Value Amidst Transition: Evaluating Strategic Opportunities for Value Addition in the Democratic Republic of Congo

2023 Policy Analysis Exercise Prepared for the World Bank Energy and Extractives Global Practice

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June 2023

M-RCBG Associate Working Paper Series | No. 204

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Value Amidst Transition

Evaluating Strategic Opportunities for Value Addition in the Democratic Republic of Congo

Policy Analysis Exercise Prepared for the World Bank Energy and Extractives Global Practice

Prepared by: Abdurrehman Naveed and Cina Vazir

Submitted in Partial Fulfillment of the Requirements for the Degree of Master in Public Policy
Advised by: Celestin Monga
Submitted on: April 4, 2023
Graduation Date: May 25, 2023

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Acknowledgements

This report would not have been possible without the time, support, and perspective of a diverse array of individuals.

First and foremost, we would like to thank Professor John Haigh for his unwavering enthusiasm and guidance over the course of this project.

We are also grateful to Professor Celestin Monga of the Harvard Kennedy School for agreeing to serve as our faculty advisor and to Martin Lokanc and Remi Pelon from the World Bank for their constructive feedback as they helped us develop our central research questions.

The report’s findings and insights were heavily enhanced by interviews with more than 100 individuals who offered an invaluable range of expertise, perspectives, and ideas. We have kept the identities of interviewees anonymous, but a list of consulted organizations can be found in Appendix B.

Interpreting and fully appreciating the complex social, political, and economic dynamics of the DRC is no easy task. For this, we are especially indebted to the various acquaintances, new and old, who helped us understand and navigate the DRC, both in a figurative and literal sense.

Lastly, we would like to express our gratitude to Harvard’s Mossavar-Rahmani Center for Business and Government and the Environment and Natural Resources Program for providing us with financial assistance to conduct research in Kinshasa and Lubumbashi.

Despite the support we have received, the views expressed in the pages below are ours alone.
Executive Summary

This report focuses on opportunities for the Democratic Republic of Congo to pursue value addition in its cobalt, copper, lithium, tin, and zinc value chains. Analysis centers on four areas — existing constraints, potential options, evaluation of options, and policy recommendations. More broadly, the report seeks to provide decision makers in the DRC and multilateral institutions with a framework for approaching value addition over the next decade.

The DRC’s relationship with global markets has historically centered around extraction. From ivory, rubber, and palm oil to copper, coltan, and cobalt, the DRC has consistently supplied the commodities underpinning waves of global industrialization, prosperity, and innovation. Throughout this journey, little value has remained in the hands of the Congolese people.

This has left the DRC in a precarious macroeconomic situation. GDP per capita has declined 60% since 1960 on a constant 2015 USD basis, only 19% of the population has access to electricity, and violent conflict continues to plague the country’s eastern provinces. Meanwhile, the DRC’s continued overdependence on commodities exposes it to fiscal and monetary instability, while an absence of manufacturing capacity poses barriers to industrialization. These challenges are furthered by a rapidly growing population that is demanding a better future.

Value addition may offer a path forward. Within the context of this report, value addition refers to the idea of moving downstream in the value chains of commodities. Value addition could offer the DRC an opportunity to diversify its exports and develop new sources of economic growth by leveraging its existing resources, capabilities, and infrastructure. However,
many countries have found that indiscriminate value addition does not guarantee structural transformation. Value addition must therefore be targeted, built on existing comparative advantages, and evaluated against a wide range of competing economic options.

**As the energy transition accelerates, the DRC faces a strategic window to evaluate its value addition opportunities for “transition minerals”**. The global economy will require tremendous increases in the supply of minerals to meet the goals of the Paris Climate Accords. This presents a strategic opportunity for the DRC, which hosts significant production and/or reserves of cobalt, copper, lithium, tin, and zinc. The DRC has an opportunity to not only benefit from upstream production, but to also develop market share in the rapidly growing midstream and downstream segments of these value chains. The geopolitics of the energy transition, marked by US-China competition, geographic concentration of supply chains, and a quest to lower product emissions, provides the DRC with a key moment of leverage to attract investment further downstream.

**Power, logistics, and governance are the primary constraints for value addition in the DRC.** The country lacks sufficient and reliable access to electricity. In some cases, this drives up costs of production; in others, it blocks the prospects of production entirely. The DRC’s dilapidated transport networks further heighten the time, uncertainty, and costs of business operations. Poor governance underlies all operating constraints, as it weakens provision of public goods, deters responsible investors, and raises risk. Secondary constraints, such as a high cost of capital, an unprepared workforce, and violent conflict, further hinder prospects for value addition.

**Nevertheless, the DRC possesses three potentially attractive opportunities for value addition — expanding midstream capacity, producing battery precursor material, and manufacturing copper products.** The first option — expanding midstream capacity — entails developing smelting and/or refining capacity for cobalt, copper, lithium, tin, and zinc. The DRC’s second option is to produce NMC precursors, an intermediate material used in lithium-ion batteries. Scaling manufacturing of copper products, including rods, wires, and cables, is the third identified option for value addition.

**Policymakers can evaluate each option by asking two fundamental questions — is this option feasible and, if so, is it worth it?** Options are deemed feasible in the near, medium, or long term based on the number of factors that would need to change for an option to be successfully implemented, and on the magnitude and likelihood of those changes. Expected benefits are evaluated based on direct macroeconomic benefits, including impact on export earnings and fiscal revenue, potential to facilitate the development of productive capabilities, degree of diversification from commodity volatility, and impact on job creation and wages.
The overarching finding of this report is that the DRC will not transform its economy simply by transforming its minerals; however, value addition does present an interesting set of potential benefits. Expanding midstream operations and producing precursors will help protect the DRC from commodity volatility while offering meaningful sources of export earnings and taxable income. Copper manufacturing, in comparison, will generate lower export earnings, taxable revenue, and financial diversification. However, copper manufacturing is more labor intensive than the other two value addition options, and also offers better prospects for horizontal and vertical linkages. Most importantly, scaling copper manufacturing is found to be feasible in the near term, while precursor production is only feasible in the long term. The prospects for expanding midstream capacity fall somewhere in between, depending on the commodity.

As a result, policymakers should consider prioritizing a strategy to scale manufacturing of copper products. The DRC’s public sector can begin by understanding the needs of the industry and engaging in easy fixes on issues such as tax policy. Policymakers can also work to encourage JVs with foreign companies that are experienced operators and show an appetite to grow their manufacturing footprint in the DRC over the longer term.

Expanding midstream operations will require a more gradual, sequenced strategy. Electricity scarcity is the main constraint for midstream operations in the DRC. Policymakers should respond by drafting standardized frameworks for public-private energy partnerships between SNEL and mining operators. They should also avoid export bans in favor of more carefully crafted incentive structures. Efforts to expand midstream operations must be sequenced, starting with copper and cobalt, before potentially later moving into lithium, tin, and zinc.

Lastly, policymakers should consider reframing precursor production as a long-term vision, not an immediate priority. Precursor production can bring meaningful benefits to the DRC, but it will require significant changes to a multitude of existing constraints. There is also reason to doubt whether precursor production will lead the DRC to lucrative lithium-ion battery manufacturing. The DRC can certainly continue to build a long-term vision and plan to produce precursors. But it would likely be well served to reassess whether precursor production should be a strategic priority, particularly in light of the urgent needs facing the country.
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Introduction

A History of Extraction

Since the DRC’s first interactions with global markets, the relationship has been an uneven one, defined by the exploitation of people and resources to meet the needs of the global consumer. With unrelenting consistency, little value has remained in the hands of the Congolese people.

The extractive relationship between the DRC and the outside world did not begin with crops nor minerals, but with labor. Following Columbus’s discovery of the Americas in the 15th century, an estimated 4-6 million slaves were extracted from modern day Angola and DRC and shipped across the Atlantic, constituting 30-50% of the Transatlantic Slave Trade.¹ As the slave trade ground to a halt, international attention shifted to the Congolese jungles, first for ivory, later for rubber, and then for palm oil.

This history of extraction continued over the next century, only the commodities changed from those above the soil to those below it. When the world needed raw materials to support industrialization, it turned to copper from the mines in Katanga. Congolese uranium was used in the nuclear bombs dropped on Hiroshima and Nagasaki.² Tin, tungsten, and tantalum later flowed onto global markets, meeting demand for consumer electronics and simultaneously

² Swain, Frank. “The forgotten mine that built the atomic bomb.” BBC.
sustaining armed groups in the eastern DRC. Today, the global transition to clean energy has once again created a new rush in the Democratic Republic of Congo, this time for cobalt.

Has the DRC benefited from supplying the world with its raw materials? Despite containing the world’s second largest rainforest, vast hydroelectric potential, 80+ million hectares of arable land, and unparalleled mineral resources, the DRC is the ninth poorest country in the world on a USD per capita basis. The promises of globalization have failed to materialize for the average Congolese. A history of extraction has generated significant value globally, but left little on the table domestically.

Figure 1: Economic, Infrastructure, and Social Indicators, 2021

<table>
<thead>
<tr>
<th>Indicator</th>
<th>DRC</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP per capita (current US$)</td>
<td>$577</td>
<td>$12,237</td>
</tr>
<tr>
<td>Life expectancy at birth (years)</td>
<td>60</td>
<td>72</td>
</tr>
<tr>
<td>Infant mortality rate</td>
<td>6%</td>
<td>3%</td>
</tr>
<tr>
<td>Population using safely managed sanitation services</td>
<td>13%</td>
<td>54%</td>
</tr>
<tr>
<td>Population with access to electricity</td>
<td>19%</td>
<td>90%</td>
</tr>
</tbody>
</table>

5 World Bank. “GDP per capita (current US$).”
6 World Bank.
Macroeconomic Indicators

The DRC’s GDP per capita has declined 60% since 1960 on a constant 2015 USD basis.\(^7\) Despite modest growth over the last two decades, per capita income remains well below the 1970 highs. This contrasts strongly with other regional countries such as Kenya, Uganda, and Rwanda, which have all experienced substantial adjusted GDP growth.

*Figure 2: GDP Per Capita (constant 2015 USD)*\(^8\)

The DRC’s economic struggles are partially linked to its commodity dependence. As of 2020, nearly 80% of the DRC’s export value came from copper and cobalt, while in 2021, exports represented 40% of GDP.\(^9\) In other words, roughly one third of GDP is indexed to copper and cobalt LME prices.\(^10\) Export dependence exposes the DRC’s economy to volatility and instability from commodity boom-bust cycles.

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\(^8\) Ibid.
Economic literature overwhelmingly demonstrates the negative effects of export instability on long-run growth. An unstable export basket can lead to fiscal deficits, exchange rate volatility, currency crises, and the decline in non-commodity tradables. Export diversification, meanwhile, is shown to drive higher economic growth and structural transformation.

The DRC’s export concentration exemplifies the country’s broader struggle to industrialize and produce goods at internationally competitive prices. Although 20% of the DRC’s GDP comes from manufacturing, 85% of manufacturing is concentrated in the food and drink sector. Most other manufacturing activities have been forced to close due to an uncompetitive business climate and unsustainable operating costs. Costs of production limit export competitiveness, with manufacturing accounting for just 3% of the DRC’s total exports.

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16 Ibid.
Value Addition — what and why

Value addition, also known in economic literature as beneficiation or vertical diversification, refers to the process of moving downstream from current production.

Developing countries frequently pursue value addition to escape volatile commodity cycles by producing a more diversified basket of products. Value addition is also pursued as a route to access lucrative downstream industries, and often represents a source of national pride with anti-colonial underpinnings. Value addition offers further advantages in terms of supply chain resilience, reduced trade costs, and lower GHG emissions from transport.

However, value addition is not without its critics. A competing strand of economic thought posits that the best opportunities for economic diversification are not exploited by vertical integration, but rather by movement into sectors that require a similar set of capabilities and skills to those that already exist in a country’s economy.17

This view, undergirded by economic complexity analysis, has aimed to empirically demonstrate that potential vertical linkages have little effect on structural transformation.18 Downstream linkages may require a different set of capabilities than those that already exist within an economy. Economic complexity analysis asserts that moving into “lateral” industries with similar technological requirements, factor intensities, and capabilities can provide a more effective route to complex production and exports.19 Proponents of this approach argue that it explains why broad value addition initiatives, ranging from regional initiatives in the African Union to domestic agendas in Namibia, have had few notable results.20

What are the implications for the DRC? Although policymakers in Kinshasa are correct to stress the benefits of value addition, they must also be aware of its limitations. The DRC must not pursue value addition indiscriminately. Rather, policymakers should seek to pursue opportunities where the capabilities required to move downstream are similar to the capabilities that already exist within the country’s economy.

18 Hausmann, Ricardo; Klinger, Bailey; and Lawrence, Robert. “Examining Beneficiation.” *Center for International Development at Harvard University.*
19 Hausmann, Ricardo; Santos, Miguel Angel; Barrios, Douglas; Taniparti, Nikita; Pye, Jorge Tudela; and Lie, Jessi. “The Economic Complexity of Namibia: A Roadmap for Productive Diversification.” *Center for International Development at Harvard University.*
20 Ibid.
Why Now?

The energy transition and a shifting geopolitical landscape present the DRC with a strategic window to evaluate if, where, and how it can move downstream in a way that is both feasible and worthwhile for long-run economic growth.

A minerals intensive future

The future will be more mineral intensive than the past. As the world seeks to meet the objectives of the Paris Climate Accords, it will require enormous quantities of minerals, including cobalt, copper, cobalt, tin, and zinc. Current supply of these minerals is insufficient to meet projected demand, while efforts to scale supply confront various obstacles, from long lead times to declining ore grades.

Figure 4: Growth in Portion of Demand Coming Specifically from Clean Energy Technologies (IEA Sustainable Development Scenario, 2040 relative to 2020, 2020 = 1)

Rampantly growing demand and slowly moving supply will create larger markets for upstream producers. However, the most attractive opportunities may be found in the midstream and downstream segments of supply chains. For example, lithium-ion batteries are projected to become a $400 billion market opportunity by 2030. Of those revenues, only 9% will be generated from mining, with the remaining 91% taking place further downstream.

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21 Hund, Kirsten; La Porta, Daniele; Fabregas, Thao; Laing, Tim; Drexhage, Don. “Minerals for Climate Action.” World Bank.


These dynamics present a unique opportunity. The DRC possesses significant reserves of cobalt, copper, lithium, tin, and zinc that are ready for production. As demand accelerates, moving into midstream operations could provide the DRC with a larger slice of a growing pie. Moving further downstream into manufacturing may offer significant commercial opportunities for government revenue, export diversification, and growth into new industries. But the window of opportunity is narrow. Economies of scale will make it increasingly difficult to gain a foothold in key segments of value chains. Recycling, meanwhile, will gradually remove demand from the market. First movers will have an advantage in capturing value from the energy transition.

A new geopolitical environment

The concentration of mineral supply chains, against a backdrop of US-China tensions and competition for clean energy markets, has given birth to a new era of mineral geopolitics.

The reserves and production of critical minerals are more geographically concentrated than those of oil and natural gas. For example, the three top producers of oil supplied 42% of the global

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24 Ibid.
market in 2021, while in 2022 the three top producers of lithium and cobalt produced 78% and 92% of global supply, respectively. With cobalt, the DRC alone produced 68% of global supply. The concentration of mineral production is striking when considering the geopolitical influence wielded by fossil fuel producers over the last half century. Upstream mineral producers, like fossil fuel producers decades ago, are discovering that resource endowments provide increased leverage and opportunities to attract investment in downstream industries.

**Figure 6: Market Share of the Three Largest Upstream Producers, 2021 (oil and natural gas) and 2022 (minerals)**

- Oil: 42%
- Dry natural gas: 47%
- Copper: 44%
- Zinc: 53%
- Nickel: 63%
- Tin: 65%
- Manganese: 76%
- Cobalt: 78%
- Rare earth elements: 90%
- Lithium: 92%

This has certainly been the case in Indonesia, which supplied 48% of global nickel in 2022. Indonesia’s dominant position in the nickel market provided it with sufficient negotiating power to ban the exports of raw materials. The response has been relatively successful. In 2022 alone, China invested $3.2b in the Indonesian nickel-producing islands of Sulawesi and Halmahera. Although the majority of initial investment was focused on nickel refining, recent investments have been made in cell manufacturing. Indonesia’s nickel resources and proximity to China rendered value addition a viable national strategy.

Other countries have been less successful in exerting resource leverage. Bolivia, for example, has the world’s largest lithium reserves but no production, in part due to policies aimed at mandating local battery production and ownership requirements. Chile also failed in its efforts to establish

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27 Ibid.
30 Ho, Yudith and Listiyorini, Eko. “Chinese Companies are Flocking to Indonesia for its Nickel.” Bloomberg.
a battery value chain, despite being the world’s second largest lithium producer. Nonetheless, concentrated markets are undoubtedly providing suppliers with increased negotiating power and the ability to attract foreign direct investment.

Suppliers’ efforts to pursue value addition are further strengthened by the concentration of midstream operations in China, which controls more than 50% of the market for the processing and refining of critical minerals such as lithium, cobalt, and graphite. Market concentration continues further down the value chain. In battery manufacturing, for example, China holds more than 75% of global production.

![Figure 7: China’s Share of Capacity in Critical Mineral Processing and Battery Manufacturing, 2021 (as a percent of total global capacity)](image)

As geopolitical competition intensifies, Chinese dominance of midstream and downstream supply chains will grow increasingly consequential. The Minerals Security Partnership (MSP), established by the United States in 2022, provides a recent example of Western efforts to secure supply of critical minerals and diversify markets. Notably, the MSP contains a strong emphasis on supporting value addition in partner countries. The MSP framework is just one example of increasing international interest in diversifying markets and reducing carbon emissions.

The globalized economic order of the past decades, fueled by specialization, complex supply chains, and falling costs of trade, is beginning to give way. Emerging in its place is an increasingly fragmented world, marked by the importance of resilient supply chains.

While these international dynamics pose problems for the DRC’s mining sector, they also generate renewed attention and interest for domestic value addition. As a strategic global supplier, the DRC can attract investment in domestic value chains through two levers. First, the DRC can pragmatically navigate geopolitical tensions, exchanging offtake agreements for

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32 Sherwood, Dan. “How lithium-rich Chile botched a plan to attract battery makers.” Reuters.
33 International Energy Association. “Energy Technology Perspectives 2023.”
34 Ibid.
downstream investment. Second, the DRC can appeal to the international community’s vision to support social development, develop processing capacity outside of China, and lower net emissions.
Moving Forward

An accelerating energy transition and new geopolitical environment, when paired with a history of extraction, precarious macroeconomic indicators, and the benefits of vertical diversification, present a compelling narrative for the DRC to pursue targeted value addition.

Various policymakers interviewed for this report stated that the DRC’s government, due to the litany of pressing challenges facing the country, should view everything as a priority. Economic theory and practice advise otherwise. The DRC’s national budget for 2023 is $16b USD. To put that figure into perspective, it is less than 0.3% of the US national budget. Nonetheless, the DRC’s government is tasked with providing essential services to a population of more than 95 million, while combating a civil war on its eastern border. Prioritization is not just essential; it is mandatory. This report seeks to analyze the options for value addition within this context.

The following sections will focus on the potential for value addition in five value chains: cobalt, copper, lithium, tin, and zinc. These value chains have been selected due to their important role in the energy transition and their prospects for industrial production in the DRC. Although the DRC contains sizable resources of other minerals, those value chains are excluded from this analysis either because of their minimal role in the energy transition or lack of concrete prospects for near-term industrial production.

The next section outlines the primary constraints for value addition in the DRC, followed by sections that map potential opportunities, provide criteria for evaluating those opportunities, and analyze how the opportunities compare against the stated criteria. The report then concludes with relevant policy recommendations.

35 Interview
36 Reuters. “Congo increases budget 46% for 2023, boosted by taxes.”
37 Congressional Budget Office. “The Budget and Economic Outlook: 2023 to 2033.”
Key Constraints for Value Addition

Power

Electricity generation mix and infrastructure

The DRC relies on hydroelectric power for almost all of its electricity generation. The installed capacity of the public operator, SNEL, consists of 15 hydroelectric power plants with 2,581 MW of installed capacity and 30 thermal units with an installed capacity of 28 MW.\textsuperscript{38} The Inga 1 and Inga 2 dams provide the bulk of this hydropower, although both currently operate at half capacity due to a severe lack of maintenance. Furthermore, total available capacity is estimated at 1,444 MW, which is only 55% of the total installed capacity.\textsuperscript{39} This becomes all the more jarring when juxtaposed with peak demand, which can reach 4,000 MW.

\textit{Figure 8: DRC Electricity Generation by Source, 2020 (GWh)}\textsuperscript{40}

\footnotesize
\textsuperscript{38} International Finance Corporation. “Creating Markets in the Democratic Republic of Congo.”
\textsuperscript{39} Ibid.
\textsuperscript{40} International Energy Association. “Democratic Republic of the Congo data explorer.”
Although SNEL’s electricity transmission possesses 6,771 kilometers of high-voltage lines and is generally in good condition, the country’s distribution networks are limited and in dilapidated condition. As a result, power in many regions is supplied by isolated grids.

The extractive industries in the ex-Katanga province depend on electricity imported from Zambia through the DRC-Zambia interconnector, which is a 220-kilovolt line between Kasumbalesa and Luano. SNEL also imports some electricity from Uganda.

Energy poverty

Electrification in the country is currently extremely limited, with the electrification rate estimated at 15-20%. Electricity access remains concentrated around cities and urban centers.

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42 Ibid.
The DRC’s electricity consumption per capita is also amongst the lowest in Africa and the world.

43 Ibid.
Figure 11: Annual Electricity Consumption per Capita, 2017 (kWh)\textsuperscript{44}

<table>
<thead>
<tr>
<th>Region</th>
<th>Consumption</th>
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<td>South Africa</td>
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<tr>
<td>Zimbabwe</td>
<td>510</td>
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<tr>
<td>Angola</td>
<td>346</td>
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<tr>
<td>Ghana</td>
<td>320</td>
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<tr>
<td>Sub-Saharan Africa</td>
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<td>Kenya</td>
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<td>Nigeria</td>
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<tr>
<td>Tanzania</td>
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<td>94</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>85</td>
</tr>
</tbody>
</table>

Electricity’s impact on costs of production

Access to sufficient and reliable power has been a perennial challenge for the DRC.

Power shortages and intermittency force manufacturing firms to source half of their electricity through generators, with electricity costing up to $1 USD per kWh. Intermittency also disrupts manufacturing output and increases production costs. Studies suggest that manufacturing firms lose 11% of their annual sales due to intermittency.\textsuperscript{45}

These findings are corroborated by interviews conducted by the authors of this report. A manufacturer in Kinshasa, for example, reported that intermittency adds 14% to its average cost of production.\textsuperscript{46} Purchasing fuel for generators further increases cost, as indicated by a mining operator which reported that using generators during periods of intermittency raises its electricity costs by 30%.\textsuperscript{47} Businesses that import diesel to fuel their generators are additionally exposed to cost volatility and exogenous risk from regional diesel prices.

One recent study summarizes these challenges by stating that 86% of surveyed businesses in the DRC agree that a lack of reliable electricity prevents their businesses from operating properly.\textsuperscript{48}

\textsuperscript{44} Ibid.
\textsuperscript{45} International Finance Corporation. “Creating Markets in the Democratic Republic of Congo.”
\textsuperscript{46} Interview.
\textsuperscript{47} Interview.
The immense potential of renewable energy

The DRC has the potential to become one of the world’s largest hydropower producers, but currently utilizes only 2.5% of its hydro potential. The country is estimated to have hydrological potential of around 100 GW, most of which is concentrated in the Bas Congo region. Vast swathes of the country also have high solar potential. Significant solar potential is located in the areas of the highest unmet demand, such as the country’s southwestern region. Although efforts are being made to improve generation capacity, particularly through new public-private partnerships, progress has been slow. It will likely take decades for the DRC to realize its full energy potential.

Figure 12: Hydropower Resources of the DRC, 2012 (Source: World Bank)
Figure 13: Photovoltaic Electricity Potential of the DRC, GHI, kWh/m2 (Source: World Bank)\textsuperscript{51}

\textsuperscript{51} Ibid.
Logistics

Generational underinvestment in the DRC’s road, rail, and port infrastructure has resulted in the significant dysfunction of its logistic networks. In a country as large as Western Europe, the dilapidated multimodal transport network (rail, road, and water) creates stark urban-rural divides and forces the regional concentration of economic activity.

One of the main access points to the DRC is the Port of Matadi, which serves the Kinshasa and Bas Congo regions and connects with the Congo River transportation network. In addition to the Matadi corridor, the DRC is integrated into regional and global markets by 13 land corridors. Five of these land corridors have outsized importance as they connect geographically dispersed areas with regional and global markets. Due to the DRC’s geography and lack of transport infrastructure, the important regions of ex-Katanga and Kivu do not have access to the DRC’s international seaports and rely on ports in neighboring countries.

The DRC has one of the lowest road network densities in Africa, at 25 km per 1,000 km², in comparison to an average of 204 km per km² for the African continent. Similarly, the DRC has a road network density of 0.9 km per 1,000 inhabitants, in contrast to an average of 3.4 for Africa. Less than 5% of the 58,000 km national road network is paved, and only around 50% is passable. Interconnectivity between various regions of the country is poor, and only six of the 26 provincial capitals can reach Kinshasa by road. These statistics take on greater significance since, in the absence of adequate rail and river infrastructure, more than 90% of freight is transported by road.

It can take up to two weeks to exit Kolwezi and cross the border into Zambia, with mining companies often considering eight days as good time. According to some estimates, it can take as long as 35 days to get from a mine in southern Congo to South Africa’s ports. With copper production in the ex-Katanga region expected to increase by 79% from 2020 to 2025, logistical bottlenecks will prove increasingly problematic.

Transit costs are a major impediment for almost every exporter in the DRC. For example, logistics charges for the Kamoa-Kakula mine in Kolwezi were $0.56 USD per pound of payable copper in Q3 2022. Shipping concentrate from Kolwezi to China therefore represented 39% of the company’s $1.43 USD cash cost per pound of payable copper.

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52 World Bank. “Second High Priority Roads Reopening and Maintenance Project (P161877)”
53 Ibid.
56 Ibid.
The cost of border and documentary compliance is also significantly higher for the DRC than for its regional peers. One study estimates border compliance costs in the DRC to be higher than average costs in Sub-Saharan Africa by a factor of four and documentary compliance costs to be higher by almost a factor of three.58 Tolls, for example, can amount to $900 USD for roundtrip exit and entry on the DRC-Zambia border.59

The Lobito Corridor offers a potential remedy for some of the DRC’s export challenges. The proposed corridor would connect the DRC and Zambia to Angola’s Lobito Port, thus providing the countries with an express connection to the Atlantic Ocean.60 Angola has already undergone significant repairs on its part of the rail connection, and a consortium of Trafigura, Mota-Engil Engenharia e Construcao Africa, and Vecturis SA recently signed a 30-year concession to run cargo operations.61 However, the project still requires substantial rehabilitation of the DRC’s rail system. If successful, the reopening of the Lobito Corridor could significantly reduce export time and cost for businesses in the ex-Katanga region. Nonetheless, uncertainty still surrounds the project, which has been discussed for more than a decade.62

61 Trafigura. “Concession agreement signed with the Angolan government for rail services and logistics support for the Lobito corridor.”
62 International Conference on the Great Lakes Region. “Lobito Corridor Project (Prefeasibility Study).”
Figure 14: Existing Routes From Copper and Cobalt Mines in Congo and Zambia to Ports (Source: Bloomberg)\textsuperscript{63}

Governance

Corruption in the DRC is deep-rooted and pervasive. The country’s ad-hoc culture of *débrouillez-vous*, translated as “fend for yourself,” has persisted since Mobutu’s reign, when state retrenchment left a vacuum for funding, services, and oversight.64 These challenges are reflected by the DRC’s ranking of 166/180 on the global Corruption Perceptions Index.65

Poor governance and rampant corruption in turn constrain value addition by debilitating infrastructure, discouraging responsible investors, and heightening project uncertainty.

A (dis)enabling environment

Governance challenges span all levels of the DRC’s public sector and damage the country’s business climate. For instance, the Natural Resource Governance Institute’s (NGRI) 2021 Resource Governance Index gave the DRC a score of 17/100 for the enabling environment of its mining sector.66 The DRC was the only country in the study, which takes into account World Governance Indicators in areas such as rule of law, control of corruption, and government effectiveness, to receive a “failing” score for its enabling environment.

*Figure 15: Scores for the Enabling Environment of the DRC’s Mining Sector, 2021 (scores below 30 indicate a “failing” environment)*67

The relationship between poor governance and unfavorable conditions for value addition is further demonstrated by the deterioration of the DRC’s state-owned enterprises.

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64 Hoebeke, Hans; Nyenyezi, Aymar; and Vlassenroot, Koen. “60 years of Congo’s independence: power, complicity and protest.” *London School of Economics.*
67 Ibid.
La Générale des Carrières et des Mines (Gecamines), the DRC’s state-owned mining company, played an essential role in the country during the 1970s and 80s as a contributor to state revenue, employment, and services. Chronic mismanagement and corruption led to the dramatic collapse of Gecamines in the 1990s. In 1988, Gecamines produced 468k tons of copper; by 1994, it was producing only 34k tons. A 94% drop in just six years. Despite continual pledges to regain its former heights, Gecamines produced less than a meager 5k tons of copper in 2022.

The privatization of the DRC’s mining sector, highlighted by the Mining Code of 2002, was largely motivated by the decline and mismanagement of Gecamines. Privatization converted Gecamines into an asset manager and gatekeeper, but governance did not improve.

Between 2010-2012 alone, the DRC lost an estimated $1.36b in revenue from underpriced asset sales. Meanwhile, the revenue that was collected was often misspent, or simply disappeared. Gecamines is estimated to have earned $1.1b in revenue from 2011-2014 from JV partnerships, royalties, and signing bonuses. However, roughly two-thirds of that revenue was improperly registered, and the bulk of it entirely untraceable.

Today, Gecamines continues to struggle with financial reporting, opaque transactions, and unsustainable debt. The corruption and mismanagement of Gecamines has cost the DRC billions in revenue that could otherwise have been reinvested in geological prospecting, production, workforce training, and basic infrastructure.

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69 Natural Resource Governance Institute. “Copper Giants: Lessons from State-Owned Mining Companies in the DRC and Zambia.”
70 Reid, Helen.” Congo’s Gecamines seeks to diversify into ‘transition’ minerals.” Reuters.
73 Carter Center. “A State Affair: Privatizing Congo’s Copper Sector.”
A similar story has played out with Société Nationale d'Electricité (SNEL), the DRC’s national utility company. The World Bank notes that SNEL “has been unable to provide reliable power supply or improve stagnating access figures due to its poor financial health, operational inefficiencies, and governance issues.”

Other examples abound. For example, the logistics challenges outlined earlier are largely tied to Société Nationale des chemins de fer du Congo (SNCC), the DRC’s railway company, which suffers from corruption, political interference, and chronic underinvestment.

Therefore, any viable value addition strategy must account for a state that faces enormous challenges and has historically struggled to offer basic inputs, coordinate moving parts, and ensure predictable delivery.

**Barriers to diversified and responsible investment**

Various interviewees in this report indicated that it is nearly impossible to operate a business in the DRC without encountering corruption. Entrenched state corruption is a barrier for responsible businesses and investors, particularly as the global ESG movement gains steam and compels companies to reconsider how social governance can influence their brand, stock price, and access to capital.

These dynamics are apparent in the makeup of the DRC’s cobalt sector. As of 2019, 15 of the 19 largest cobalt mines in the country had full or partial Chinese ownership. China’s growing stake in the DRC’s mining sector is closely tied to Chinese firms’ apathetic stance toward corruption. A Sentry report on the famous Sicomines mines-for-infrastructure deal between the DRC and China, for example, discovered “all the hallmarks of a massive bribery scheme.” Other Chinese operators have been embroiled in similar scandals involving corruption.

Challenges with social governance are not limited to Chinese companies. Israeli businessman Dan Gertler, commodity trader Glencore, and mining company ERG rank among the various

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75 World Bank. “DRC Electricity & Water Access and Governance Project (P173506).”
77 Interviews.
79 Lipton, Eric; Searcey, Dionne; and Forsythe, Michael. “Race to the Future: What to Know About the Frantic Quest for Cobalt.” *New York Times*.
80 The Sentry. “The Backchannel.”
operators in the DRC that have seen their public image tarnished through large social governance and corruption scandals. ⁸²

Corruption in the DRC clears the market for actors that are willing, or forced, to engage in unethical practices. Responsible businesses certainly do exist in the country; however, they face large barriers to operate and succeed. ⁸³ This is a particular constraint for value addition, since manufacturers often have different profiles of branding and risk than seasoned mining companies. Many downstream players, as a result, may be wary of investing in the country.

**Unpredictability and a looming threat of expropriation**

Although the DRC is a notable mining jurisdiction, investors continue to perceive substantial risk of expropriation and rapid regulatory change, limiting inbound investment.

Perceived risk in the country’s mining sector increased following implementation of the 2018 Mining Code, with risk consultancy Maplecroft citing heightened risks of government intervention and extortion. These risks have materialized through blocked commercial asset transfers, threats to take over existing operators, and export bans (see next page). ⁸⁴

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⁸³ U.S. Department of State. “2022 Investment Climate Statements: Democratic Republic of the Congo.”

⁸⁴ Maplecroft. “Resource nationalism rises in 30 countries.”
It is debatable whether the perceived level of expropriation risk is merited. However, a more tangible risk is extortion. Gecamines, for example, has often blocked asset transfers or threatened to shut down mining operations in order to demand further payment.\(^8\) Financial expropriation, using fines, bans, or other extortionary measures to demand additional payment, is common in the DRC.\(^7\) Perceived risk is currently heightened by the government’s forced renegotiations with Sicomines and Tenke Fungurume, in addition to upcoming elections in 2023.

Prospective investors will therefore be wary of entrenched interests that can, at best, result in higher project costs and, at worst, completely derail the path to successful operation.

\(^{85}\) Ibid.

\(^{86}\) Carter Center. “A State Affair: Privatizing Congo’s Copper Sector.”

\(^{87}\) U.S. Department of State. “2022 Investment Climate Statements: Democratic Republic of the Congo.”
Secondary Constraints

In addition to the primary constraints listed above, a high cost of capital, shortage of know-how, and violent conflict further constrain the potential for value addition in the DRC.

The DRC’s tax policy also constrains value addition, with taxes often exorbitant, duplicative, and predatory. However, this report does not view taxation as a core constraint since the tax hurdle can be rapidly overcome through changes to the tax code, selective exonerations, special economic zones, or similar mechanisms. In contrast, the other constraints outlined in this report are entrenched and resistant to near-term change.

Cost of capital

The DRC’s lending rate, which is the bank rate that typically meets short- and medium-term private sector financing needs, was 23% in 2021. That reflects a rate approximately double that of Kenya, three times that of South Africa, and eight times that of the United States.

Figure 18: Lending Interest Rate, 2021 (percent)

<table>
<thead>
<tr>
<th>Country</th>
<th>Rate (%)</th>
</tr>
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<tbody>
<tr>
<td>DRC</td>
<td>23</td>
</tr>
<tr>
<td>Kenya</td>
<td>12</td>
</tr>
<tr>
<td>South Africa</td>
<td>7</td>
</tr>
<tr>
<td>China</td>
<td>4</td>
</tr>
<tr>
<td>United States</td>
<td>3</td>
</tr>
</tbody>
</table>

High interest rates result from the DRC’s poor business climate and underdeveloped financial sector. Consequently, large projects often turn to foreign markets to raise capital. Interviewees in this report indicated that while established companies can sometimes raise capital at 6-12%, it is more common for new projects to raise capital at 15-20%. The situation is made more dire by the recent rise in global interest rates. As monetary tightening continues, the DRC’s lending interest rate will continue to remain elevated. This will pose a barrier for downstream projects.

88 Ibid.
90 Ibid.
91 Privacy Shield Framework. “Congo, Democratic Republic - Financial Sector.”
92 Interview.
Workforce

The DRC’s education system struggles with low coverage and quality, while unemployment and underemployment hinder productive growth.94 Labor productivity in the DRC is among the lowest in the world.95 More importantly, the domestic workforce lacks a diverse range of skills and expertise, severely limiting the country’s ability to move into new industries. This is reflected by the DRC’s inability to export complex products, revealing a low level of know-how and capabilities within the country’s economy.

Figure 19: Economic Complexity Index, 2021 (ranked 1-133)96

<table>
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<tbody>
<tr>
<td>China</td>
<td>46</td>
<td>39</td>
<td>29</td>
<td>24</td>
<td>17</td>
</tr>
<tr>
<td>DRC</td>
<td>122</td>
<td>106</td>
<td>130</td>
<td>126</td>
<td>122</td>
</tr>
<tr>
<td>Kenya</td>
<td>73</td>
<td>91</td>
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<td>76</td>
<td>90</td>
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<tr>
<td>Poland</td>
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</tr>
<tr>
<td>South Africa</td>
<td>47</td>
<td>44</td>
<td>48</td>
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<td>70</td>
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<tr>
<td>United States</td>
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<td>8</td>
<td>12</td>
<td>12</td>
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<tr>
<td>Zambia</td>
<td>91</td>
<td>94</td>
<td>106</td>
<td>105</td>
<td>107</td>
</tr>
</tbody>
</table>

Violent conflict

Efforts to address violent conflict in the eastern DRC consume an enormous amount of public resources, while the conflict itself generates massive economic losses. A 2007 study by Oxfam estimated that the DRC’s lost $18b in GDP from the First and Second Congo Wars.97 Conflicts destabilize a country and place it in a mode of crisis response, distracting focus from long-term,

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97 Oxfam. “Africa’s Missing Billions.”
strategic planning. This explains why few, if any, successful examples of value addition exist in underdeveloped economies that are experiencing armed conflict.

After more than two decades of war and damage to basic infrastructure, few industrial mines operate in the eastern DRC despite sizable resources of gold, tantalum, tungsten, and tin. Industrial production in the region has been further hampered by ties with forced labor. Conflict minerals — labeled as gold, tantalum, tungsten, and tin — are produced in hundreds of artisanal mines, often operated by armed groups with ties to Uganda and Rwanda.\footnote{United States Government Accountability Office. “Conflict Minerals.”} A strategy to process and market that supply will face significant logistical, commercial, and ethical hurdles.
Options for Value Addition

Despite its various constraints, the DRC possesses interesting pathways for value addition in the cobalt, copper, lithium, tin, and zinc value chains. Three opportunities merit further examination based on their prospective feasibility and benefits.

The first opportunity is to increase the DRC’s capacity to refine minerals that are mined domestically. Although the exact steps and feasibility are different for each mineral, the opportunity applies across all five value chains included in this study.

The second opportunity is to produce precursor material (often referred to as pCAM) for lithium-ion batteries. Battery precursors are one of several intermediary steps between raw material production and a fully-assembled lithium-ion battery.

The third opportunity is to scale the manufacturing of copper products, including rods, wires, and cables. Although nascent operations exist, this strategy would seek to scale domestic manufacturing capacity and encourage long-term spillovers into other types of manufacturing.

The following sections explore each option in more detail. A general overview of mineral value chains can be found in Appendix C.
Expanding Midstream Capacity

The *Expanding Midstream Capacity* option focuses on expanding the DRC’s capacity for mineral smelting and refining. The specific midstream opportunity is distinct for each mineral.

**Cobalt**

The DRC produced an estimated 130,000 tons of contained cobalt in 2022, equating to 68% of global supply. Cobalt from the DRC is predominantly exported as cobalt hydroxide. The DRC’s cobalt hydroxide typically travels to China, where it is refined into cobalt chemical or metal products. Cobalt chemicals are the fastest growing segment of cobalt refining, driven by demand for batteries, which accounted for 65% of total cobalt demand in 2021.

The DRC does not currently refine notable quantities of cobalt, either as a chemical or metal. However, the country was one of the world’s foremost cobalt refiners (mostly metal) from 1950-1990. The DRC’s domestic refining peaked at 17,600 tons in 1974. After that, cobalt refining, which often requires more energy than mining, was constrained by insufficient and unreliable electrical power. From 1990-93, civil unrest and looting, inflation, and input shortages decimated domestic cobalt refining, reducing output from 10,000 tons in 1990 to 800 tons in 1993. The DRC’s refining industry never recovered, and was gradually replaced by the rise of Chinese refineries.

Within the cobalt value chain, the midstream opportunity lies in increasing domestic cobalt metal or chemical refining capacity.

**Copper**

In 2022, the DRC produced 2,200 kt of contained copper, placing it within the world’s top five producers and generating the bulk of the DRC’s export revenue. Refined copper accounted for 1,700 kt, or 77%, of the DRC’s copper exports in 2022. Refined copper in the DRC typically takes the form of copper cathode with a purity of 99.995%. The DRC has significant refining capacity compared to Chile and Peru, historically the world’s two largest copper producers.

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100 Gulley, Andrew. “One hundred years of cobalt production in the Democratic Republic of the Congo.” Resources Policy.
102 Ibid.
104 United State Geological Survey. “Copper.”
105 Ibid.
Within the copper value chain, the midstream opportunity is to export all copper as refined products. Currently, 500 kt of contained copper is exported as concentrate. A portion of this supply could be refined domestically through the successful buildout and operation of the Kamosa-Kakula smelter.\textsuperscript{107} However, ensuring all exports take the form of copper cathode would require the development of new projects to meet planned increases in domestic mine production.

\textit{Figure 20: Refinery Production as a Percent of Total Copper Production for top Five Mining Countries, 2022}\textsuperscript{108}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure20.png}
\caption{Refinery Production as a Percent of Total Copper Production for top Five Mining Countries, 2022.}
\end{figure}

\textbf{Lithium}

Although the DRC does not currently produce lithium, the Manono project could become one of the world’s largest hardrock lithium mines.\textsuperscript{109} The mine is expected to produce 700,000 tons per annum (tpa) of lithium spodumene concentrate and 46,000 tpa of lithium sulfate.\textsuperscript{110}

The next step in the value chain is for lithium sulfate to be refined into lithium hydroxide. Lithium hydroxide or carbonate are the final form of lithium used in lithium-ion batteries.

\begin{flushright}
\textsuperscript{107} Ivanhoe Mines. “Progress Update: June 2, 2021.”
\textsuperscript{108} United State Geological Survey. “Copper.”
\textsuperscript{109} AVZ Minerals. “Manono Project.”
\textsuperscript{110} AVZ Minerals. “AVZ Delivers Highly Positive Definitive Feasibility Study for Manono Lithium and Tin Project.”
\end{flushright}
According to AVZ Minerals, the majority stakeholder of the Manono Lithium and Tin Operations (MLTO), the project plans to export both lithium spodumene concentrate and lithium sulfate. It has also considered entering lithium hydroxide production at a later point:

“AVZ’s assessment is that producing Lithium Hydroxide from day one would be a challenge and that starting out along an incremental product production route would be a better fit for the MLTO organisation, which is a start-up mining operation. AVZ is not averse to revisiting the opportunity of producing Lithium Hydroxide once the MLTO is stabilised and operating in the DRC.”

As such, the DRC’s midstream value addition option for lithium is to scale production of lithium sulfate and/or push commencement of lithium hydroxide production.

**Tin**

According to USGS, the DRC produced 20 kt of contained tin in 2022, approximately 7% of global supply. The DRC’s Ministry of Mines estimates that 74% of the DRC’s tin supply is produced industrially, with the remainder produced from artisanal mining. Over half of the DRC’s tin production comes from Alphamin’s Bisie tin mine in the eastern DRC, which produced 12,493 tonnes of contained tin in 2022.

Tin is primarily exported as concentrate, although mining company MMR currently operates a small tin smelter. The DRC’s value addition option in the tin value chain is to focus on developing smelting capacity. Since artisanal production is largely off limits, tin smelting would focus on industrial production. This would require building a tin smelter in the eastern DRC close to the Bisie tin mine. An alternative would be to build a smelter to service the Manono mine, which, in addition to lithium, expects to annually produce approximately 3.6 kt of tin.

**Zinc**

The DRC produced around 14 kt of zinc in 2022, only 0.1% of global supply. However, the Kipushi project, operated by Ivanhoe mines in a JV with Gecamines, is expected to annually produce...
produce 3,294 kt of contained zinc.\textsuperscript{118} The Kipushi project is currently in construction, with target production in Q4 of 2024.\textsuperscript{119} The mine is located in the town of Kipushi, slightly southwest of Lubumbashi. Kipushi is currently planning to process zinc ore and export zinc concentrate.\textsuperscript{120}

A midstream value addition strategy for zinc would involve building zinc smelter capacity to service Kipushi’s zinc concentrate.

\textit{Figure 21: Summary of Midstream Value Addition Opportunities}

\begin{tabular}{|c|c|c|c|c|}
\hline
\textbf{Cobalt} & \textbf{Copper} & \textbf{Lithium} & \textbf{Tin} & \textbf{Zinc} \\
\hline
Build chemical or metal refining capacity & Ensure all exports take form of refined copper & Expand sulfate capacity and refine hydroxide & Build industrial level smelting capacity & Develop smelting capacity \\
\hline
\end{tabular}

\textsuperscript{118} Ivanhoe Mines. “Kipushi Feasibility Study.”
\textsuperscript{119} Bloomberg. “Ivanhoe and Gécamines Host Ceremony Commemorating the Start of Construction Activities at the Historic Kipushi Mine.”
\textsuperscript{120} Ivanhoe Mines. “Kipushi Feasibility Study.”
Producing Battery Precursor Material

There is a growing conviction that the DRC has an opportunity and right to a greater share of the economic benefits from the electric vehicle (EV) value chain. Global EV sales are forecast to surpass 70 million units by 2040. The DRC, despite playing an essential role in EV production through the supply of mined cobalt, only participates in the very first stage of the supply chain.

The cobalt found in EVs is primarily used within its lithium-ion batteries, which constitute 30-40% of an EVs total cost. The demand for lithium-ion batteries is projected to rise sixfold by 2030, reaching 4.7 TWh and providing annual revenue opportunities of $400b USD.

Lithium-ion batteries consist of four primary components: cathodes, anodes, electrolytes, and separators. Although battery chemistries are rapidly evolving, the market is currently dominated by NMC and LFP batteries. The name of the battery denotes the type of cathode material it uses: NMC batteries use a mix of nickel, manganese, and cobalt, while LFP batteries use a mix of lithium, iron, and phosphate.

A precursor, also referred to as pCAM (pre-cathode active material), is an input to the cathode active material (CAM) that is used in lithium-ion batteries. The main raw materials that are required to produce an NMC precursor are nickel, cobalt, and manganese. These minerals first undergo processing and refining to be converted from ore to sulfate. Once nickel, manganese, and cobalt sulfate are procured, the precursor production process can commence.

The value addition opportunity identified in this report is the production of NMC precursor material. An NMC battery chemistry is selected since it relies on cobalt and will likely retain a significant market share, with sizable growth potential, over the next five years.

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121 Goldman Sachs. “Electric vehicles are forecast to be half of global car sales by 2035.”
122 U.S. Department of Energy. “Reducing Reliance on Cobalt for Lithium-ion Batteries.”
125 Samsung. “The Four Components of a Li-ion Battery.”
Figure 22: Flowsheet of Precursor Production Process (Source: BloombergNEF)\textsuperscript{126}

\textsuperscript{126} BloombergNEF. “The Cost of Producing Battery Precursors in the DRC.”
Manufacturing Copper Products

The third value addition option for the DRC would entail the development of copper-based manufacturing in the ex-Katanga region, with a focus on transforming the region into a manufacturing cluster with a local concentration of similar or complementary industries. In this option, the region would specialize in the production of electrical products, starting from copper wires, cables and other semis and eventually move into products such as motors and transformers. In addition to increasing the breadth of manufacturing capabilities by product, firms could also specialize in more complex and sophisticated products within a product category. For instance, firms could develop their manufacturing capabilities to move from low-voltage cable production to medium- and high-voltage cables. Firms could also develop cables that are optimized for signal transmission and other advanced industrial use cases.

Figure 23: Copper Value Chain

Wire rod is the most important copper product, accounting for more than 60% of copper usage. Some wire rod manufacturers are vertically integrated, with their own smelting and refining operations, while other manufacturers purchase copper cathode and scrap from the market.

Copper rods are then used by cable companies to make wires and cables. Cable companies can be vertically integrated or operate independently. The production capacity of most cabling facilities is between 1,000 tons to 15,000 tons per year.

Other key copper products include strips, tubes, and bars, which account for 30% of the copper market. These products are also known as “semis” due to their semi-manufactured nature. While copper derived from scrap only accounts for a small percentage of the inputs in wire rods, around 50% of the copper used in making semis is derived from scrap. With semis, there is large

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127 Guidehouse. “Economic Clusters: Four Design Principles for Success.”
129 Ibid.
130 Ibid.
variation in geometries, alloy composition, and qualities and hence little standardization, which is quite different from the wire rod market. Semis manufacturing also has a longer lead time.\textsuperscript{131}

Copper wire can be segmented based on its application, such as its use in power transmission and distribution, telecommunications, and as building wire. At its core, copper wire has two main use cases: electrical power transmission and signal transmission.

The DRC has a nascent copper product manufacturing industry with only two players. One of those players, Proton, which is based in Kinshasa and is a family-owned business operating across different industries, has manufactured copper cables in DRC under the brand CABELEC since 2004.\textsuperscript{132} Proton has an installed capacity of 3,000 tons per year and manufactures a range of low-voltage wires and cables.\textsuperscript{133}

The other player, Mining Engineering Services (MES)\textsuperscript{134}, is also a family-owned business based in Lubumbashi and operates primarily as an EPC contractor and solutions provider to the mining sector.\textsuperscript{135} MES also has various subsidiaries operating in mining and piping, and launched a copper rod and cable manufacturing facility under the brand Congo Cables in January 2023. The facility is in the process of commencing operations, with an installed capacity of 4,200 tons of copper products per year.\textsuperscript{136} MES plans to supply the domestic market for copper wires, cables and other semis, with longer term ambitions for regional exports. It currently has capabilities to manufacture low-voltage cables and intends to expand into medium- and high-voltage cables as its operations scale.

Both Proton and MES primarily use copper scrap, as most virgin copper cathode supplies are locked in offtake agreements. Furthermore, copper cathode suppliers are reluctant to service the small volumes that are currently required by these manufacturers. Given its manufacturing base in Kinshasa, another complicating factor for Proton is its distance from the ex-Katanga region, which is the main copper production belt in the DRC. Kinshasa and the ex-Katanga province are commercially disconnected for freight transport purposes, with little road connectivity, inadequate rail infrastructure, and no river or sea-borne transport. This limits the potential to competitively supply copper cathode from the ex-Katanga region to copper manufacturers in Kinshasa and Bas Congo, necessitating the need for ex-Katanga based cluster approach.

\textsuperscript{131} Ibid.
\textsuperscript{132} Groupe Rawji. “Overview”
\textsuperscript{133} Groupe Rawji. “Electrical Services.”
\textsuperscript{134} DRC Mining Week.
\textsuperscript{135} Mining Engineering Services. “Download Center.”
\textsuperscript{136} Interview.
Evaluation Criteria

Assessing the various options for value addition involves two fundamental questions:

1. Is the option feasible?
2. Is it the option worth undertaking based on its expected benefits?

Five criteria are used to measure these two overarching questions. These criteria are intended to provide decision makers with a sense of clarity as they prioritize the various strategic options vying for their attention.

Feasibility

Feasibility given the set of existing constraints

The DRC’s existing constraints can significantly impede the implementation of value addition. It is therefore critical to assess how dependent each option is on a change to the country’s constraints. A value addition strategy that demands less fiscal resources, leverages existing capabilities, and succeeds despite existing constraints is more feasible than a strategy that requires substantial changes.

Feasibility is assessed based on how many factors would need to change for an option to be successfully implemented, and on the magnitude and likelihood of those changes. Options are deemed feasible in the near term (1-2 year), medium term (3-4 years), or long term (5-10 years).

Benefits

Four criteria are used to assess the benefits of the value addition options. Each criteria is scored as low, medium, or high. Scores denote the following:

- **Low** — little or no change from existing economic activity
- **Medium** — generates improvement, but will likely not create a sizeable difference
- **High** — has the potential to generate a significant and perhaps groundbreaking impact
**Direct macroeconomic benefit through fiscal revenue and export earnings**

Value chains that require limited government support and create robust fiscal revenue are more advantageous than value chains which require sustained subsidies, tax holidays, and other forms of public concessions. Furthermore, options which boost the total value of exports are important for a country’s current account stability, especially in the absence of capital account flows.

Given the importance of the national budget and monetary stability, options are evaluated based on their potential to directly increase the DRC’s fiscal revenue and export earnings.

**Development of productive capabilities**

Countries often attain long-term economic growth by diversifying into products and services with increasingly complex production processes.\(^{137}\) This type of diversification is more successful when countries move into products that build on existing capabilities and use know-how that is embedded within the domestic economy.\(^{138}\) Countries can pursue structural transformation by developing products that enable future linkages to high-complexity products and open opportunities for continued diversification.

The options for value addition are assessed on their potential to enable linkages to other types of products, particularly those that involve more complex production processes.

**Financial diversification**

While commodity reliance stimulates growth during boom cycles, it exposes countries to macroeconomic instability during inevitable bust cycles. Diversifying away exposure to exogenous shocks reduces economic volatility, therefore helping to maintain the predictable fiscal and monetary policies that are required for long-term economic growth.

Options are evaluated based on the estimated sensitivity of expected revenues and profits to the change in price of the underlying commodity. In other words, can value addition help the DRC’s economy diversify away the volatility associated with commodity boom-bust cycles?

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**Labor intensity and wages**

Employment is a strategic priority in the DRC given the country’s rapidly growing young population (see Appendix D) and struggle with unemployment, low wages, and labor informality. It is therefore important to assess the impact of each option value on job creation and wages.

Labor intensity and median wages are used to assess how the different options compare in terms of the number of jobs created and compensation. The measures assume each option can be scaled over time and exclude benefits from construction and ancillary service provision. Resulting estimates of labor intensity and wages are benchmarked against the mining sector.

**A Note on Greenhouse Gas Emissions**

An assessment of greenhouse gas (GHG) emission reductions is beyond the scope of this report, but it is important to note that all three value addition options will achieve significant reductions in GHG emissions due to the DRC’s clean grid and reduced transit requirements. Further analysis can be found in Appendix E.
Scoring the Value Addition Options

Expanding Midstream Operations

Feasibility — Medium term

Smelting and refining are energy-intensive operations. It is estimated that an average zinc smelter, for example, uses more than twice as much energy as zinc mining and concentration.\(^\text{139}\) Midstream electricity demand varies depending on commodity, production process, and technology. However, for all of the minerals analyzed in this report, smelting and refining requires a significant supply of electricity.

The International Energy Association’s data on GHG emission intensity serve as a crude proxy for comparing the electricity requirements of mining and processing. As shown below, smelters and refineries often have even higher GHG emissions than mining.

*Figure 24: Average Tons of CO2-equivalent Emissions per ton of Metal Content Production*\(^\text{140}\)

\(^{139}\) Genderson, Eric Van; Wildnauer, Maggie; Santero, Nick; and Sidi, Nadir. “A global life cycle assessment for primary zinc production.” The International Journal of Life Cycle Assessment.

\(^{140}\) International Energy Association. “Average GHG emissions intensity for production of selected commodities.”
The DRC already faces a substantial mismatch between domestic electricity supply and demand. Expanding midstream capacity will widen the deficit. Reliability will also prove problematic, as energy is often a major operating cost for smelters and refineries. Businesses that are forced to power operations with backup diesel generators will experience painful increases in operating cost. Backup generators are also often insufficient to properly operate a large smelter or refinery, resulting in a double blow from decreased output and damage to expensive equipment.

Recent experience in the mining sector shows that companies will likely have to step forward to construct their own energy infrastructure. The Kamoa-Kakula and Manono projects are examples of companies investing in infrastructure rehabilitation and development to secure sufficient access to power. Scaling these initiatives will require capital, time, and complex public-private coordination. Within that context, a holistic strategy to substantially expand the DRC’s midstream operations is likely only feasible in the medium term.

Few other constraints stand in the way of expanding midstream operations.

Exporting refined products in place of concentrate will help remedy the country’s logistical challenges by reducing the total tonnage of transported material. The DRC’s workforce can also leverage its know-how in materials science and midstream operations to rapidly learn how to operate other types of smelters and refineries. Corruption and cost of capital will present barriers, but existing operations show that these hurdles can be overcome. Violent conflict, meanwhile, is only a major roadblock for the tin value chain.

With that said, sequencing will prove important for midstream expansion, as value addition is not equally feasible in all five value chains.

Copper smelting and refining is likely the nearest option for expansion given the DRC’s existing refining capabilities and the concentration of activity in the ex-Katanga province. Cobalt refining, despite its energy intensity, may be the second closest option for similar reasons: geography, prior experience, and existing upstream production.

Lithium, tin, and zinc will likely have to wait longer. The Bisie tin mine recently entered production and is focused on attaining financial stability and peak output. It already struggles with electricity and operates largely off diesel. Industrial lithium and zinc projects, meanwhile, are yet to come online. All three value chains will likely first need to reach steady production before private operators look further downstream.

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141 Interview.
**Direct macroeconomic benefits — Medium**

The financial characteristics of smelters and refineries can vary substantially based on the commodity, efficiency, market dynamics, and type of technological process. A broad overview of typical smelter and refinery revenue streams can be found in *Appendix F*.

Despite the large level of variability, policymakers can gain an idea of the direct macroeconomic benefits of midstream operations by examining existing and planned facilities. In the table below, publicly available data from five midstream facilities are provided. For three of these operations, the indicated cash margin positioning provides a comparison of the operation’s cost competitiveness relative to the rest of the industry. Cash margin positioning is not available for GEM Co. (cobalt) and Malaysia Smelting Corporation (tin), although both are assumed to be competitive due to large operations and location in countries with low wages, relaxed environmental regulations, and existing know-how.
Figure 25: Estimated Macroeconomic Benefits

<table>
<thead>
<tr>
<th>Category</th>
<th>Cobalt</th>
<th>Copper</th>
<th>Lithium</th>
<th>Tin</th>
<th>Zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark</td>
<td>GEM Co</td>
<td>Boliden (Rönnskär)</td>
<td>Piedmont Lithium</td>
<td>Malaysia Smelting Corporation</td>
<td>Boliden (Kokkola)</td>
</tr>
<tr>
<td>Operation</td>
<td>Tricobalt tetraoxide refinery</td>
<td>Copper smelter</td>
<td>Lithium hydroxide refinery</td>
<td>Tin smelter</td>
<td>Zinc smelter</td>
</tr>
<tr>
<td>Country of operation</td>
<td>China</td>
<td>Sweden</td>
<td>United States</td>
<td>Malaysia</td>
<td>Finland</td>
</tr>
<tr>
<td>Cash margin quartile</td>
<td>--</td>
<td>Q1</td>
<td>Q1</td>
<td>--</td>
<td>Q3</td>
</tr>
<tr>
<td>Average annual production (kt)</td>
<td>14</td>
<td>218</td>
<td>22</td>
<td>17</td>
<td>294</td>
</tr>
<tr>
<td>Annual revenue ($m USD)</td>
<td>$604</td>
<td>$341</td>
<td>$293</td>
<td>--</td>
<td>$282</td>
</tr>
<tr>
<td>Annual operating profit before tax ($m USD)</td>
<td>$86</td>
<td>$96</td>
<td>$149</td>
<td>$3</td>
<td>$83</td>
</tr>
<tr>
<td>Operating margin</td>
<td>14%</td>
<td>28%</td>
<td>51%</td>
<td>--</td>
<td>29%</td>
</tr>
<tr>
<td>Estimated annual taxable revenue for DRC at 35% corporate income tax rate ($m USD)</td>
<td>$30</td>
<td>$34</td>
<td>$52</td>
<td>$1</td>
<td>$29</td>
</tr>
<tr>
<td>Estimated annual increase in DRC budget (2023 budget)</td>
<td>0.19%</td>
<td>0.21%</td>
<td>0.33%</td>
<td>0.01%</td>
<td>0.18%</td>
</tr>
<tr>
<td>Estimated annual increase in DRC export earnings (2021 exports)</td>
<td>2.70%</td>
<td>1.53%</td>
<td>1.31%</td>
<td>--</td>
<td>1.26%</td>
</tr>
</tbody>
</table>

Midstream operations can also have positive secondary economic effects. Expanding midstream capacity in the DRC will allow mining companies to reduce transit costs and gain cheaper access to by-products such as sulfuric acid. However, expanding midstream capacity is likely not the most direct nor efficient way to resolve existing inefficiencies in the DRC’s mining sector.

Based on benchmarked operations, for every large smelter or refinery the DRC builds, the country is estimated to receive an increase in export earnings of less than 3% and an increase in taxable revenue amounting to less than 1% of the current government budget. The combined annual operating profit expected from a large cobalt refinery, copper smelter, lithium refinery, tin smelter, and zinc smelter, as outlined above, will only amount to about one quarter of the Kamoa-Kakula mine’s 2022 EBITDA.\(^{144}\) The direct macroeconomic benefits from expanding midstream will be additive, but not transformative.

**Development of capabilities — Low**

Smelting and refining require specific know-how that has a limited range of outside applications. As a result, the capabilities a country develops are not particularly useful for diversifying into a wider range of products, although countries leading cutting-edge research may be more likely to develop capabilities that can be applied to a broader range of areas within materials science.

Midstream operations can hypothetically lead to a wider set of secondary forward linkages. Producing refined products may provide countries with comparative advantages for downstream applications. For example, if the DRC smelts and refines tin, it may later be more competitive to manufacture tin products due to lower transit and marketing costs. Manufacturing tin products could then open a wider variety of diversification opportunities.

However, data from the Atlas of Economic Complexity do not paint a promising picture. The Atlas’s Product Space is a visualization that shows the connections between different products based on the similarities in know-how that are needed to produce them.\(^{145}\) The Product Space approximates available opportunities for adjacent linkages based on existing production. Bubbles represent products and lines represent linkages between products. The colored bubbles represent the DRC’s existing exports.

In the figure below, it is apparent that the know-how from producing midstream products offers few opportunities for diversifying economic activity. Refined copper, unwrought zinc (most of which contains >99% purity), sulfates, carbonates, and cobalt oxides and hydroxides are all located on the periphery of the product space. A peripheral location indicates that the know-how required to produce these midstream products offers few linkages.

\(^{144}\) Ivanhoe Mines. “2022 Annual Results.”

\(^{145}\) Atlas of Economic Complexity. “Glossary.” Center for International Development at Harvard University.
The know-how required to operate a smelter or refinery is unlikely to provide the DRC with substantial horizontal linkages. Although potential secondary forward linkages could form, it will likely take a long time, and several new “jumps”, for those possibilities to unfold.

Financial diversification — High

The revenues and operating profits of midstream operations depend on a complex array of variables (see Appendix F for more information). While some of these variables are directly indexed to underlying commodity prices, others pull in contradictory directions.

The relationship between underlying commodity prices and the financial flows of midstream operations is estimated using historical information from mining company Boliden’s Rönnskär copper smelter and Kokkola zinc smelter. Data from 2014 to 2022 shows the sensitivity of the operating profits for Boliden’s copper and zinc smelters to changes in the market prices for copper and zinc, respectively (termed as the beta). The negative values suggest that midstream operations may hedge some of the risk associated with commodity volatility by offering an element of countercyclicality (i.e. when commodity prices trend downward, the operating profits of these facilities trend upward).

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147 Home, Andy. “Copper smelter terms at rock bottom as mine squeeze hits.” Reuters.
It is challenging to extrapolate this finding from the financial performance of just one operator. Additional research is needed to validate these preliminary findings. However, this initial analysis paints a promising picture. Although the long-term prosperity of commodity prices and midstream operations are closely connected, that connection does not seem to hold for annual financial fluctuations.

Accompanying results are provided in the figures below.

**Figure 27: Sensitivity Between Commodity Prices and Smelter Financial Flows, 2014-2022**

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual change in Rönnskär revenue and copper price</td>
<td>-0.21</td>
</tr>
<tr>
<td>Annual change in Rönnskär operating profit and copper price</td>
<td>-0.82</td>
</tr>
<tr>
<td>Annual change in Kokkola revenue and zinc price</td>
<td>-0.25</td>
</tr>
<tr>
<td>Annual change in Kokkola operating profit and zinc price</td>
<td>-0.90</td>
</tr>
</tbody>
</table>

**Figure 28: Standard Deviation of Annual Change (2014-2022, using Boliden Rönnskär copper smelter and Kokkola zinc smelter)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Copper</th>
<th>Zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commodity price</td>
<td>0.229</td>
<td>0.199</td>
</tr>
<tr>
<td>Smelter revenue</td>
<td>0.085</td>
<td>0.170</td>
</tr>
<tr>
<td>Smelter operating profit</td>
<td>0.625</td>
<td>0.639</td>
</tr>
</tbody>
</table>

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Figure 28: Annual Change in Copper Price, Rönnskär Smelter Revenue, and Rönnskär Smelter Operating Profit
Figure 29: Annual Change in Zinc Price, Kokkola Smelter Revenue, and Kokkola Smelter Operating Profit

Labor intensity and wages — *Low*

The differences in workforce benefits from midstream and upstream operations are estimated using data from the US Bureau of Labor Statistics (BLS). These statistics are a proxy to compare labor intensity and wages in the two sectors. In reality, labor intensity varies based on automation, production process, efficiency, commodity, and other variables. Likewise, wages are based on delicate supply-demand dynamics of labor markets that differ for each geography and commodity. Nonetheless, BLS data are directionally insightful as a broad estimate of how labor intensity and wages compare in the upstream and midstream segments of mineral value chains.

The data are summarized in the table below.
**Figure 30: Comparison of Labor Intensity and Wages of Mining and Processing in the US**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Metal ore mining</th>
<th>Nonferrous metal production and processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jobs per USD $1b in output</td>
<td>1,458</td>
<td>1,075</td>
</tr>
<tr>
<td>Median hourly wage</td>
<td>$29.53</td>
<td>$23.20</td>
</tr>
</tbody>
</table>

The results indicate that mining in the United States requires 36% more labor than production and processing for every unit of output. Furthermore, median hourly wages in the upstream segment of the value chain are 27% higher than those in the midstream segment.

Applying these findings to the DRC, it is likely that midstream expansion will result in less jobs than commensurate expansion in the upstream sector. This is particularly surprising given mining’s reputation as a sector with low labor intensity. Furthermore, although activities such as lithium refining may initially offer high wages due to a lack of trained domestic labor, midstream wages as a whole will likely be comparable, or perhaps even lag, those of the mining sector.

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Producing Battery Precursor Material

Feasibility — Long term

Developing a 60,000 metric ton precursor facility in the DRC is assessed to be feasible in the long term (5-8 years) based on the development timeline and existing constraints.

In an optimistic scenario that assumes no significant delays, the DRC could possibly build a 60,000 metric ton precursor facility within four years. The key steps and assumptions undergirding this timeline are outlined in the figure below:

Figure 31: Optimistic Timeline to Build a 60,000 Metric ton Precursor Facility in the DRC

<table>
<thead>
<tr>
<th>Action items</th>
<th>Expected time</th>
<th>Year of completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete feasibility study; begin tender process; evaluate proposals; formalize contract; issue all proposals and paperwork</td>
<td>1 year</td>
<td>2024</td>
</tr>
<tr>
<td>Construct a 10,000 metric ton modular pilot facility</td>
<td>1 year</td>
<td>2025</td>
</tr>
<tr>
<td>Operate pilot facility, proving commercial feasibility; raise capital</td>
<td>1 year</td>
<td>2026</td>
</tr>
<tr>
<td>Undertake construction to build a 60,000 metric ton facility, including completing necessary permitting and operational adjustments</td>
<td>1 year</td>
<td>2027</td>
</tr>
</tbody>
</table>

The number and magnitude of constraints that need to change for the DRC to build a 60,000 metric ton facility cast large doubt on the feasibility of achieving production in an expedited four year timeline. A list of changes that the DRC must execute to ameliorate existing constraints, based on BloombergNEF’s analysis and additional research, are provided below:
• **Develop the ability to refine cobalt and manganese.** High-purity nickel can be procured from Madagascar’s Ambatovy mine, but manganese from Gabon will need to be refined into sulfate form, as will the DRC’s cobalt.\(^{150}\)

• **Generate reliable and sufficient electricity.** A 60,000 metric ton facility will use an estimated 400 GWh annually.\(^{151}\) This would account for about 3% of the DRC’s current electricity capacity, meaning new generation capacity will need to be built. Intermittency must also be addressed to prevent snowballing costs and decreased output.

• **Improve logistical networks.** If import and export challenges are not resolved, they could significantly drive up operating costs relative to global competitors. This would hinder, although perhaps not disclude, commercial viability.

• **Upskill the country’s workforce.** The DRC’s workforce is not currently prepared for precursor production, although advances have been made by the team at the University of Lubumbashi. It is estimated that at least four years of sustained investment are needed to sufficiently prepare the DRC’s workforce for large-scale precursor production.\(^{152}\)

• **Secure support from an operator with precursor experience.** Policymakers in the DRC are seeking to grant the precursor project to a Western company.\(^{153}\) Given that almost all precursor producers are currently Chinese companies, the DRC’s ambition to enter into agreement with an experienced Western company limits the list to only a handful of players. It will be difficult to negotiate terms that can entice these companies, benefit the DRC, and form a JV with an existing cobalt producer.

• **Enhance fiscal certainty.** The DRC’s government has already set out to establish a Special Economic Zone (SEZ) to protect capital, lower tax requirements, and create a predictable business environment. As evidenced by the Maluku Pilot Zone near Kinshasa, successfully operating an SEZ is not easy. The newly created Agency for Special Economic Zones faces the challenges of designing carefully crafted rules, increasing its institutional power, bolstering its staff, and finding a private sector player to operate the SEZ in ex-Katanga. This will take time.

• **Operate a functional one stop shop.** The DRC has attempted to run a functional “one stop shop” for import and export management, permitting, and licensing since 2005.\(^{154}\)

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151 BloombergNEF. “The Cost of Producing Battery Precursors in the DRC.”

152 Interview.

153 Interview.

154 United States Trade Representative. “Democratic Republic of the Congo.”
The initiative’s success has been limited by challenges with coordination, authority, and corruption. Customs, permitting, and licensing must be streamlined to expedite implementation of a precursor project, but as detailed above, full operationalization is easier said than done.

- **Secure cheap capital.** BloombergNEF notes that “the interest rate could significantly impact the viability of the precursor project.”\(^{155}\) The DRC’s high lending rates, coupled with a recent spike in global interest rates, will make it difficult to raise blended financing at 8%, let alone the 3% project target.

Precursor production is not simple. Australia — a country with an effective grid, functional logistics, a skilled workforce, strong governance, and dynamic capital markets — has had to prioritize a national multi-year plan to produce precursors at commercial scale.\(^{156}\)

The capital cost of building a facility in the DRC is projected to be lower than benchmarked countries due to cost advantages in land, permitting, and construction. But this same logic would apply to most manufacturing facilities, and yet the DRC has almost no manufacturing capacity. A precursor facility in China, meanwhile, is projected to require more than twice the capital cost of a facility in the DRC. Nevertheless, China is the world’s foremost precursor producer and manufacturing foundry.

This implies that capabilities, risk, and operating environment are the true determinants of project success. If the DRC is to successfully build and operate a 60,000 metric ton precursor facility, it will need to address its existing constraints. The country has made progress in the right direction. But these steps have taken time — the DRC announced the project in November 2021 and, more than a year later, still has much to do. It is certainly feasible for the DRC to ameliorate current constraints, and for a project to succeed even while some constraints still exist. But policymakers should understand the magnitude of the task ahead. Many entrenched variables will need to change, not just one by one, but all at once. This indicates that the project will most likely be feasible in the long term (5-8 years).

**Direct macroeconomic benefits — Medium**

Macroeconomic benefits are estimated under the assumption that the DRC would build a 60,000 metric ton precursor facility to produce precursor material for NMC 622 batteries. Such a plant would rank among the world’s largest and could be constructed following the initial operation of a smaller modular plant.\(^{157}\) NMC 622 precursors are selected due to their relatively high cobalt content, which would provide an integrated plant in the DRC with a competitive cost advantage.

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\(^{155}\) BloombergNEF. “The Cost of Producing Battery Precursors in the DRC.”

\(^{156}\) Future Battery Industries. “Cathode facility officially launched.”

\(^{157}\) BloombergNEF. “The Cost of Producing Battery Precursors in the DRC.”
An NMC 622 precursor price of $15,425 USD per metric ton is used to estimate potential plant revenue. This price was reported in 2020, converted to USD at the 2020 AUD-USD exchange rate, and adjusted for 2021 and 2022 US inflation. Although precursor prices are volatile and opaque, the validity of the price assumption is backed by data provided in expert interviews.

Using a price assumption of $15,425 USD per metric ton, the annual revenue of a 60,000 metric ton precursor facility is estimated to be $926m USD. Expected annual revenues would represent a 4.1% increase to the DRC’s 2021 total export earnings. These revenues would cannibalize an estimated $200-300m USD in export earnings from cobalt sales. As a result, the expected increase in export earnings is bumped down to 3%.

Using this price assumption, three measures are analyzed to provide an idea of potential taxable revenue from operating a 60,000 metric ton precursor facility.

The first measure comes from Finnish Minerals Group’s planned 60,000 metric ton precursor facility. The facility is projected to generate $116.4m USD in annual tax revenue under the October 15, 2022 Euro-USD exchange rate. Applying a 50% increase due to the difference in Finland and the DRC’s corporate income tax rate, a similar facility is estimated to generate $175m USD in annual taxable revenue for the DRC.

In the second measure, taxable revenue is benchmarked against Chinese company GEM Co., one of the world’s largest precursor producers. In the first half of 2022, GEM produced 66,001 metric tons of ternary precursor material. The company reported $197m USD in operating profit from its precursor business at the prevailing RMB-USD exchange rate, representing an 18% gross margin. This would result in $69m in annual taxable revenue for the DRC at a 35% tax rate.

The last measure uses BloombergNEF’s estimated operating cost to produce a ton of precursor material in the DRC for a 10,000 metric ton plant. These costs are scaled down by 20% to factor for efficiencies from economies of scale, and increased by 8% to account for cost inflation between 2021 and time of writing. Operating costs are thus estimated at $11,343 per ton of precursor material. Total annual operating profit is estimated at $245m USD. Assuming a 35% tax rate, this would result in $86m in annual taxable revenue for the DRC.

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158 Future Battery Industries. “Li-ion Battery Cathode Manufacture in Australia.”
159 Interview.
161 BloombergNEF. “The Cost of Producing Battery Precursors in the DRC.”
162 Finnish Minerals Group. “Major economic impact from cathode material plant projects.”
164 BloombergNEF. “The Cost of Producing Battery Precursors in the DRC.”
In summary, estimates show that a 60,000 metric ton NMC 622 precursor plant can be expected to increase the DRC’s export earnings by around 3%. Taxable revenue from the plant could likely result in somewhere between 0.4-0.5% of the current government budget. In a bull case, using the Finnish benchmark, annual taxable revenue could increase by 1% of the current government budget.

These benefits will be important, but will not alter the DRC’s economic fabric. To place things into perspective, the effect on export earnings will likely be similar to that of the Kipushi zinc mine and the effect on taxable revenue will likely be similar to that of the Bisie tin mine.165

Rapidly changing battery technologies can implant significant risk into the commercial feasibility of an NMC precursor facility.166 Existing technologies like LFP batteries and emerging technologies such as sodium-ion batteries threaten to displace demand for NMC precursors.167 The long timeline of building a commercial precursor facility in the DRC heightens the project’s exposure to risks of an uncertain future. Although demand for NMC batteries will remain robust in the near and medium term, a rapidly evolving market could destabilize the commercial prospects of NMC precursors exactly when the DRC is ready to enter production.

**Development of productive capabilities — Low**

The know-how required to produce precursors is relatively complex, but highly specific.168 The production process in some ways resembles that of operating a refinery, with an emphasis on chemistry. Meanwhile, the carefully designed and optimized production process to meet strict quality standards is similar to that of a manufacturing operation.

Despite precursor production being more complex than smelting and refining, it will likely share a dearth of horizontal linkages due to its niche know-how. In other words, although complexity may be relatively high, horizontal linkages to other complex products are limited.169

The forward linkages from precursor production are also limited.

Although the capabilities required to produce precursors and cathode active material (CAM) are similar, CAM is difficult to transport due to its sensitivity to air and moisture. As a result, CAM transport is costly and requires short delivery times under precise conditions. The DRC’s logistical challenges make it infeasible to export CAM, although exports could be feasible in the

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167 Nikkei Asia. “China leads global battery patent race for post-lithium-ion era.”
168 Interview
169 Interview
future if the DRC upgrades its export routes. Precursors represent around 60% of the monetary price of cathodes, with CAM accounting for the remaining 40%.170

Can the DRC leverage its precursor production to produce lithium-ion batteries?

Experts indicate that the know-how, infrastructure, and resources needed to produce precursors and lithium-ion batteries are substantially different.171 This is why the largest precursor producers, such as GEM, Huayou Cobalt, and Umicore, do not produce batteries. Rather, these companies are focused on materials science, chemistry, and metallurgy. The jump from developing the capabilities to make precursors to developing the capabilities to manufacture batteries is tremendous. Producing precursors does not bring a country substantively closer to manufacturing batteries, although it may help generate a small cost advantage.

Manufacturing lithium-ion batteries, as one expert put it, is “mind-blowingly complex”.172 It would likely be imprudent for the DRC, with its vast challenges and lack of competitive manufacturing capacity, to suddenly attempt to manufacture one of the world’s most complex products. Yes, the DRC has cobalt, but that only amounts to a limited cost reduction from marketing and transport. And cobalt is only a small part of the battery manufacturing equation. For an NMC 811 battery, for example, a 10% change in cobalt price corresponds to only a 0.4% change in production cost.173 It seems illogical that the DRC should compel itself to spend its scarce resources trying to produce lithium-ion batteries simply because it has cobalt.

Although battery manufacturing may be a commendable national vision, precursor production would only be a small step in a much longer and more complicated journey.

Financial diversification — Medium

Demand for precursors and cobalt, either as concentrate or hydroxide, is largely driven by growth in the lithium-ion battery market. Changes in demand for precursors and cobalt products will therefore remain tightly linked for the foreseeable future. Supply dynamics between the two markets are less connected. A supply-demand mismatch in precursors will not materially influence or depend on a supply-demand mismatch in mine supply, and vice versa. The differences in supply dynamics between the two markets likely weakens the correlation between the annual volatility of precursor prices and cobalt prices.
The direction of annual volatility in operating profits for precursor facilities and cobalt mines may also differ since cobalt accounts for 30-50% of the operating cost for precursor production. Higher cobalt prices boost margins for miners while tightening margins for precursor facilities.

Reliable historical precursor pricing or operating profit data are not publicly available to the extent needed for meaningful analysis of the sensitivity to cobalt prices. However, the logic outlined above supports the assumption that a precursor facility will likely help diversify the DRC’s export earnings and taxable revenue away from cobalt price volatility.

**Labor intensity and compensation — Low**

A precursor facility is estimated to have low labor intensity.

BloombergNEF estimated that a 10,000 metric ton facility requires 100 employees. The 60,000 metric ton facility mentioned earlier in Finland, meanwhile, is projected to directly employ 270 workers. These two figures are not contradictory, as labor does not scale linearly to production. It can therefore be estimated that a 60,000 metric ton facility in the DRC would directly employ around 300 individuals. Exact figures will depend on variables such as contracting structure and level of automation.

The direct employment impact of a precursor facility is low when compared to mining operations or other available diversification opportunities. Employment, as a percent of output, lags well below that of benchmarked mining operations in the United States and in the DRC.

Wages for a precursor facility’s employees in the DRC will likely be higher than wages in the country’s mining sector. In the United States, the hourly mean wage for chemical plant operators in non-ferrous metal production is about 6% higher than wages of employees in metal ore mining. This proxy, in addition to an initial deficit of skilled domestic workers, hints that wages for a precursor facility in the DRC will be higher than in the country’s mining sector. Nevertheless, low labor intensity and initial reliance on expatriate workers will blunt the direct workforce benefits of a precursor facility.

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174 BloombergNEF. “The Cost of Producing Battery Precursors in the DRC.”
175 Finnish Minerals Group. “Major economic impact from cathode material plant projects.”
176 Ivanhoe Mines. “Kipushi Feasibility Study.”
Manufacturing Copper Products

**Feasibility — Near term**

Manufacturing copper products does not require as much energy as the other upstream and midstream activities discussed above. Therefore, despite DRC’s challenges with reliable and affordable electricity, it can develop a robust manufacturing cluster for copper products without having to invest heavily in new electrical infrastructure. While precise figures for energy intensity differ based on location, facility, and copper product, the illustration below conveys that, relative to upstream and midstream energy consumption, manufacturing copper products entails energy usage that is lower by a factor of ten.  

**Figure 32: Energy use in the Copper Value Chain**

Despite low energy intensity, intermittency can still hurt operating margins. As such, DRC operators would need to focus on ensuring stability of available supply.

In terms of workforce capabilities, the DRC’s existing operations are proof of concept that it already has sufficient know-how, supported by expatriate labor, to produce copper products.

The option to develop an export-focused manufacturing cluster also encounters limited logistical challenges. Existing transit networks for copper can be leveraged to support exports of copper products to neighboring markets. As such, producing and exporting copper products does not require the development of new road infrastructure or logistical capabilities. While there is significant room for improvement in logistics, this option can likely function well within the existing environment. Other constraints in terms of exports include quality assurance and product specifications. Due to the large range of product varieties, DRC producers will need to adjust production to meet various demand specifications of target markets. Quality control will also need to be certified by international certifiers due to the DRC’s lack of domestic regulations.

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178 Kelly, Jared C; et al. “Updated Life Cycle Inventory of Copper: Imports from Chile.”
179 Ibid.
The market feasibility for exporting manufactured copper-based products is illustrated with the example of copper wires. The regional market for copper wire imports is close to a quarter of a billion USD.\textsuperscript{180} While not all regional demand will be met through DRC exports, data demonstrate the existence of a sizable market that can be accessed by ex-Katanga-based manufacturers situated close to existing trade routes. North African markets may also serve as viable export destinations.

*Figure 33: Gross Imports of Copper Wire, 2020\textsuperscript{181}*

<table>
<thead>
<tr>
<th>Total - All Regional Countries</th>
<th>238M</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Africa</td>
<td>204M</td>
</tr>
<tr>
<td>Tanzania</td>
<td>19M</td>
</tr>
<tr>
<td>Botswana</td>
<td>11M</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>2M</td>
</tr>
<tr>
<td>Malawi</td>
<td>1M</td>
</tr>
<tr>
<td>Mozambique</td>
<td>576K</td>
</tr>
<tr>
<td>Namibia</td>
<td>366K</td>
</tr>
<tr>
<td>Zambia</td>
<td>273K</td>
</tr>
</tbody>
</table>

*Regional countries are classified as those which either trade copper products or support the trade of copper products with/by the DRC*

\textsuperscript{180} These regional markets are those that can be supplied by the ex-Katanga regional cluster using existing, well-established trade routes
\textsuperscript{181} Atlas of Economic Complexity.
Figure 34: Top African Importers of Copper Wire, 2020\textsuperscript{182}

<table>
<thead>
<tr>
<th>Total - Top 5 African Importers</th>
<th>917M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morocco</td>
<td>448M</td>
</tr>
<tr>
<td>South Africa</td>
<td>204M</td>
</tr>
<tr>
<td>Tunisia</td>
<td>126M</td>
</tr>
<tr>
<td>Algeria</td>
<td>71M</td>
</tr>
<tr>
<td>Egypt</td>
<td>68M</td>
</tr>
</tbody>
</table>

The South African copper wire market presents an interesting case, where 58% ($119m USD) of copper wire needs are met by Russian imports. Here, the DRC’s ability to competitively supply the South African market is arguably higher than that of Russia given its geographical proximity, copper cathode production, established trade connections, and more recently, geopolitical tensions surrounding Russian exports.

\textsuperscript{182} Ibid.
As the clean energy transition gathers pace and economies pursue increasing electrification, demand for copper products will likely grow. Furthermore, Africa’s population boom and increasing urbanization will also likely lead to regional demand growth for copper products, which are strongly indexed to construction activity and infrastructural development. Taken together, these factors provide powerful tailwinds for this segment of the value chain.

**Direct macroeconomic benefits — Low**

The manufacturing of copper products involves a non-negligible degree of value addition during the process, with the “Industry Value Added” metric conveying the industry’s contribution to GDP. This value is left on the table when the DRC exports copper cathode. Relevant metrics from the copper-based product industry are illustrated below.

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IBIS World. “Industry Report C27.320, Other Electronic Wire & Cable Manufacturing in the UK.”
**Figure 36: Metrics From Copper-Based Product Industry**

<table>
<thead>
<tr>
<th></th>
<th>Industry value added as a percent of revenue (average from 2013 - 2022)</th>
<th>Operating profit margin</th>
<th>Labor intensity (workers employed in 2022 per $1b USD of production)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>22.20%</td>
<td>4.50%</td>
<td>4,013</td>
</tr>
<tr>
<td>US</td>
<td>20.70%</td>
<td>7.60%</td>
<td>1,761</td>
</tr>
<tr>
<td>UK</td>
<td>24.30%</td>
<td>1.40%</td>
<td>2,978</td>
</tr>
<tr>
<td>Australia</td>
<td>22.40%</td>
<td>6.30%</td>
<td>1,933</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>22.40%</strong></td>
<td><strong>5.00%</strong></td>
<td><strong>2,671</strong></td>
</tr>
</tbody>
</table>

Assuming that the DRC is able to export $500m USD of copper-based products per annum, that would result in $112m of additional export earnings and value added. This would only account for a 0.5% increase in export earnings. Assuming a 5% profit margin and 35% tax rate, exporting $500m USD of copper-based products would add only $9m in annual taxable revenue.

Most small firms within the copper product industry have relatively low-level production equipment and technologies, and therefore manufacture low-end products. The financial performance of such manufacturers can be lackluster as there is little product differentiation within this segment, which can result in downward price pressure and volatility. However, the labor intensity of this segment is higher precisely due to such technological constraints. The segment for high-end and special cables is generally a more profitable market.

**Development of capabilities — High**

Copper-based products come in various levels of technical complexity. Therefore, the manufacturing of less complex copper products allows for skill acquisition that can then be used to manufacture more advanced and technically sophisticated products. The relevance of such know-how is generally limited beyond power and signal transmission. For example, manufacturers of copper-based products can subsequently move into motor and generator manufacturing, but the overlap between the capabilities required for the two activities is not as related or complementary as moving from low-end cables to high-end cables.

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185 Ibid.
186 Industry Value Added (IVA) is the market value of goods and services produced by the industry minus the cost of goods and services used in production. IVA is also described as the industry's contribution to GDP, or profit plus wages and depreciation.
188 Interview.
Given its recent history and deindustrialization over the past four decades, there is a general apprehension associated with the DRC’s ability to manufacture at scale and on competitive terms. Within this context, the successful development of a copper-based manufacturing cluster in ex-Katanga can have positive spillovers for emerging manufacturing enterprises in other sectors. It can also have reputational benefits and serve as a proof of concept that manufacturing in the DRC can be commercially viable. Copper manufacturing may prove one of the DRC’s most attractive opportunities to simultaneously leverage its existing capabilities, develop new capabilities, and explore future diversification into more complex products.  

Financial diversification — *Low*

Most copper-based products are commodities par excellence and offer limited benefits for diversifying away from commodity price exposure. Products such as rods, wires, cables, “semis” and motors sell in highly commoditized markets and enjoy little product differentiation, with manufacturers often competing on price. There is some product differentiation in the market for advanced cables and generators, but copper constitutes a smaller fraction of the overall value in those product lines.

Based on their commoditized nature, the price of many copper products is largely a function of global copper cathode prices, with premium and surcharges added onto that base price for any expenses incurred during the manufacturing process. As such, the export of these products can be exposed to similar price volatility as that experienced by copper cathodes. This limits the benefit that this option will have on reducing the volatility of the DRC’s export earnings.

Labor intensity and wages — *Medium*

The labor intensity data from China, US, UK and Australia presented earlier indicate an average labor intensity of 2,671 workers employed per $1b USD of production. Given that production technology and equipment in the DRC is most likely to mirror that of China, the DRC’s labor intensity can be estimated at 4,000 workers employed per $1b of production. Based on the export target of $500m, this option can be expected to create around 2,000 manufacturing jobs.

For additional context, Mining Engineering Services (MES), the Lubumbashi-based EPC contractor discussed earlier, currently plans to manufacture 4,200 tons of copper-based products at its facility with 60 employees.

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191 Interview.
However, the data shown earlier demonstrate that labor intensity can vary greatly. In the case of the United States, for example, labor intensity is relatively low. Nonetheless, labor intensity per $1b USD of output is still 20% higher than the Bureau of Labor Statistics (BLS) data for the labor intensity of US metal ore mining. The upshot is that copper manufacturing is more labor intensive than copper mining, although the scale will vary.

Wage data is not readily available, but using BLS data, it is found that electrical equipment manufacturing median wages are 22% lower than those of metal ore mining. These data are imperfect since copper manufacturing is only a small part of the broader category of electrical equipment manufacturing. Within the context of the DRC, shortages in local skilled labor supply will likely mean that copper manufacturing wages remain high for the near future. MES, for example, has had to rely on international expertise as it develops its operations, indicating a labor shortage at the managerial level.

Although the creation of 2,000 jobs may seem like a small figure, it is higher in relative terms than the jobs that would have been created by a similar increase in mining production, while wages between the two will likely be comparable. Job creation would also be much higher than a precursor facility, which will directly employ around 300 individuals for ~$1b in output.

194 Interview.
### Figure 37: Scoring of Value Addition Options

<table>
<thead>
<tr>
<th>Value addition option</th>
<th>Feasibility</th>
<th>Macroeconomic benefits</th>
<th>Development of productive capabilities</th>
<th>Financial diversification</th>
<th>Labor intensity and wages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanding Midstream Operations</td>
<td>Medium term</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Producing Battery Precursor Material</td>
<td>Long term</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Manufacturing Copper Products</td>
<td>Near term</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Policy Recommendations

Recommendation #1 — Prioritize scaling copper manufacturing

Despite the DRC’s constraints in areas such as energy, logistics, and governance, the manufacturing of copper products can be feasibly undertaken using existing resources. Furthermore, production can be rapidly scaled given the DRC’s current set of capabilities and the commercial viability of the regional export market.

In this regard, policymakers should first engage with existing players in this sector to better understand the private sector’s needs and align the policy environment accordingly. A number of bureaucratic and administrative frictions currently erode the competitiveness of the sector. For example, the existing tax code allows mining companies VAT exemptions for imported copper wires and cables, but imposes a VAT charge on domestic manufacturers. This directly places domestic manufacturers at a disadvantage to foreign firms. Policymakers should seek to rapidly understand and ameliorate these types of basic inefficiencies.

Second, given the capital investment required to build a manufacturing facility, the government should consider a limited-time tax holiday with clearly defined sunset provisions to incentivize private sector players to make greenfield investments. Tax benefits on the import of plant equipment and machinery should also be considered.

Third, while it is becoming increasingly difficult to separate geopolitics from the flow of foreign direct investment, the DRC should stay partner-agnostic when facilitating the entry of new players to manufacture copper products. Instead, JV partner selection should be guided by potential partners’ commercial and technological capabilities. This approach will not expose the DRC to international pressure given the relatively uncontroversial nature of copper rods, wires, cables, and similar products.195

Lastly, while the manufacturing of copper products may organically lead to spillovers for other manufacturing activities, the government can play a role in inducing these spillovers by facilitating the entry of investors with diversified, multisectoral experience. For instance, if given the option to facilitate the market entry of a “pure play” cable manufacturer or a diversified operator, for whom cables are just one of its many business lines, policy preference should steer towards the latter.

Recommendation #2 — Pursue a sequenced strategy to gradually increase midstream operations

Onshoring midstream operations can provide various benefits including export earnings, tax revenue, and insulation from commodity volatility. It can also reduce existing constraints, such as road congestion and high sulfuric acid prices, while opening future opportunities for vertical diversification. However, energy scarcity stands in the way.

Policymakers should respond in the short term by drafting consistent frameworks for public-private energy projects. SNEL has worked with Ivanhoe and Zijin to upgrade Inga’s capacity in an innovative partnership that provides the Kamoa-Kakula mine with discounted electricity. Meanwhile, the Manono project and various Chinese operations have built off-grid generation capacity. Considering SNEL’s difficulties and the private sector’s increasing willingness to invest in electricity generation, there is currently a window to formalize a framework for public-private cooperation between mining sector operators and SNEL. Codification, procedural consistency, and transparency can promote public-private partnerships to expand electricity generation and, as a result, support midstream operations.

Energy scarcity also implies that policymakers should carefully craft incentives instead of imposing crude export bans. Although proponents argue that export bans have helped lead to more exports of cobalt hydroxide and copper cathode, inconsistent implementation of these bans erodes government credibility and reduces foreign direct investment in ways that are difficult to trace. The problem with export bans in the DRC is that in most cases there is simply not enough electricity for the private sector to adjust.

Well-crafted incentives may be a smarter policy approach. The DRC can experiment with various tools, such as temporary tax differentials between refined and semi-refined exports, to incentivize midstream production. Another option is to adjust the tender process in a way that rewards proposals which put forward concrete plans for long-term energy investments.

The third policy implication is that the DRC should approach midstream operations with a sequenced strategy. Boosting copper refining capacity should be the most immediate objective given existing know-how, booming production, and the geographic concentration of assets. Cobalt can be targeted as a second objective for similar reasons, but the shift should be more gradual in light of the large energy requirements. Efforts to refine lithium, tin, and zinc should be withheld until those value chains have reached steady upstream production.
Recommendation #3 — Reframe precursor production as a long-term vision, not an immediate strategic priority

International organizations, the DRC government, and the private sector have focused on determining whether the DRC can competitively produce precursor materials. An equally important question is whether precursor production warrants its status as a strategic priority.

Policymakers are correct in acknowledging some of the benefits, such as revenue and export earnings, that precursor production can provide. However, they should also be realistic about the limit of these benefits, the resources it will take to successfully implement the project, and the significant jump in capabilities required for moving from the production of precursor materials to the manufacturing of lithium-ion batteries.

Producing precursors will require careful planning and deployment of state resources on a significant scale and sustained basis. It is worth reconsidering the national-level prioritization of building a precursor facility at the expense of other policy options, particularly given the limited benefits, significant constraints, and uncertain future cash flows.

To this end, it is recommended that policymakers reframe precursor production as a long-term vision rather than an immediate strategic priority. The DRC should continue to lay the building blocks for a precursor facility. This includes continuing current initiatives to invest in workforce development, establish a battery council, conduct feasibility studies, operationalize a special economic zone, and bolster a one stop shop for regulations and permitting. Policymakers are also taking the right steps in building partnerships with the United States and Zambia. International partnerships can focus on addressing the constraints outlined earlier in this report. Collaboration on energy, logistics, and financing will have the greatest impact.

But these initiatives should not distract policymakers from more immediate priorities. In addition to the other two value addition options, progress on issues like fiscal management, reform of artisanal mining, and investment in geological prospecting will prove more achievable than precursor production in the short term, and arguably also more beneficial in the long term. The quest to produce battery precursors should not divert scarce resources from more urgent needs, challenges, and opportunities.
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Appendices
Appendix A — About the Authors

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Abdurrehman Naveed and Cina Vazir are Master in Public Policy candidates at the Harvard Kennedy School. Together, they share expertise in strategy design, finance, policy implementation, geopolitical analysis, and market entry. Their professional experience spans various areas, including economic development, metals & mining, strategy consulting, and public sector management. Both can be reached by email for further inquiries.
Appendix B — List of Consulted Organizations

- Agency for Special Economic Zones, Democratic Republic of Congo
- Alfred H Knight Group
- Arab Bank for Economic Development in Africa
- BloombergNEF
- The Carter Center
- Columbia University
- Common Fund for Commodities
- Copper Alliance
- Department of Commerce, United States
- Department of Energy, United States
- Department of State, United States
- Extractives Industry Transparency Initiative
- Engagement Pour La Citoyenneté et Le Développement
- Ensemble pour la République
- Federation of Businesses of Congo (FEC)
- Federal Institute for Geosciences and Natural Resources (BGR), Germany
- Glencore
- Harvard University
- International Tin Association
- International Wire Association
- International Zinc Association
- Kamosa Copper S.A.
- Kearney
- LG Energy Solution
- Massachusetts Institute of Technology
- Mining Engineering Services
- Ministry of Industry, Democratic Republic of Congo
- Ministry of Mines, Democratic Republic of Congo
- Natural Resource Governance Institute
- New York Times
- Organization for Economic Co-operation and Development
- Office of the Presidency, Democratic Republic of Congo
- Office of the Secretary General, Democratic Republic of Congo
- RMG Minerals
- Trafigura
- United Nations Special Envoy for the Great Lakes
- United Nations Economic Commission for Africa
- University of Lubumbashi
- United States Agency for International Development, United States
- United States Geological Survey, United States
- Windward Commodities
- World Bank Group
Appendix C — Overview of Mineral Value Chains

Mineral value chains generally consist of upstream, midstream, and downstream stages. Although each mineral and production process is distinct, a simplified explanation of each stage is provided below.

In the upstream stage, mineral deposits are identified through a process of exploration, which entails locating deposits, conducting surface mapping, drilling, and undertaking analysis that culminates in a feasibility study. Assuming favorable results and success in obtaining permits, a company will move forward with mining, in which ore is extracted from the earth.

Following the extraction of ore, minerals move into midstream operations which consist of two phases: processing and refining. In the processing phase, ores typically undergo crushing, grinding, classification, concentration, and dewatering. The resulting product is a mineral concentrate, which is typically produced at the mine site. Mineral concentrates are then chemically refined, generally through hydrometallurgical or pyrometallurgical processes. The location of refineries depends on a complex array of factors, including proximity to final goods, project economics, local regulations, fiscal incentives, and availability of inputs.

The final stage of the value chain is manufacturing. In this stage, refined minerals enter production facilities and are manufactured into a wide range of final products. After end-use, these products can also be recycled, repurposed, or reused, generating a circular economy and reducing the need for primary material production.

Figure 38: Simplified Model of Mineral Value Chains

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197 Rangefront Mining Services. “8 Steps of Mineral Exploration.”
198 Flyability. “What is Mineral Processing in Mining?”
Appendix D — A Population Boon or Bane?

In the last 60 years, the DRC’s population has increased by more than a factor of six, from slightly under 16 million in 1961 to just under 96 million in 2021. Population growth in the DRC has been well above the average of Sub-Saharan Africa over the last two decades and far above the world average. The result is an extremely young population. According to UN estimates, 45% of the DRC’s population is currently under the age of 14.

Figure 39: Population by Age Group, 2022 (% of total population)

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202 Ibid.
It is unclear whether DRC may soon be dealing with a demographic dividend. Fertility rates remain high despite gradual declines.\textsuperscript{204} The share of the working age population has been stable since the 1980s and the youth dependency ratio continues to prove problematic.\textsuperscript{205} Regardless, a youth bulge and growing population presents a pressing need for more jobs. If properly harnessed, a larger labor force can generate increases in GDP and productive capacity. Alternatively, persistent rates of underemployment, low wages, and informality will strain existing infrastructure and potentially provoke civil unrest. Job creation is a strategic priority.

Value addition could be part of the answer. As discussed earlier, the DRC is lagging in diverse manufacturing capacity and job growth.\textsuperscript{206} A more robust manufacturing sector will absorb large numbers of workers while placing upward pressure on wages and productivity.\textsuperscript{207} It could also promote a shift from capital-intensive mining to more knowledge-intensive industries.\textsuperscript{208} The challenge is finding and scaling nascent manufacturing operations that are economically feasible, while designing policy to encourage spillovers. Initial manufacturing growth could come through

\textsuperscript{204} World Bank. “Fertility rate, total (births per woman) - Congo, Dem. Rep.”
\textsuperscript{205} World Bank. “Jobs Diagnostic: Democratic Republic of Congo.”
\textsuperscript{206} Ibid.
\textsuperscript{207} Signe, Landry. “The potential of manufacturing and industrialization in Africa.”
\textsuperscript{208} Abreha, Caleb; et. al. “Industrialization in Sub-Saharan Africa: Seizing Opportunities in Global Value Chains.”

*World Bank.*
vertically integrated value chains that leverage access to raw materials to reduce cost and attract investment.

The quantity, stability, and productivity of job creation in the DRC over the next decade will ultimately dictate whether the country’s demographics are a boon or bane for its economic and political future. Value addition could have a timely and important role to play.
Appendix E — A Note on Greenhouse Gas Emissions

Hydroelectric power accounts for an estimated 99% of the DRC’s electricity generation.\(^\text{209}\) In contrast, only 29% of China’s electricity comes from renewable sources, with 63% of Chinese electricity generated by coal.\(^\text{210}\) Nonetheless, most of the DRC’s cobalt and copper is shipped to China, where it is eventually manufactured into final products. If smelting and refining, precursor production, or wire manufacturing were to take place in the DRC, it would allow domestic businesses to leverage the DRC’s clean grid to reduce GHG emissions. The extent of reductions will depend on grid capacity and the required level of backup generator usage.

Figure 41: Percent of total electricity generation by source, 2020\(^\text{211}\)

<table>
<thead>
<tr>
<th></th>
<th>Renewable</th>
<th>Fossil Fuels</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRC</td>
<td>99.6%</td>
<td>0.4%</td>
<td>0.0%</td>
</tr>
<tr>
<td>China</td>
<td>28.7%</td>
<td>66.6%</td>
<td>4.7%</td>
</tr>
</tbody>
</table>

Value addition can also reduce the GHG emissions from transit. Refined metal, for example, is generally 99% or higher in purity, compared with concentrate which typically contains 20-50% metal content. Shipping refined metal instead of concentrate significantly reduces total transport bulk, often by a factor of two to five. According to BloombergNEF, precursor production in the DRC will also reduce transit emissions.\(^\text{212}\) A similar story applies to copper manufacturing. Currently, copper concentrate or cathode usually travels from the DRC to China, where it is manufactured into products, and often reimported back to Africa.\(^\text{213}\) Domesticization or regionalization of the supply chain will reduce transit and lower emissions.

Emissions reductions are viewed as a compelling argument for pursuing \textit{any} of the three value addition options. Beyond the environmental and ethical rationale, a lower GHG footprint will improve project economics by facilitating access to capital, insulating operating cost from volatile fossil fuel prices, and building a comparative advantage in the face of looming carbon border adjustment mechanisms.

\(^{211}\) International Energy Association. “Electricity Information.”
\(^{212}\) BloombergNEF. “The Cost of Producing Battery Precursors in the DRC.”
\(^{213}\) Copper Alliance. “Stocks and Flows.”
Appendix F — Overview of Smelter and Refinery Revenue Streams

Smelters and refineries have different sources of revenue depending on a range of factors, including the value chain in which they operate and the specific characteristics of the operation. Additionally, smelter and refinery revenue characteristics are often different, although in copper, tin, and zinc both operations are typically integrated.

As a gross generalization, midstream operations can be thought of as deriving revenue from four principal streams:\(^\text{214}\)

- **Treatment, refining, and penalty charges.** Treatment and refining charges are levied for the conversion of concentrate, or other input, into a refined metal product. These charges can be negotiated in fixed contracts or on the spot market. Penalty charges apply to concentrates that are low-grade or carry contaminants or deleterious elements.

- **By-product recovery.** In addition to the target metal, smelters and refineries are often able to recover valuable by-products which can be sold for additional profit. Copper smelting, for example, can typically result in recovery of silver, tellurium, zinc, and other metals. Sales of sulfuric acid and surplus energy are also commonly grouped into this category.

- **Free metal.** Free metal is determined by the difference between a smelter or refinery metal recovery rate and the rate it pays for its feedstock. With zinc, for example, a smelter will typically pay for slightly less than 85% of the zinc contained in concentrate, but often recover upwards of 95% of the contained metal. The difference between the amount of metal paid and the amount recovered is called free metal, which a smelter or refinery can then sell to an exchange or market participant.

- **Metal premia.** Metal premia are the difference in price between selling metal to a market participant or to an exchange, such as the LME. Metal premia typically depend on a market’s supply-demand balance, logistics costs, and the quality and shape of the metal.

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\(^{214}\) Noranda Income Fund. “Zinc Smelter Revenue Model.”
Appendix G — Further Detail About Copper Value Chains

Copper cathodes can be melted and cast into ingots, cakes, billets, or rods. Ingots are rectangular bricks which are remelted to make brass and bronze products.\textsuperscript{215} Cakes are rectangular slabs and are rolled to make copper plates, strips, sheets, and foil products.\textsuperscript{216} Billets are cylindrical logs and are drawn to make copper tubing and pipe.\textsuperscript{217} Copper rods are round and cast into long lengths and then coiled. This coiled material is then drawn further to make copper wire.\textsuperscript{218}

The pricing for all goods within the copper value chain revolves around the exchange-listed price of copper cathode. For instance, the price of wire rods and semis is usually a function of the price of copper cathode on an exchange such as the LME, COMEX, or Shanghai Futures Exchange, in addition to a premium for using copper cathode and a surcharge which accounts for the costs and margin associated with the manufacturing process. The surcharge also includes operational and financing costs in addition to the cost of scrap.

\textsuperscript{215} Border States. “Why Isn’t the Price of Wire Following the Price of Copper?”
\textsuperscript{216} Ibid.
\textsuperscript{217} Ibid.
\textsuperscript{218} Ibid.