supply-chain emissions.
- **U.S.**: The country has the second highest utilized capacity for high-nickel-chemistry batteries, 88,000MWh. Still, its imports of battery raw materials from Africa is lower than China's, but it could compete as a favorable destination for battery precursor investments because of its growing electric vehicle demand coupled with government policies and incentives to indigenize its supply chains.
- **Poland**: It could grow to become the fourth largest lithium-ion cell manufacturer by 2025 after China, Germany and the U.S. This growing cell-manufacturing capacity coupled with the country's highly skilled battery workforce and direct proximity to electric vehicle manufacturers in Germany and other European countries put it in direct competition with the DRC for new investments in precursor manufacturing.

4.3. Capital cost

The cost of developing a 10,000 metric-ton precursor plant in the DRC for NMC 811 or NMC 622 battery chemistries is $39 million (real 2020). We break the capital cost into three main areas. The cost of developing the project, which includes land acquisition and construction cost. The cost of purchasing equipment for the plant and finally the balance of plant, which includes auxiliary services such as water, heat, inventory, power and waste disposal. Overall, the cost of providing auxiliary services is the most capital intensive, at $29 million, followed by the development cost at $6 million, and equipment acquisition and installment at $4 million, as shown in Figure 24.

Figure 24: Capital cost of a 10,000 metric-ton precursor plant in the DRC



Source: BloombergNEF. Note: Balance of plant include auxiliary services such as water and heat.

Benchmarking the cost

Building a 10,000 metric-ton precursor facility in the DRC will cost $39 million, which is three times cheaper that it would cost for a similar plant in the U.S.

Building a 10,000 metric-ton precursor facility in the DRC will cost $39 million, which is three times cheaper than it would cost for a similar plant in the U.S. A similar project in China and Poland will cost $112 million and $65 million, respectively. These are still significantly higher than the DRC, as shown in Figure 25. The project cost in the DRC is cheaper than all three countries, mainly due to the lower cost required to develop the project. Land cost, permits and construction costs are lower in the DRC. China has the highest development cost, mainly due to the cost of land acquisition and the rising cost of construction labor as shown in Figure 26. Government subsidies are excluded in this analysis. Including them, however, could reduce the capital cost of new projects.

Figure 25: Capex for precursor production

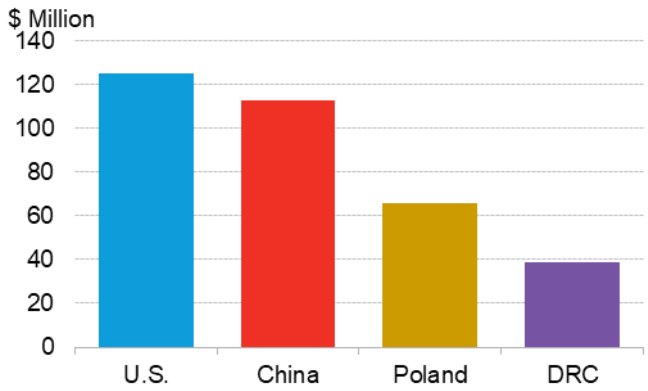
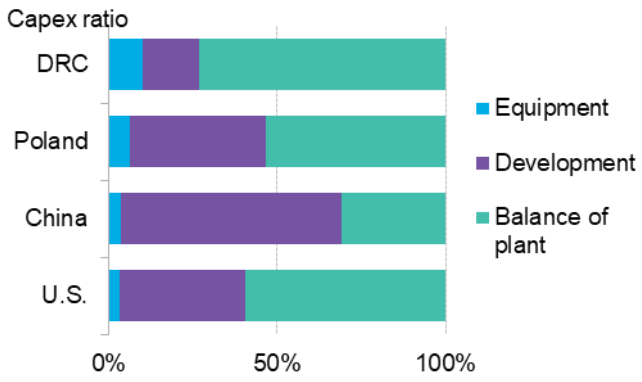


Figure 26: Capex ratio for precursor production



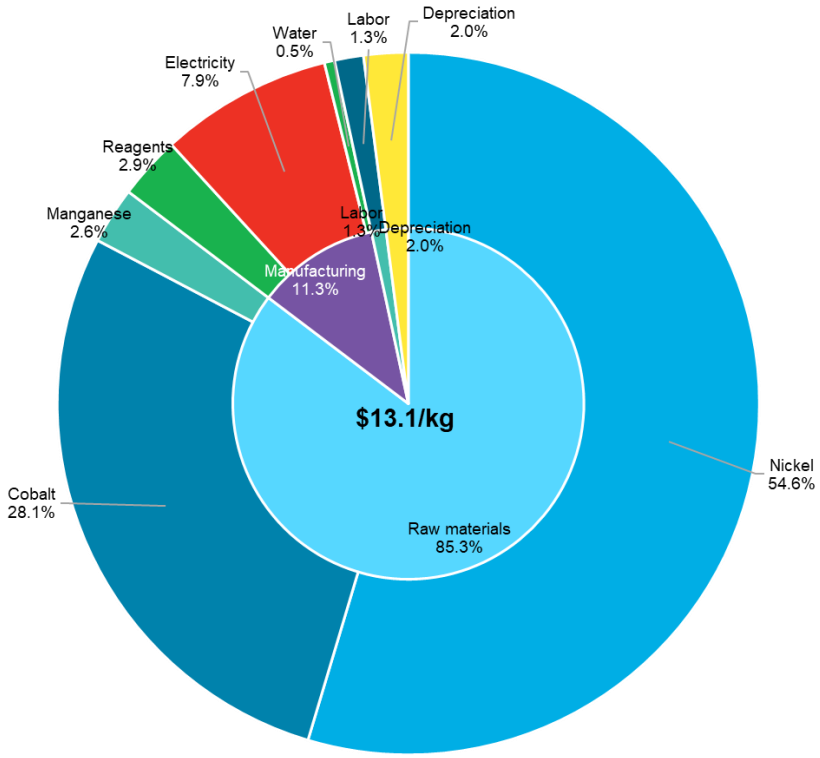
Source: BloombergNEF. Note: The cost is for a 10,000 metric-ton precursor facility and does not include any government subsidy.

4.4. LCOP for NMC 622 cathode chemistry

The cost of operating a 10,000 metric-ton integrated precursor facility in the DRC is $13.1/kg (2020 real) as shown in Figure 27. We break the cost of running the facility into raw materials (cobalt, manganese, nickel), reagents, water, labor, electricity and the cost of plant and equipment depreciation. Procuring nickel is the highest operation cost for precursor plants. This is 55% of the total levelized cost of production. Cobalt comes in next at 28.1% of the levelized cost of producing precursors at a 10,000 metric-ton plant to be used in NMC 622.

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, we also included a non-integrated precursor facility scenario in the DRC in which the company will procure its cobalt at the assumed spot price just like other countries.

Figure 27: Cost of operating a precursor plant for NMC hydroxide 622 in the D.R.C.



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

Benchmarking the cost of operation

With an integrated model, the DRC becomes the most cost-competitive country to operate a 10,000 metric-ton precursor facility compared to the U.S., China and Poland, as shown in Figure 28. However, Poland becomes more competitive if the plant in the DRC is not integrated with a cobalt mine.

Figure 28: Levelized cost of precursor production (LCOP)

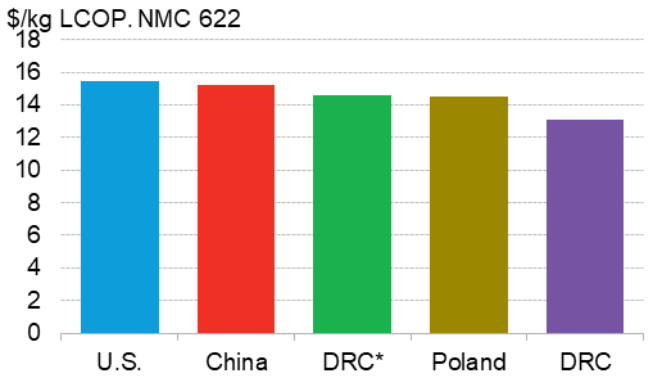
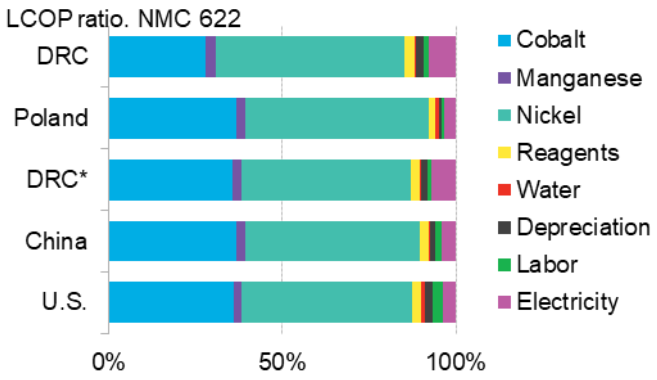


Figure 29: LCOP ratio for precursor production



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

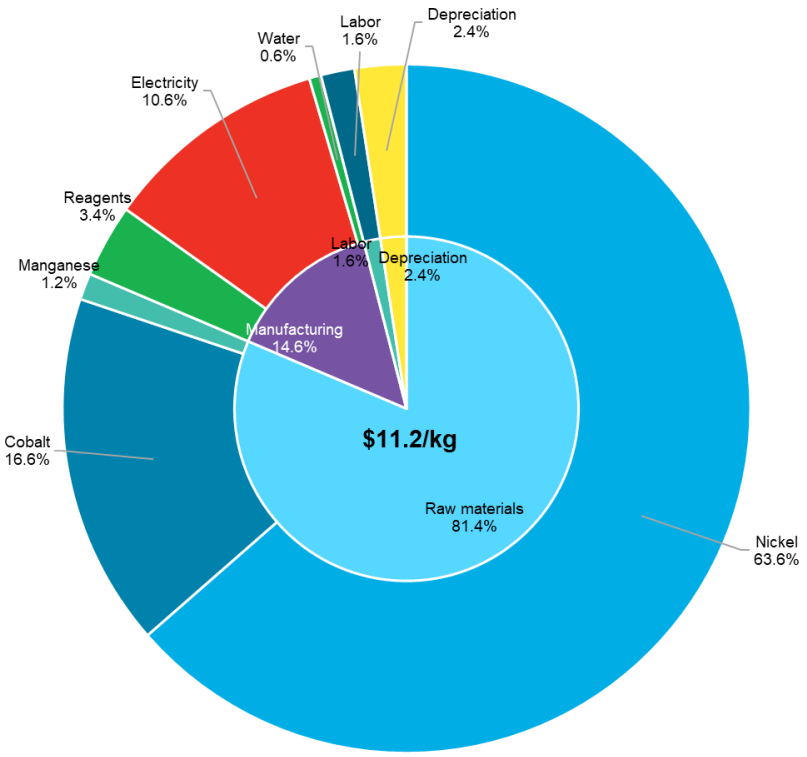
The precursor plant in the DRC can procure cobalt at the cost of production under our integrated scenario model. This lowers its cost of raw materials significantly compared to countries like the U.S. and China, where companies are assumed to purchase their raw materials at spot prices, as shown in Figure 29. This effect will be amplified during times of high commodity prices. However, it must be noted that China-based Huayou Cobalt owns some captive cobalt mines in the DRC.

Cost of electricity is relatively more expensive in the DRC compared with other countries due to the unreliability of the national grid, which leads to companies relying on independent power producers (IPPs) for electricity. This increases the unit cost compared to sourcing electricity from the national utility generator. Labor cost in the DRC is also higher than in Poland due to the reliance of the DRC on expatriates for the initial five years of the project to facilitate knowledge transfer. It remains, however, well below that of the U.S. and China.

4.5. LCOP for NMC 811 cathode chemistry

The cost of operating a 10,000 metric-ton integrated precursor facility for NMC 811 in the DRC is $11.2/kg (2020 real). This is lower than that of the NMC 622 due to the reduced use of cobalt in the chemistry. Cobalt is the most expensive raw material in the battery on a per ton basis. Like the NMC 622, we break the cost of running the facility into raw materials (cobalt, manganese, nickel), reagents, water, labor, electricity and the plant and equipment depreciation. Procuring nickel is the highest operation cost for precursor plants. This is 64% of the total cost of operation for the plant. Cobalt comes in next at 17% an NMC 811 (Figure 30).

Figure 30: Cost of operating a precursor plant for NMC hydroxide 811 in the DRC



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

Overall, raw materials make up 81% of the total cost of operation, compared to 85% in the NMC 622. This is followed by manufacturing costs, which are 14% compared to 11% for the NMC 622. Like the NMC 622, we included a non-integrated precursor facility scenario in the DRC, where the company will procure its cobalt at the assumed spot price just like other countries.

Benchmarking the cost of operation

Similar for our analysis with the NMC 622, the DRC remains the cost competitive country to operate a 10,000 metric-ton precursor facility for the NMC 811 battery chemistry compared to the U.S., China and Poland.

Figure 31: Levelized cost for precursor production (LCOP)

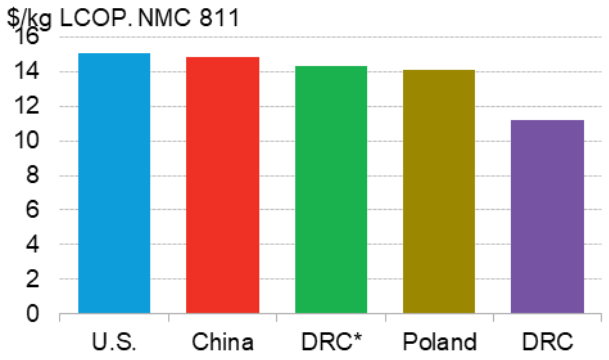
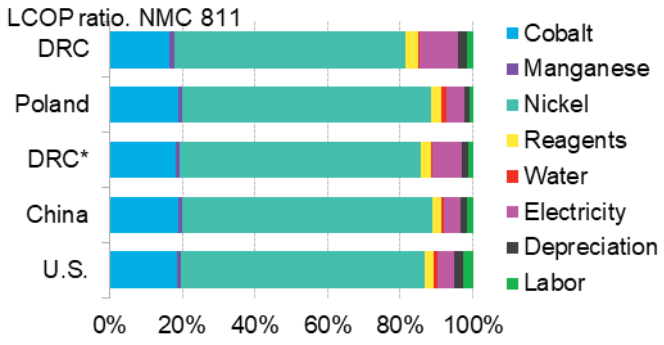


Figure 32: LCOP ratio for precursor production



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

The DRC has a higher cost-competitive advantage with NMC 622 cathode chemistry due to the high amount of cobalt required. With NMC 811, its cost advantage for cobalt, even under the integrated model, wanes compared to the other countries (Figure 32). Similar to the NMC 622, cost of electricity is relatively higher in the DRC compared to other countries due to the unreliability of the national grid. This leads to companies relying on independent power producers (IPPs) for electricity. The labor cost is also higher in the DRC compared with Poland due to the initial reliance on expatriates to transfer knowledge, expertise and technology.

4.6. Financing the project

The main scope of this project was to determine the cost of building and operating a precursor plant in the DRC and benchmark it with selected countries. However, to understand the impact of interest rates on project costs, we developed a hypothetical valuation model using BloombergNEF's proprietary project finance tool (EPVAL) to determine the impact of interest rates on project net present value (NPV). In consultation with the project partners, we sampled the interest rates project financiers use across the countries we covered in the report. The average interest rate was 3% in U.S. and Europe, 5% in China and 8.5% in the DRC.

EPVAL is BloombergNEF's proprietary project finance model. It leverages a pro-format project balance sheet with explicit modelling of investments, operational expenditure, mortgage payments, depreciation, corporate tax, and equity cashflows to model projects. By default, all inputs in EPVAL are in nominal local currency, but the model can also handle USD project modelling in emerging markets, as is the case with this precursor study. EPVAL's macroeconomic

data support calculations use inflation forecasts from the IMF, currency exchanges rates from the Bloomberg Terminal, corporate tax rates from KPMG.

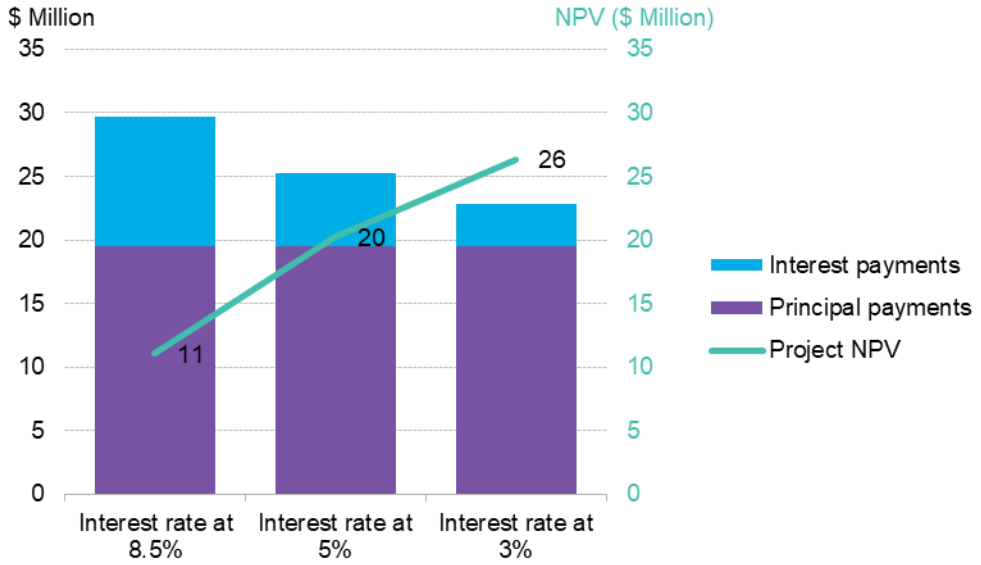
We assumed a 10% post-tax equity return, a principal of $19.5 million and a project-life of 20 years. For the valuation model, we assumed project financing in U.S. dollars and a 50% debt-to-equity ratio. We also assumed a one-year development period and another full year to construct the plant. The repayment period is 12 years. The tax rate was assumed to be 30% and inflation rate at 2.5%, consistent with U.S. dollar financing. All assumptions can be found in Appendix A.

At an interest rate of 8.5% and a theoretical precursor price of $32/kg, the project net present value (NPV) is $11 million. The project NPV increases to $20 million at 5% interest and $26 million at 3% interest rate (Figure 33). Investors can therefore maximize their project NPV when interest rates are low.

The interest rate could significantly impact the viability of the precursor project. We ran the model using the three interest rates to determine the ratio of principal and interest repayments. Over a repayment period of 12 years at an 8.5% interest rate, 34% of the total debt repayments go into servicing the interest. This is reduced by about half to 15% when the interest rate is 3% as shown in Figure 33. This shows that relying heavily on commercial loans to finance the project could increase cost.

On the other hand, working with development finance institutions to add a tranche of concessional financing – debt at a discount compared to typical interest rates -- could significantly reduce the cost of borrowing. As with every project financing in most parts of Africa, rates are subject to a wide variability depending on credit worthiness of the parties involved, and the country-specific currency risks. A typical project would have an optimal mix of concessional loans, development funds, private debt and equity to maximize project NPV.

Figure 33: Repayment profile and project NPV based on three interest rates



Source: BloombergNEF. Note: We assumed a 10% post-tax equity return and a principal of $19.5 million, a project-life of 20 years. Project financing is in U.S. dollars and a 50% debt-to-equity ratio. Repayment period is 12 years and tax rate was assumed to be 30% and inflation at 2.5%.

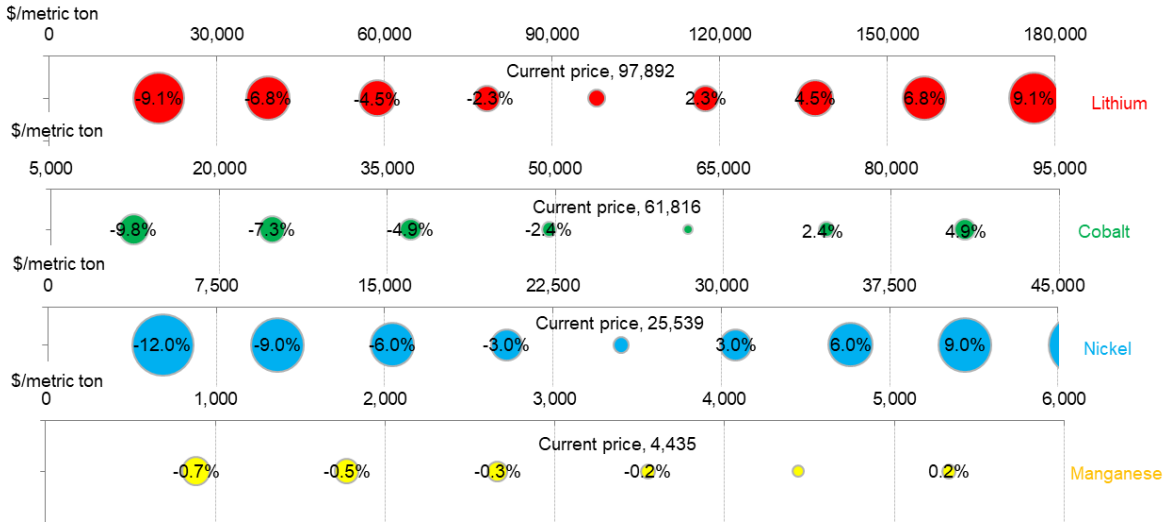
Sensitivity analysis on commodity prices

Raw materials prices have risen the last 12 months for all battery prices. Nickel and cobalt price swings have the largest effect on the cost of both NMC (811) and NMC (622) packs. We used BloombergNEF's battery price sensitivity to estimate the impact of volatile raw material prices on NMC 811 battery packs.

Doubling of cobalt prices for an NMC 811 battery will increase battery pack cost by 6% only. Doubling of lithium hydroxide prices increase the battery cost by 9% at the level as shown in Figure 33. Nickel price volatility has the highest impact on the battery (Figure 34).

The impact of raw materials will be higher at the precursor level, especially for nickel and cobalt.

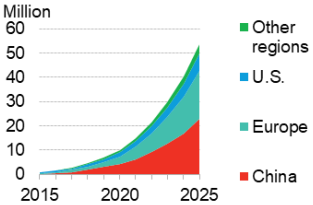
Figure 34: Impact of material price changes on NMC 811 battery pack price



Source: BloombergNEF

4.7. Scaling up precursor manufacturing in the D.R.C.

Figure 35: Global passenger electric vehicle fleet by market

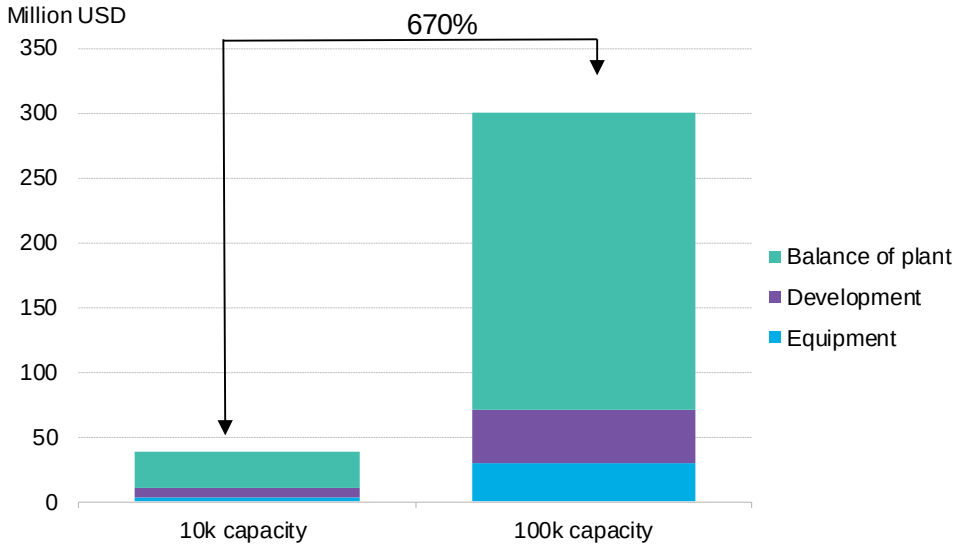


Source: BloombergNEF.
Note: Passenger electric vehicles include small, medium, large cars and sport utility vehicles (SUVs)

The project partners indicated their interest in developing a 100,000 metric tons capacity precursor plant in the DRC by mid-decade. Global passenger electric vehicle fleet will reach 54 million by 2025 as shown in Figure 35. A 100,000 tons can supply precursor materials for the manufacturing of 1 to 2 million electric vehicles, depending on the battery pack size. To scale-up our capex model for a 100,000 metric tons facility, we applied scaling factors to equipment procurement, development cost and balance of plant. This differs from our model developed for estimating the capex for a 10,000 tons plant. The scaling is not linear due to economy of scale, as plant capacity increases, the project benefits in cost for some parameters. Development cost, particularly land, does not increase linearly with capacity expansion beyond a certain limit.

Based on engagements with equipment manufacturers and benchmarking with existing plants, 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, we estimate a 100,000 metric tons precursor plant built in the DRC could cost $301 million (Figure 36).

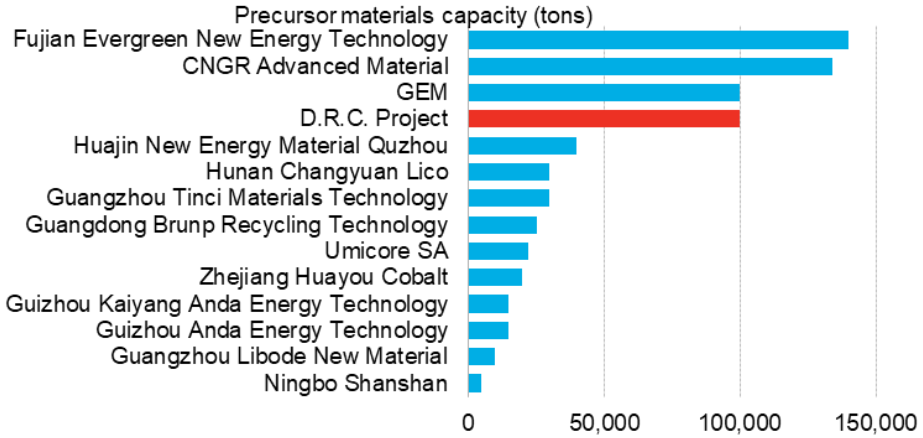
Figure 36: Cost of building a 100,000 tons precursor plant in DRC



Source: BloombergNEF

To compare the capital expenditure, GEM announced in September, it will invest 2.8 billion yuan ($431 million) in an 80,000 tons per year NMC precursors and lithium iron phosphate (LFP) plant in China's Hubei province. Should the 100,000 tons precursor plant in the DRC be developed, it would be amongst the largest in the world. The cost of operating the plant in the DRC is also likely to fall by 10-20% due to economy of scale. Unit cost of inputs like reagents, labor and electricity are likely to fall due to increasing scale. For labor, investing in automation as capacity increases could lead to the reduction in labor per metric ton of production as the plant scales up capacity. For electricity, the plant can negotiate favorable unit cost with the IPPs as demand increases with capacity expansion. The production of 100,000 metric tons per annum of NMC (622) precursor material will require 16,000 metric tons of cobalt each year as well as 48,000 metric tons and 15,000 metric tons for nickel and manganese, respectively. The DRC mined about 100,000 metric tons of cobalt in 2020 with about 3.6 million in reserves.

Figure 37: Precursor manufacturing plants stated capacities



Source: Bloomberg. Note: D.R.C. Project is indicative

Section 5. Supply chain emissions

5.1. Global supply chain emissions

Electric vehicles have zero tailpipe emissions, but the energy used to charge and manufacture them has emissions. Manufacturing the battery can account for almost 50% of emissions throughout the life of an electric vehicle.[1] Total emissions vary hugely depending on where the active material, cell and pack are manufactured, and the manufacturing conditions.

The DRC has a relatively clean grid due to its reliance on hydroelectric power. Its grid, however, has not been stable nor reliable due to long-term maintenance neglect. Despite these challenges, the plant can still capitalize on hydroelectric power to produce precursors with relatively clean carbon footprint.

The transport of raw materials, precursor materials, active materials, cells or packs between different locations can increase the carbon footprint of the finished pack. Transport using diesel ships produce the lowest amount of carbon per ton of freight moved each kilometer, and diesel trucks produce the highest emissions. A traditional route tracked by BloombergNEF, where raw materials such as manganese and cobalt are shipped from Africa to China for battery manufacturing would have a higher emissions compared to a localized supply chain in Africa. The impact of transporting raw materials, particularly as concentrates, is much greater than if transporting precursor materials.

The emissions associated with battery manufacturing will continue to decline over the next decade. Reducing carbon intensities of electricity grids around the world will help but we expect bigger emissions reductions to come from the introduction of new manufacturing techniques and equipment. For the D.R.C. to compete globally on low emissions, the precursor plant would have to recycle energy and heat within the facility and invest in renewable electricity onsite or remotely.

5.2. Methodology

BloombergNEF used its proprietary Lithium Battery Emissions Model to estimate emissions associated with the supply chain from raw materials to cell manufacturing. We estimated the emissions associated with the movement of materials as well as the manufacturing process. These include, raw materials extraction, metals refining, precursor production, cell manufacturing and pack assembly. We then estimated the overall CO2 emissions associated.

Table 1: Raw materials supply chain and associated emissions using precursors from the D.R.C.

Metal	Origin	Destination	Distance (km)	Mode	Transport emissions (kgCO2/ton)
Lithium	Atacama, Chile	Antofagasta, Chile	241	Road – Diesel	33.3
	Antofagasta, Chile	Gdansk, Poland	31,584	Ship – Diesel	315.8
	Gdansk, Poland	Nysa, Poland	563	Road -Diesel	78.7

[1] International Council on Clean Transport, February 2018

Metal	Origin	Destination	Distance (km)	Mode	Transport emissions (kgCO2/ton)
Nickel	Ambatovy, Madagascar	Toamasina port, Madagascar	238	Road – Diesel	33.3
	Toamasina port, Madagascar	Beira Port, Mozambique	2,577	Ship - Diesel	25.8
	Beira Port, Mozambique	Lubumbashi, D.R.C.	1,839	Road – Diesel	257.1
Cobalt	Lubumbashi, D.R.C.	Lubumbashi, D.R.C.	100	Road – Diesel	14
Manganese	Moanda, Gabon	Lubumbashi, D.R.C	2,937	Road – Diesel	410.6
Graphite	Yingkou, China	Gdansk, Poland	25,450	Ship – Diesel	254.5
	Gdansk, Poland	Wroclaw, Poland	490	Road – Diesel	146.1
Aluminum	Neus, Germany	Wroclaw, Poland	846	Road – Diesel	118.3
Copper	Atacama, Chile	Antafogasta Port, Chile	241	Road - Diesel	33.7
Copper	Antafogasta Port, Chile	Gdansk, Poland	18,849	Ship – Diesel	188.5
	Gdansk, Poland	Nysa, Poland	576	Road – Diesel	80.5

Source: BloombergNEF. Note: All metals are processed into their chemical products.

BloombergNEF also tracked the emissions associated with the four main processes after the mine-level: precursor production, active material process, cell manufacturing and pack assembly. The assumptions are below.

Table 2: Cell manufacturing supply chain and associated emissions using precursors from the D.R.C.

Process	Origin	Destination	Distance (km)	Mode	Transport emissions (kgCO2/ton)
Precursor	Lubumbashi, D.R.C.	Port of Durban, South Africa	3,226	Road – Diesel	451
	Matadi port, D.R.C	Gdansk port, Poland	11,882	Ship – Diesel	118
	Gdansk port, Poland	Nysa, Poland	576	Road - Diesel	80.5
Active material	Nysa, Poland	Wroclaw, Poland	87	Road – Diesel	12.2
Cells	Wroclaw, Poland	Salzgitter, Germany	563	Road – Diesel	78.7

Source: BloombergNEF

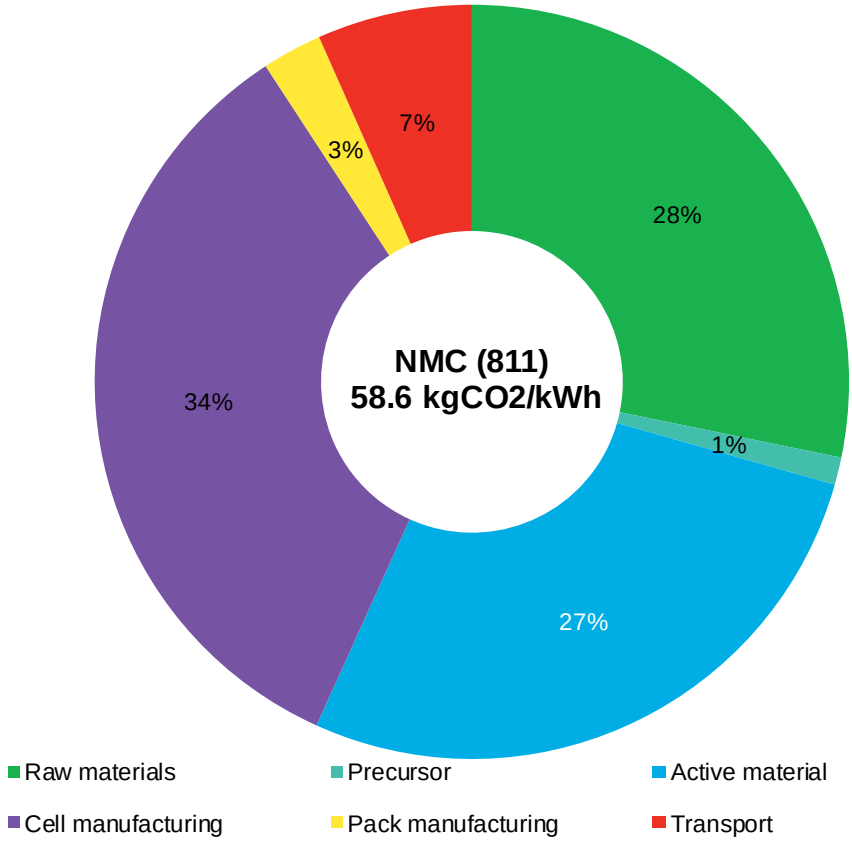
5.3. DRC results

Using our proprietary model, we estimate that manufacturing a 100kWh lithium nickel manganese cobalt oxide NMC 811 battery pack with precursor production in the DRC, cathode material and cell production in Poland, and pack production in Germany will emit 58.6kgCO2/kWh as shown in Figure 38.

The country where cells are manufactured has a significant impact on the carbon emissions associated with manufacturing, likewise its supply chains associated with the raw materials.

China's high grid emissions, 300-400gCO2/kWh in the regions that produce batteries, make for cells with poor environmental footprints. However, the DRC, whose electricity is predominantly hydroelectric power, has average grid emissions of 55gCO2/kWh.

Figure 38: Cell manufacturing emissions with precursors produced in D.R.C.



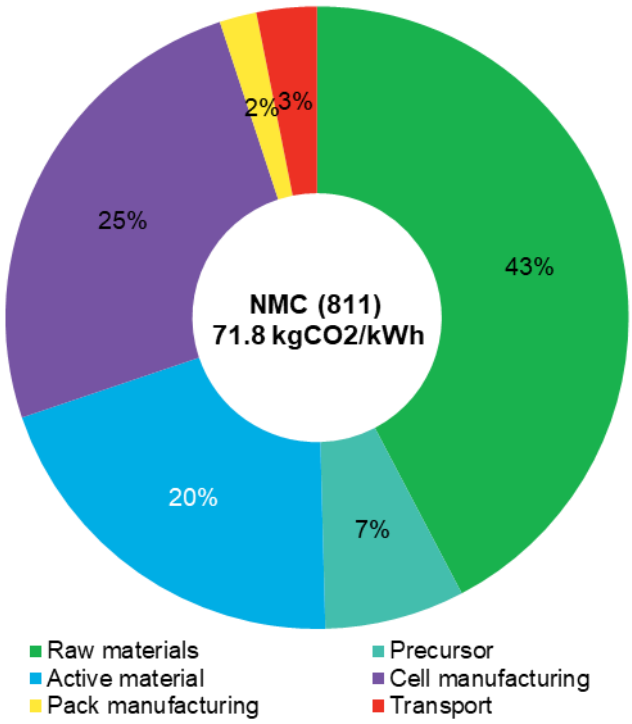
Source: BloombergNEF

5.4. Benchmarking results to Poland and China

For packs assembled in Salzgitter, Germany and cells manufactured in Nysa, Poland, producing the precursors in the DRC will significantly reduce the life-cycle missions of cells by 30% compared to making the precursors in China and 9% compared to making them in Poland (Figure 39 and Figure 40). This is due to the DRC's proximity to the three main cathode raw materials and relatively clean grid.

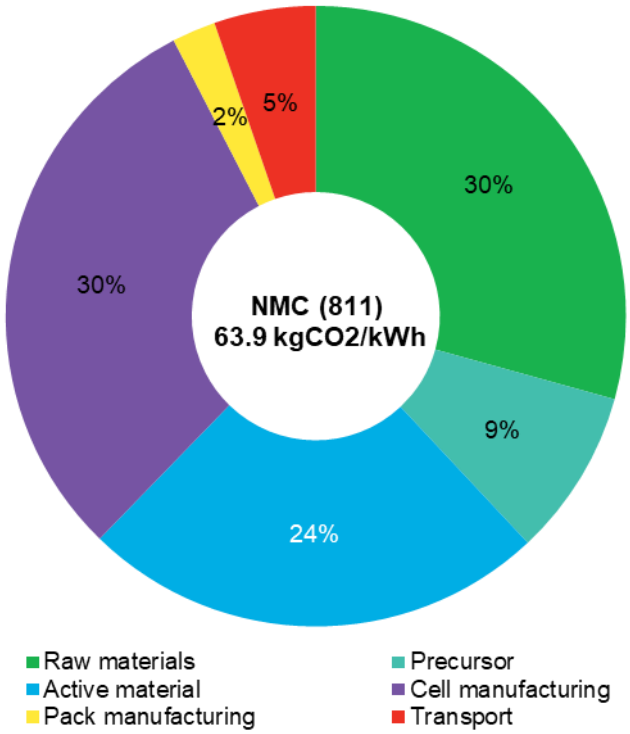
Cell manufacturing is the highest source of emissions for a scenario where precursors are produced in the DRC. This scenario assumes that raw materials are processed to produce sulfates in the DRC, again, taking advantage of the country's low grid emissions. The other two supply chains (Poland and China) have raw material refining in China, which has higher grid emissions. Two-thirds of the associated emissions come from active materials and cell manufacturing.

Figure 39: Cell manufacturing emissions with precursors produced in China



Source: BloombergNEF

Figure 40: Cell manufacturing emissions with precursors produced in Poland



Source: BloombergNEF

Section 6. Coordination of value-chain in Africa

The African Continental Free Trade Area (AfCFTA) agreement has the potential to create the largest free trade area in the world by participating countries. It covers 1.3 billion people across 55 countries with a combined gross domestic product valued at $3.4 trillion, according to the World Bank[2].

According to the World Bank, AfCFTA could facilitate growth of intracontinental trade from $294 billion in 2014 (base year) to $532 billion after implementation of AfCFTA in 2035. In volume terms, manufacturing exports will dominate Africa's market. Of the $2.5 trillion in exports projected in 2035 for Africa, $823 billion will be in manufacturing, $690 billion in natural resources, $191 billion in agriculture, and $256 billion in services. Of the total growth in exports of $560 billion, the increase in exports of manufactures represents some $506 billion[3].

The global electric vehicles industry will be a $46 trillion market between 2021 and 2050, according to BloombergNEF's Long Term Electric Vehicle Outlook. This market could play a role toward the African Union's Agenda 2063, which is an African blueprint and masterplan to transform Africa. Leveraging on the continental free trade agreement to boost manufacturing could provide a pathway.

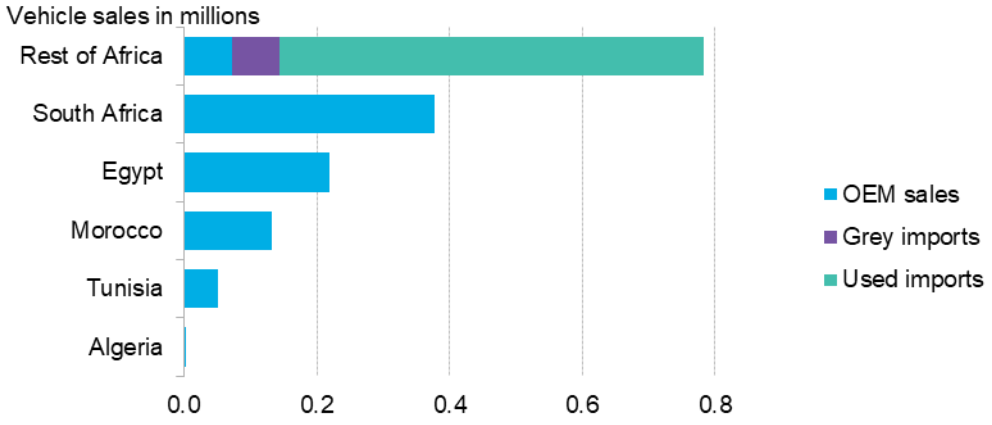
6.1. Leveraging on AfCFTA

AfCFTA could support Africa's auto sector by improving cross-border manufacturing and sales. In 2020, original equipment manufacturers (OEMs) sold 856,792 vehicles assembled in Africa, according to data from the Africa Automotive Data Network (Figure 41). That is 55% of the total auto market on the continent, the remaining 45% was from grey and used vehicle imports (grey imports are vehicles imported into a country outside the local distributor's normal channels). Of the vehicles assembled on the continent, OEMs in South Africa sold 44% of the vehicles, followed by Egypt and Morocco with 26% and 16%, respectively. Tunisia sold 50,825 new vehicles in 2020, representing 6% of the market. The rest of Africa assembled and sold only 72,424 vehicle units, a paltry 8% of the overall market size. These include countries like Ghana, Uganda and Ethiopia. A key differentiator between the top five countries and the rest of Africa is the policy restriction on the importation of used vehicles.

[2] https://www.worldbank.org/en/topic/trade/publication/the-african-continental-free-trade-area

[3] https://openknowledge.worldbank.org/bitstream/handle/10986/34139/9781464815591.pdf

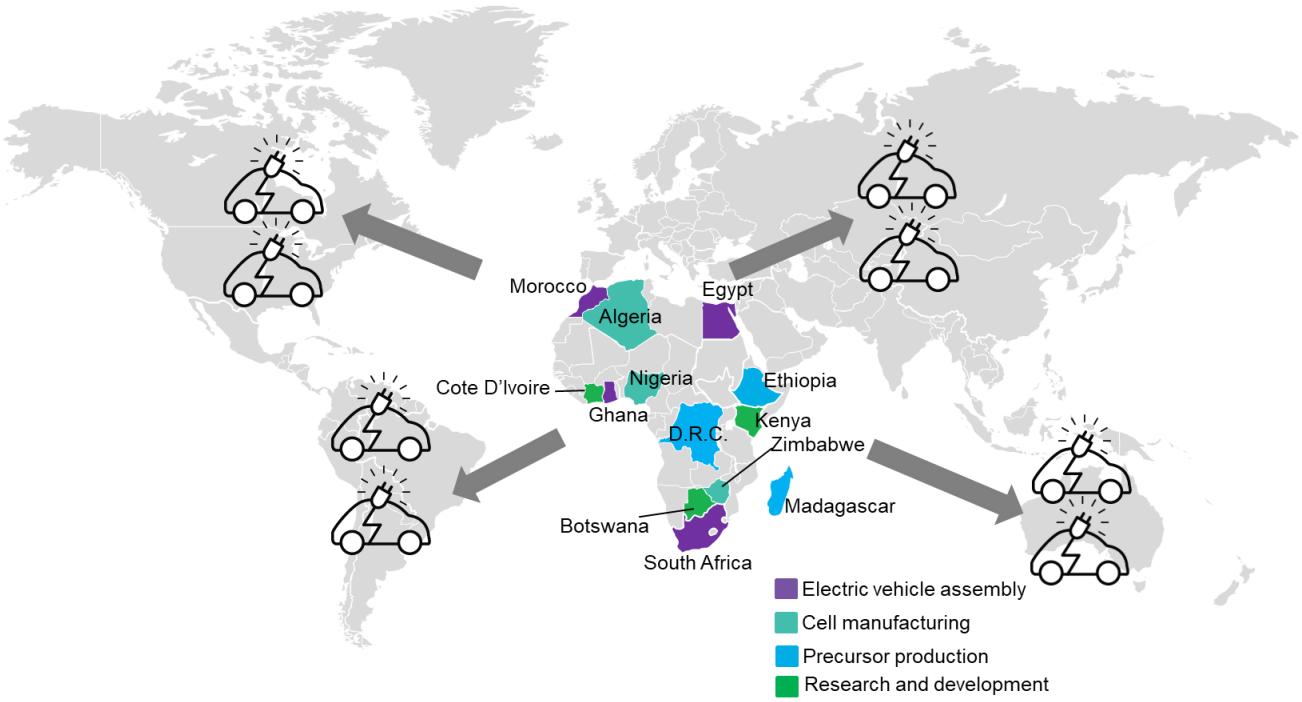
Figure 41: Africa's auto market in 2020



Source: Africa Automotive Data Network, BloombergNEF. Note: All OEM sales are internal combustion engines. OEM sales is 80% diesel and 20% gasoline.

Africa can leverage on its existing internal combustion engine expertise, the AfCFTA, raw materials and geographical proximity to key auto markets to become a major electric vehicle supply chain player, as shown in Figure 42. This proposed structure could diversify the market regionally. South Africa, Ghana, Morocco and Egypt could be electric vehicle assembly hubs. Nigeria, Algeria and Zimbabwe could be cell manufacturing hubs due to their proximity to the vehicle assembly countries. DRC, Madagascar and Ethiopia could be precursor production hubs due to their raw materials and transport hubs.

Figure 42: Leveraging on AfCFTA to build a regional value chain for a global market

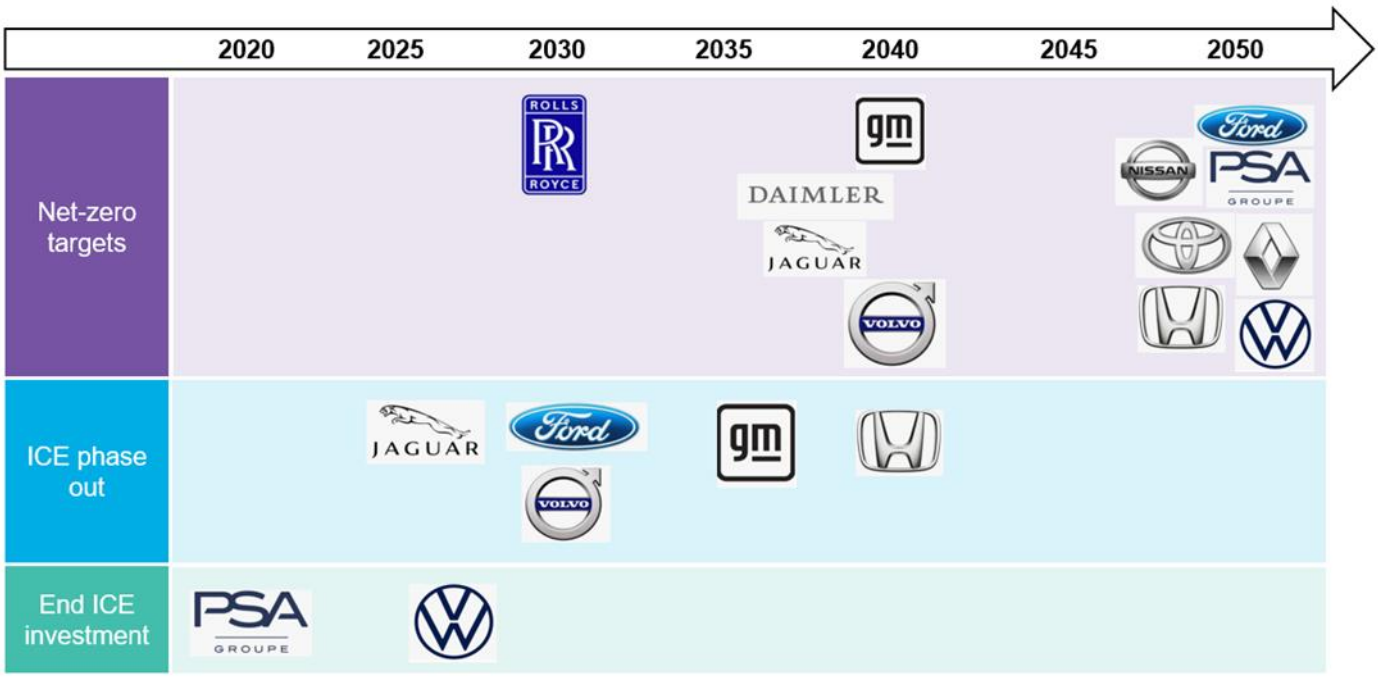


Source: BloombergNEF

Electric vehicle assembly: South Africa, Egypt, Morocco, Ghana

South Africa, Egypt Morocco and Ghana have all implemented automotive policies to attract investments into their auto sectors. The following OEMs have established assembly plants in the four countries: Toyota, Nissan, Ford, Volkswagen, Isuzu, Mazda, BMW, Mercedes Benz, BYD, Chery, Geely, Hyundai, Mitsubishi, Chevrolet, Nissan, Lada, Jeep, KIA, Renault, Dacia and BYD. Collectively, these OEMs sold over 730,000 units in 2020. Electric vehicle uptake has been slow in Africa but that hasn't stopped the OEMs to make global commitments to either attain net zero, phase out internal combustion engines or end internal combustion engine investment at a stated date. BloombergNEF tracks these commitments by automakers (Figure 43). In the medium-to-long term, OEMs operating in Africa will have to align their drivetrain targets with the corporate targets to either phase-out ICE or set net-zero targets. German automakers announced over 50,000 job cuts in 2019, heralding the beginnings of the painful transition toward electrifying transport. Production lines for component-light electric vehicles are likely to be highly automated. A German government-commissioned report predicts job cuts in a worst-case scenario could be as high to 410,000 by 2030 – this is against a base of 869,000 employed in 2017. Electric vehicle uptake coupled with automation could result in widespread disruption for the job-market in countries such as South Africa, where the production of vehicles employs 30,162 people in 2020 and an additional 76,800 in the component sector, according to Naamsa, The Automotive Business Council. In May 2021, the South African government launched its Auto Green Paper "to establish a clear policy foundation that will enable the country to coordinate a long-term strategy that will position South Africa at the forefront of advanced vehicle and vehicle component manufacturing, complemented by a consumption leg, and increase competitiveness in the global race to transition from the internal combustion engine era into electro-mobility solutions and technologies".

Figure 43: Automakers' drivetrain development targets



Source: BloombergNEF. Note: Ford ICE phase-out target is for Europe only.

South Africa can align its electric vehicle policy with its Industrial Policy Action Plan (IPAP), which coordinates various ministries and policy areas and to subordinate trade and other economic goals to the exigencies of industrialization. The government created the Tshwane Automotive Special Exclusive Zone out of this policy to boost employment and investment in the industry.

Morocco's aeronautic industry has recorded significant growth the last decade, with over 100 companies operating in the country, mostly in the Midparc Casablanca Free Zone. This was followed by the establishment of the Institut des Metiers de l'Aeronautique to develop the skilled labor in 2011. To replicate this success in the automotive sector, the government has been offering fiscal and tax incentives in certain free zones such as well-connected Greater Tanger-Med Industrial Platform. In 2012, Renault commissioned a $1.5 billion factory in Tanger Automotive City.

Ghana is an emerging automotive destination. As a new entrant, the country can work with automakers to build forward-facing assembly lines which prioritizes new technologies such as electric vehicles.

BloombergNEF take

Electric-vehicle focused special exclusive zones, good policy action plans, investment in skills upgrade and transport and port infrastructure will make Africa a competitive destination for the global automotive industry.

Cell manufacturing: Nigeria, Zimbabwe, Algeria

Sales of vehicles have increased in Nigeria in the last decade. The country produced its first domestic automobile in 2015 after the government launched its New Automobile Industrial Policy Development in 2013. This has been followed by initiatives such as import-tariff hikes on used vehicles, infrastructure investments and skills improvement to drive domestic auto production. Nigeria has also developed the Lagos Free Trade Zone, a privately owned trade zone. The Lekki Free Trade Zone hosts the Dangote Petroleum Refinery, a multi-billion project to refine about 650,000 barrels of crude to meet Nigeria's domestic market. The success of the country's free trade zone in attracting mega projects, coupled with its bourgeoning domestic auto market, could make it an attractive destination for cell manufacturing investments.

Zimbabwe has lithium reserves of about 230,000 metric tons, according to the U.S. Geological Survey. The country can leverage its deposits and proximity to the DRC to be a cathode active material producer and ultimately manufacturer cells for the South Africa vehicle manufacturing market.

Algeria's auto industry is growing. In 2020, OEMs sold about 2,500 vehicles in the country. Its proximity to Morocco, a cobalt producer and automotive manufacturing hub, as well as Egypt, could serve as an incentive to develop its domestic cell manufacturing capacity.

BloombergNEF take

Africa can capitalize on its growing demand for vehicles as it urbanizes, to create a critical mass for battery demand to support cell manufacturing at a macro scale. The availability of the main raw materials required to make cells within the continent could make it both a cost-competitive destination and an environmentally friendly one as well.

Precursor production: DRC, Madagascar, Ethiopia

In September, BloombergNEF published its global lithium-ion battery supply chain rankings to assess the competitiveness of 30 countries within the lithium-ion battery industry for both 2021 and 2026. The rankings assessed countries based on their available raw materials, cell and component manufacturing, environmental factors, regulations/infrastructure and innovation performance and finally electric vehicle downstream demand. The DRC was ranked 29th in 2021 and 27th in 2026 out of the thirty countries. The DRC has failed to leverage on its existing cobalt capacity, 70% of global supply in 2020, to build a domestic refinery capacity. Almost all the cobalt mined in the country is exported to China or Europe to be refined into finished products.

Like the DRC, Madagascar is well endowed with nickel and cobalt. The country can develop its supply chain and leverage on its proximity to South Africa to contribute to the regional supply chain.

Ethiopia is well connected to other countries through its transport supply networks. Its proximity to Europe and a gateway to Asia can serve as an opportunity for the country to import raw materials from other countries and develop battery precursors for the vehicle industry in Egypt.

BloombergNEF take

Direct export of raw materials in the form of concentrates or intermediary products is not economically beneficial to host-countries in the long term. Countries can retain more value locally by investing into manufacturing facilities that refine these raw materials into semi-finished or finished products. Precursors can provide such opportunity for countries like the DRC and Madagascar.

Research and development: Botswana, Cote D'Ivoire, Kenya

Kenya has a strong manufacturing base backed by quality research in areas such as pharmaceuticals, chemicals and fabricated metals production. Kenya is becoming a fast-growing hub for motor vehicles in East Africa. One-fifth of manufacturing jobs are located in the country's Export Processing Zones, mostly dominated by the agricultural industry. In 2021, Kenya was third in Sub-Saharan African on the Global Innovation Index after Mauritius and South Africa. The country was an early adopter of technology and has produced fintech companies pioneering new solutions at the continental level.

Botswana has been successful in developing a reputable downstream market for its diamond industry through a strategic partnership with De Beers. As part of its diversification process, the country established the Botswana International University of Science and Technology (BIUST) to become a leading research institution globally.

Cote D'Ivoire has built a reputation in using research and development to boost domestic industries despite little investment. Investing in research and development could serve as a catalyst for the country to develop research in the battery and electric vehicle industry.

BloombergNEF take

African countries rank the lowest on innovation and research. This trend, however, is changing as more private companies become more sophisticated with their products and assembly lines. Africa can only compete for electric vehicle capital with other regions such as Southeast Asia and South America by investing in cutting edge research and development. Investing in research will ensure the next generation of workers are well trained

Section 7. Lessons from the past: country spotlights

Large-scale copper mining (of which cobalt is often a by-product) in the DRC has existed for well over a century, since the formation of the Union Minière du Haut-Katanga, an Anglo-Belgian mining company. In 1967, when the DRC gained independence from colonial rule, the new government nationalized the majority of the company's assets, leading to the formation of La Générale des Carrières et des Mines (Gecamines). Assets that were not nationalized were subsequently absorbed by present-day company Umicore, headquartered in Belgium.

Gecamines activities were crippled at the turn of the new millennium due to years of mismanagement, falling copper prices, government interference and wars. The country went through two years of civil war until the current governing system was solidified under Laurent Kabila in 1997. During 10 years of peacetime rebuilding that followed, the World Bank and international stakeholders played a key role in leading reforms for the DRC's mining sector. This included financial lifelines to support the restructuring of Gecamines, based on strict conditions, and subsequently the promulgation of the DRC's mining code in 2002. The reforms led to Gecamines becoming a JV partner in most of the assets it owned.

The DRC's GDP has grown from $8.7 billion in 2002 to $49.87 billion in 2020. After the introduction of the mining code in 2002, several private foreign companies invested alongside the World Bank and IFC in mining projects across the country. The mining code at that time guaranteed the companies low taxes, and a 10-year stability clause, which guaranteed no changes to code and regulations. What the code lacked were mechanisms for enforcement, transparency and accountability for revenue collected and how the wealth was to be utilized.

The absence of transparency and accountability eroded the effectiveness of the mining code. By 2010, the World Bank had suspended its loans program with the government due to concerns raised on mining concession agreements. The African Development Bank also withheld an $87 million budget support and the IMF halted its $225 million loan program due to the government's failure to fully disclose some mining deals.[4] From 2010 to 2012 alone, the Africa Progress Panel reported that the DRC lost over $1.36 billion in revenue through the underpricing of at least seven mining assets.

Several companies retreated from further investing in the country's copper and cobalt market. As foreign investment into the sector dried up, Chinese companies filled the void. Starting in 2007, the Chinese government made its most significant Chinese investment in Africa by entering into an agreement with DRC government under a joint venture, Sino Congolaise des Mines (Sicomines). The Chinese government committed $9 billion to the DRC through loans and infrastructure projects like roads, schools and hospitals, which will then be paid back through natural resources exploited by Sicomines under the JV. This partnership led to several other large-scale mining companies from China entering into concession agreements for copper and cobalt in the DRC, such as China Molybdenum, Jinchuan, and Zijin Mining.

In 2018, the country revised its mining code to increase the government's share of mining revenue, reduce the stability clause for new projects and improve transparency of the industry. Key among the changes is the introduction of a contribution of a minimum of 0.3% of the turnover

[4] http://africaprogressgroup.org/

by mining companies to the development of communities affected by mining activities. The code also disallowed the export of raw materials without further refining unless it is impossible to do so locally. Additionally, contractors working with mining companies should be Congolese or majority owned by Congolese shareholders. Collectively, these new provisions could help support local communities, develop domestic human resources and improve local linkages between Congolese companies and the multinational mining firms.

As the DRC proceed with expanding its downstream capacity in battery metals through investments, there are lessons it can draw from other resource rich countries that attempted this in the past with varying degrees of success. Below, we discuss plans by the Chilean and Indonesian governments to build domestic supply chain and share some lessons for the DRC.

Leveraging resources to attract the downstream supply chain

Chile's earlier attempt to become a battery player

In 2018, Chile's government announced its intention to attract major battery manufacturers into the country to produce cathode materials for electric vehicles. The key to the government's strategy was a 2016 agreement with the U.S. lithium miner Albemarle Corp, to supply a fraction of their future lithium to the battery makers at a discounted price.

Once this agreement was in place, Chile's development agency, Corfu, commenced a tender process in 2017. The tender attracted 12 bids. Three companies won the bid: Fulin, Molymet and Posco-Samsung. The three companies requested for 28,496 metric tons of lithium, according to Reuters, twice more than the government's agreed quantity with Albemarle.

Albemarle produces lithium carbonate in Chile. The Posco-Samsung plant was supposed to produce high-nickel chemistry batteries, which use lithium hydroxide. Posco and Albemarle failed to reach an agreement on developing lithium hydroxide for the cathode material plant.

Chile's ambition to build a domestic battery manufacturing supply chain failed due to the lack of clarity on pricing, technological differences and lack of stakeholder buy-in at the agreement stages.

Lessons for the DRC precursor project

- The project partners must engage stakeholders and agree on primary parameters such as raw materials supply chain offtake, pricing, technology and product qualification.
- Government should avoid entering into strategic multi-year investment agreements with mine production that is not yet operational.
- The government must be transparent with all stakeholders to ensure the free flow of information to improve decision making.
- Overpromising and under-delivering on promises such as discounted cost of raw materials and policy uncertainty could harm the country's investment attractiveness in future.

Indonesia's bold plan to become an electric vehicle powerhouse in Southeast Asia

The Indonesian government is trying to utilize its vast nickel resources–a key ingredient for high energy density lithium-ion batteries – to attract foreign investment in building up a domestic electric vehicle and battery manufacturing value-chain. A flurry of announcements over the last two years, suggests Indonesia is succeeding in its plans to attract investment. However, a closer look suggests many challenges lie ahead.

To attract foreign investment in domestic electric vehicle and battery manufacturing value-chain, Indonesia has proposed incentives as well as restrictions on raw nickel ore exports.

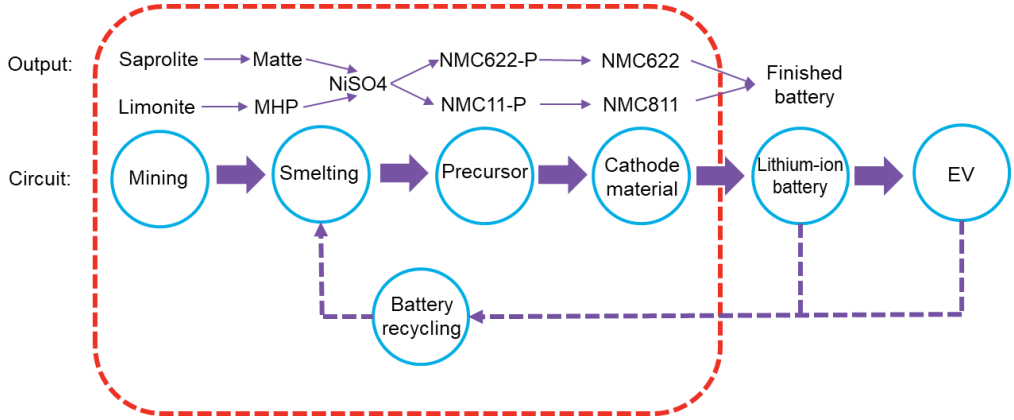
Over the period of September 2018 through December 2020, BloombergNEF identified investment announcements totaling $22.1 billion, suggesting Indonesia is succeeding in its plans. However, 86% of those announced investments have not been formally confirmed, according to data we track. Indonesia has thus far made the most progress in attracting investment in nickel refining and not electric vehicle manufacturing. This shows that export bans only attract investment into the lower end of the value chain.

Another challenge Indonesia faces is its poor environmental performance. The country's cheap energy costs are due to heavy reliance on coal power. Its nickel supply has a higher carbon footprint than other major suppliers such as Australia. Automakers and their battery suppliers are increasingly concerned with the environmental footprint of their supply-chain. Without significant improvement to its environmental performance, Indonesia is unlikely to fully achieve its lithium-ion battery domestic manufacturing ambitions. The government now intends to provide hydroelectricity sources for the battery manufacturers to reduce their footprint.

Lessons for the DRC precursor project

- Addressing legacy environmental, social and governance (ESG) issues such as raw materials transparency is important.
- Export bans can incentivize domestic investments in intermediary products like nickel metal but not high value products like electric vehicles.
- Incentives attract investors but addressing factors associated ESG would make them stay in the country in the long term.
- A one-stop joint venture partner to coordinate local investment and implementation can help reduce regulatory red tape, de-risk projects and facilitate a well-structured knowledge transfer between multinationals and local companies.

Figure 44: PT Aneka Tambang battery manufacturing plan



Source: PT Aneka Tambang, BloombergNEF. Note: MHP is Mixed hydroxide product, NiSO4 is nickel sulfate, NMC is nickel-manganese-cobalt, and P stands for precursor. Dotted line represents Antam's initial plan, LG Energy Solutions is likely to be responsible for the 'Finished Battery' portion.

Section 8. Policy implications

8.1. Regional Policies

Capital

Policy Implication 1: *Countries in Africa must create a diversified capital market that supports battery research, early-stage products and scales up manufacturing for the electric vehicle industry. Development finance institutions such as the AfDB and BADEA can support research and early-stage projects through grants. Also, institutions such as the Afreximbank and the AFC can complement commercial banks by providing loans to mature companies to support expansion, whilst the ALSF provide legal support for business transactions.*

Demand

Policy implication 2*: African countries must formulate policies such as zero-emissions subsidies, emissions regulations and consumer incentives to boost demand for electric vehicles in order to attract cell manufacturing capacity to the continent.*

8.2. Country policies

Infrastructure

Policy implication 3*: The DRC must upgrade its infrastructure, ranging from electricity, roads, ports, rail and electric vehicle charging port to support low-cost manufacturing and integration of electric vehicles.*

Research and development

Policy implication 4*: In line with setting-up the precursor manufacturing plant, the DRC must also develop a research center to invest in next generation battery technology to support the budding industry and train the local workforce.*

Fiscal certainty

Policy implication 5: *Government must promote fiscal certainty through the provision of laws and regulations that support local businesses. The government could also create specialized economic zones with focus on the electric vehicle industry with a clear mandate to protect investment capital, guarantee business continuity and lower the risk of operating business in the country.*

Governance improvement

Policy implication 6*: The government could set up a one-stop-shop to coordinate and streamline engagement with third-party organizations. This will improve transparency and reduce red tape associated with activities such as licensing, permits and intellectual property negotiations. This could either be a joint venture between the state and its strategic partners or a special purpose vehicle.*

Appendix A. Appendix

The appendix details the assumption used in developing the cost of precursors as well the associated emissions.

Table 3: Modelling assumptions

Parameters	Value – DRC	Value - Poland	Value - China	Value – U.S.	Unit
Plant capacity	10,000	10,000	10,000	10,000	Metric tons per annum
Plant utilization	90	90	90	90	%
Inflation	2.5	2.5	2.5	2.5	%
Tax rate	30	19	25	21	%
Development	1.00	1.00	1.00	1.00	years
Construction	1.00	1.00	1.00	1.00	years
Operation life	20.00	20.00	20.00	20.00	years
Land cost	32.00	79.90	234.30	146.00	$/m2
EPC cost	318.00	371.00	390.50	822.50	$/m2
Equipment cost	0.40	0.40	0.40	0.40	$/kg
Labor intensity (manager)	15.00	15.00	15.00	15.00	ppl/yr (for 10ktpa)
Labor intensity (production worker)	85.00	85.00	85.00	85.00	ppl/yr (for 10ktpa)
Labor cost (manager)	7.57	60.20	109.30	180.0	$/hour
Labor cost (production worker)	4.92	4.5	8.6	4.7	$/hour
Electricity cost	0.08	0.09	0.09	0.09	$/kWh
Electricity intensity (NMC 622)	0.15	0.15	0.15	0.15	kg/kWh
Electricity intensity (NMC 811)	0.14	0.14	0.14	0.14	kg/kWh
Debt Cost Type	Fixed Rate	Fixed Rate	Fixed Rate	Fixed Rate	
Debt Cost	850	300	500	300	bps
Cobalt intensity (NMC 622)	8.22	8.22	8.22	8.22	kg/kg
Cobalt intensity (NMC 811)	16.49	16.49	16.49	16.49	kg/kg

Parameters	Value – DRC	Value - Poland	Value - China	Value – U.S.	Unit
Cobalt cost	59.44	59.44	59.44	59.44	$/kg
Manganese intensity (NMC 622)	8.81	8.81	8.81	8.81	kg/kg
Manganese intensity (NMC 811)	17.69	17.69	17.69	17.69	kg/kg
Manganese cost	14.05	14.05	14.05	14.05	$/kg
Nickel intensity (NMC 622)	2.76	2.76	2.76	2.76	kg/kg
Nickel intensity (NMC 811)	2.07	2.07	2.07	2.07	kg/kg
Nickel cost - mid	29.12	29.12	29.12	29.12	$/kg
Sodium hydroxide intensity	1.12	1.12	1.12	1.12	kg/kg
Sodium hydroxide cost	0.43	0.43	0.43	0.43	$/kg
Water intensity	12.50	12.50	12.50	12.50	kg/m3
Water cost	0.77	2.11	0.94	1.78	$/m3

Source: BloombergNEF, UNECA, Afreximbank, AfDB, AFC, DRC Government and project developers in the DRC.

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