Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical & Industrial Engineering

“Lithium-Ion Battery Value Chain Analysis: Assessing Ethiopia's Competitiveness and Strategic Framework”

A Thesis Submitted to the School of Graduate Studies of Addis Ababa Institute of Technology, Addis Ababa University in partial fulfillment for the Degree of Master of Science in Industrial Engineering

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Declaration

I hereby declare that the work which is being presented in this thesis entitled "Lithium-Ion Battery Value Chain Analysis: Assessing Ethiopia's Competitiveness and Strategic Framework" is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

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ABSTRACT

The Lithium-Ion Battery (LIB) industry has gained significant importance as a key enabler for electric vehicles. The Federal Democratic Republic of Ethiopia has ambitious plans to decarbonize its transportation sector through the introduction of a sizable number of electric buses and small cars. However, these cars will eventually require new batteries after a while.

This study uses a value chain analysis of the LIB industry, with a focus on assessing Ethiopia's competitiveness in the LIB value chain. It examines the entire value chain of LIBs, starting with the upstream stage involving the extraction and processing of raw materials, moving on to the midstream stage involving the manufacture of battery cells and component assembly, and finishing with the downstream stage involving battery integration and end-use applications. The study assesses Ethiopia's current position and potential for competitive advantage in each stage of the value chain using a combination of SWOT and Porter's five-force frameworks. It examines important elements such as the availability of raw materials, technological capabilities, and infrastructure development.

The results highlight that Ethiopia has an estimated total of 3 million tons of Lithium brines linked to the potash horizons in Danakil, Afar region, with a 50% recovery rate. The nation also possesses abundant reserves of other important raw materials like nickel and graphite. Lithium, a key component of LIBs, holds significant value and is abundantly available in Ethiopia. Compared to graphite and nickel, lithium extraction requires less complex infrastructure and lower capital investments. Experts suggest that Ethiopia should prioritize lithium extraction to maximize its potential in the LIB value chain. However, substantial investments in infrastructure, technology, and knowledge are still required for the extraction and processing of these materials.

Based on the analysis, the study provides a strategic framework to enhance Ethiopia's competitiveness in the LIB value chain. It can also serve as a valuable resource for policymakers, industry stakeholders, and investors interested in understanding Ethiopia's competitiveness in the LIB sector.

Keywords: Lithium-Ion Battery (LIB), Value Chain Analysis, strategic framework, Ethiopia Competitiveness

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Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

List of Abbreviations	Description
APDP	Automotive Production Development Programme
ARENA	Australian Renewable Energy Agency
BAM	Battery Anode Material
BEV	Battery Electric Vehicle
BMS	Battery Management Systems
CAGR	Compound Annual Growth Rate
EPR	Extended Producer Responsibility
ESS	Energy Stationary Storage
EV	Electric Vehicle
GHG	Green House Gases
GWh	Giga Watt Hour
HEV	Hybrid Electric Vehicle
ICEs	Internal Combustion Vehicle
IP	Intellectual Property
Kt	Kilo tones
kWh	Kilo Watt Hour
LCE	Lithium Carbonate Equivalent
LCO	Lithium Cobalt Oxide
LFPC	Lithium Iron Phosphate Cathode
LIBs	Lithium-Ion Batteries
LME	Lithium Metal Equivalent
LMO	Lithium Manganese Oxide
NCAO	Nickel Cobalt Aluminum Oxide
NMCO	Nickel Manganese Cobalt Oxide
NREL	National Renewable Energy Laboratory
PHEV	Plug-in Hybrid Electric Vehicle

CHAPTER ONE

1. Introduction

The demand for lithium-ion batteries (LIBs) has experienced a significant surge in recent years, driven by the increasing adoption of electric vehicles. As the world transitions towards a more sustainable and electrified future, LIBs have emerged as a crucial component in powering these advancements. Recognizing this global trend and Ethiopia's potential as a mineral-rich nation, it becomes essential to conduct a comprehensive analysis of Ethiopia's competitiveness within the lithium-ion battery value chain.

The aim of this study is to assess Ethiopia's competitiveness in the LIB value chain by examining its mining sector policies, industrial development strategies, and the potential for sustainable lithium extraction. By evaluating the country's current framework and identifying key strengths and opportunities, this study will develop a strategic roadmap to enhance Ethiopia's competitiveness and establish a thriving LIB industry within its borders. Through a value chain analysis, this study will explore various aspects of Ethiopia's LIB value chain, including mining operations, lithium extraction processes, battery component manufacturing, and technological advancements. It will analyze each stage of the value chain, including raw material extraction, processing, component manufacturing, battery production, and end-of-life LIB recycling. SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis will be conducted to identify the potential and capability of Ethiopia's competitiveness in the LIB value chain, based on expert opinions. Additionally, Porter's Five Forces framework will be used to assess the competitive environment and market dynamics of the marketplace. The study will also highlight the obstacles and limitations that Ethiopia must overcome in order to advance technologically, build its infrastructure, and implement environmentally friendly mining techniques.

Ultimately, this study seeks to provide policymakers, industry experts, and investors with valuable insights into Ethiopia's competitiveness in the LIB sector and the strategic framework required to foster its development. By understanding the opportunities, challenges, and necessary actions, Ethiopia can formulate targeted policies, attract investments, and unlock the full potential of its lithium resources, thereby establishing a strong foothold in the rapidly evolving lithium-ion battery industry.

1.1 Background and Justification

The rapid global transition towards sustainable energy systems and the increasing demand for electric vehicles (EVs) have placed lithium-ion batteries (LIBs) at the forefront of technological advancements. LIBs have become the preferred energy storage solution due to their high energy density, longer lifespan, and rechargeability. As a result, the global LIB market is experiencing exponential growth, with projections estimating its value to reach billions of dollars in the coming years.

Ethiopia, endowed with abundant mineral resources, including significant lithium reserves, has the potential to play a substantial role in the LIB value chain. However, to fully capitalize on this opportunity, it is essential to conduct a comprehensive analysis of Ethiopia's competitiveness and develop a strategic framework tailored to its unique strengths and challenges. Ethiopia possesses vast mineral wealth, particularly in untapped lithium deposits, making it crucial to understand their potential and assess their viability for sustainable lithium extraction. By conducting a value chain analysis, specific stages and components of the LIB industry where Ethiopia can enhance its competitiveness can be identified. This includes evaluating the current policies and regulations related to mining and exploring opportunities for local value addition and component manufacturing.

This study addresses the need to provide policymakers, industry stakeholders, and potential investors with a comprehensive understanding of Ethiopia's LIB competitiveness and the strategic framework necessary to capitalize on its mineral resources. By undertaking this analysis, gaps and bottlenecks within the value chain can be identified, regulatory challenges, and targeted interventions can be proposed to foster a thriving LIB demand in Ethiopia. Furthermore, the study will contribute to sustainable development by promoting responsible mining practices, encouraging local value addition, and reducing the country's dependency on imported LIBs. It will also support Ethiopia's broader economic diversification agenda by nurturing a technology-driven sector capable of generating employment opportunities and attracting foreign direct investment.

Overall, conducting a lithium-ion battery value chain analysis in Ethiopia is crucial for harnessing the country's untapped potential, maximizing competitiveness, and establishing a strategic framework that aligns with global trends in sustainable energy and transportation.

1.2 Problem Statement

According to the ten-year perspective plan of the Federal Democratic Republic of Ethiopia's Minister of Transportation and Logistics, the nation aims to decarbonize its fleet by introducing 4,850 electric buses and 148,000 small vehicles (Transport Officials Eye Transition to Electronic Vehicles – Ethiopian Monitor, n.d.). After a few years, these vehicles will require battery replacements. Currently, batteries comprise roughly 40% of the total weight and contribute to approximately 50% of the final cost of electric vehicles. With their commendable energy efficiency, these batteries grant electric vehicles an average range of up to 150 km, capable of reaching speeds of 120 km/h. Moreover, they exhibit durability by enduring up to 2000 recharge cycles, which translates to approximately 5 years of service life. (Jussani et al., 2017). This will generate a substantial local demand for lithium-ion batteries. Therefore, it is crucial to evaluate Ethiopia's competitiveness in the value chain for lithium-ion battery manufacturing in order to meet this future local demand.

Despite having ample reserves of important raw materials, Ethiopia has yet to fully capitalize on the opportunities provided by the LIB value chain. The country faces challenges in leveraging the economic and environmental advantages associated with this sector due to a lack of thorough understanding of its competitiveness in the LIB industry and the difficulties it encounters.

One major issue is the lack of knowledge regarding Ethiopia's current position in the LIB value chain. Without a comprehensive value chain analysis of the upstream, midstream, and downstream stages, it is difficult to assess Ethiopia's strengths, weaknesses, and areas for improvement. The country also faces challenges related to technology transfer, infrastructure development, and market access. The absence of clear strategic interventions hinders Ethiopia's ability to attract investments, foster innovation, and create a favorable business environment for the LIB industry. Therefore, it is imperative to conduct a thorough value chain analysis of the LIB value chain in Ethiopia to identify key barriers and opportunities for enhancing competitiveness.

1.3 Research Questions:

I. What are the various stages in the lithium-ion battery value chain?
II. Where does Ethiopia currently stand in the global lithium-ion battery value chain?
III. What is the natural potential and capability of Ethiopia to be involved in the LIB value chain?

IV. Which strategic framework should be applied to utilize competitive advantages in the specific value chain segments of the lithium-ion battery value chain?

1.4 Objectives

1.4.1 General Objective

The general objective of the thesis is to assess Ethiopia's competitiveness and develop a strategic framework to utilize its competitive advantages in the lithium-ion battery (LIB) industry value chain.

1.4.2 Specific Objective:

1) To assess the various stages involved in the lithium-ion battery value chain.

2) To evaluate Ethiopia's current position within the global value chain.

3) To assess Ethiopia's competitiveness to be involved in the lithium-ion batteries value chain.

4) To identify a strategic framework to utilize competitive advantages in the precise value chain segments of the lithium-ion batteries value chain.

1.5 Scope and Limitation

1.5.1 Scope

This study aims to thoroughly examine Ethiopia's competitiveness along the global value chain for lithium-ion battery (LIB) production. It will primarily focus on Ethiopia's competitiveness within the LIB value chain, taking into account the nation's natural resources, current capabilities, and the anticipated demand for LIBs in electric vehicles.

The study will concentrate on the physical flow of commodities throughout the entire LIB value chain. It will primarily focus on the technical and economic aspects of Ethiopia's involvement in the LIB value chain. Therefore, the system boundary for definition and analysis will start from raw material extraction, material processing, battery cell production, battery assembly, end-product manufacturing, and end-of-life battery recycling. The study will utilize data from 2014-2030 related to the LIB value chain. Additionally, the researcher will not develop a new value chain map for LIBs but will instead use the existing LIB value chain map to identify the key stages and key governance factors within the chain.

Long-Term Viability: The study will concentrate on the opportunities and advantages of Ethiopia's participation in the LIB value chain. However, it will not delve into great detail regarding how shifting global priorities, advancing technology, and changing market dynamics may affect the long-term viability and sustainability of Ethiopia's involvement.

Factors of a Socioeconomic Nature: The study may not fully capture the broader socioeconomic implications, such as the potential social and environmental effects of increased mining activities, the displacement of local communities, and the need for sustainable development practices.

The focus will be on identifying strategic areas to enhance Ethiopia's competitiveness in the international market and assessing its competitiveness through value chain analysis that evaluates Ethiopia's current position.

1.5.2 Limitations

1) Lack of Data: The study may be constrained by a lack of additional data on Ethiopia's mineral reserves.

2) Market dynamics: The LIBs market is impacted by rapid changes in technology, consumer preferences, and economic factors.

3) Lack of Stakeholder Perspectives: The study might not fully take into account the perspectives and insights of key stakeholders, such as local communities, policymakers, and investors.

4) External Dependencies: External variables, such as global economic conditions, trade regulations, and geopolitical dynamics, may influence Ethiopia's performance in the LIBs value chain. These external dependencies, which could affect the findings and recommendations, are not thoroughly examined in the study.

Interpreting the study's conclusions and recommendations must consider these limitations, and additional research and analysis may be necessary to address these gaps and clarify any uncertainties.

1.6 Significance

Conducting a Lithium-Ion Battery (LIB) Value Chain Analysis to assess Ethiopia's competitiveness and develop a strategic framework holds significant theoretical importance. It enhances understanding of value chain dynamics, identifies competitive advantages and disadvantages, assesses the nation's potential and capabilities, explores barriers to entry and industry dynamics, and develops a theoretical roadmap for strategic decision-making.

This analysis contributes to theoretical knowledge about global value chains, competitiveness, barriers to entry, and industry dynamics in the LIB sector. Ultimately, it expands our understanding of strategic decision-making and the determinants of competitiveness in a rapidly evolving industry. The study's significance lies in its comprehensive analysis of Ethiopia's competitive advantage (capabilities, potential, challenges, and opportunities) within the LIBs value chain.

1.7 Organization of the Paper

In this chapter, the background and justification of the study are provided, presenting a rationale statement and justifying the purpose of the study. It also outlines the scope, limitations, and contributions of the research. The second chapter discusses the concept of Lithium-ion batteries (LIBs) technology. The conceptual framework of the lithium-ion battery value chain is explored, drawing upon literature reviews from various sources such as journals, reports, books, and papers. The objective is to gain a comprehensive understanding of the lithium-ion battery value chain and identify any literature gaps.

The third chapter focuses on the methodology employed, specifically the value chain analysis. The concept and importance of value chain analysis are clarified to meet the objectives and address the research questions. The chapter also covers the identification of required data types, their sources, and the analysis methods employed. A structure for conducting the study is developed.

The fourth chapter presents detailed results and analysis, proposing a Strategic Framework for Ethiopia's Engagement in the LIBs Value Chain to address the study's objectives. Finally, the fifth chapter discusses the conclusion and recommendations, proposing potential future research areas.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

This chapter's literature review delves into the LIB value chain, value chain analysis, battery metal prices, projected demand, and empirical studies in detail. It aims to identify gaps in the existing literature and establish a conceptual framework for conducting the Lithium-Ion Battery Value Chain Analysis within the context of Ethiopia's competitiveness. This comprehensive knowledge foundation serves as a basis for the subsequent chapters, facilitating a thorough assessment and strategic planning for Ethiopia's involvement in the LIB industry.

2.2 The Soaring Demand for Automotive LIB in the Evolving World of Mobility

The world of mobility is undergoing rapid changes, driven by the exponential growth of the market for electric vehicles (EVs) in all their forms. This, coupled with technological disruptions in the energy sector, has made battery technologies essential for sustainable development. In the market dominated by lithium-ion batteries (LIBs), multiple technologies and chemistries compete, each with their own advantages and drawbacks.

The demand for automotive lithium-ion batteries is on the rise due to the increased production and sales of electric vehicles. Many governments are offering incentives and tax credits to encourage the adoption of electric vehicles, which is expected to further boost the demand for automotive lithium-ion batteries. According to reports, the global lithium-ion battery market was valued at USD 48.19 billion in 2022 and is projected to grow at a compound annual growth rate (CAGR) of 18.9% from 2023 to 2030 (Lithium-Ion Battery Market Size, Share [2023 Trends Report], n.d.).

2.3 Concepts of Value Chain Analysis

The term "value chain" refers to the complete set of activities required to bring a product or service from conception to its final disposal (Porter, 1980). As it progresses from one link to the next, the value chain is expected to become more valuable. It serves as a tool to break down a company into its key activities, helping identify sources of competitive advantage (Hellin & Meijer, 2006).

Value chain analysis involves dissecting the chain into its individual components to gain a better understanding of its structure and operations. By identifying the actors involved at each stage, the value-adding activities, and the costs associated with each activity, it becomes possible to comprehend their roles and connections within the value chain. Value chain analysis was initially developed as a means to enhance competitiveness by identifying areas and strategies for achieving efficiencies, cost reductions, and value enhancement. It provides valuable insights into structural linkages, actors, and dynamics, answering questions about where, how, why, and by whom value is added along the value chain (General, 2013).

Value chain analysis aids in identifying the key stages of the global value chain for LIBs, encompassing raw material extraction, processing, manufacturing, distribution, and end-of-life recycling. It serves as a vital tool for examining structural changes within the value chain. The technical structure, actors involved, territorial considerations, input-output relationships, and governance structures constitute the four dimensions of a value chain. Analyzing these structures provides insights into the production process, participation at each stage, geographic distribution, linkages, benefits, and more (Gereffi, 1994).

Value chain analysis is particularly beneficial for new and less privileged producers, as well as economically disadvantaged countries seeking to enter international markets in a way that promotes sustainable income growth. While value chain analysis has mainly been employed as an analytical tool for understanding how businesses and nations participate in the global economy, it is also useful for comprehending the policy environment that facilitates the efficient allocation of resources within the domestic economy. The value chain consists of three crucial components: barriers to entry, governance, and different types of value chains (Kaplinsky & Morris, 2000). Barriers to entry play a significant role in determining how returns are distributed within a value chain. Typically, primary returns are captured by parties who can protect themselves from competition. Understanding these barriers is essential for assessing competitiveness and identifying areas where participants can enhance efficiencies and create value.

Governance within value chains ensures that interactions between firms exhibit some degree of organization rather than being haphazard. It involves setting parameters that require product, process, and logistical qualifications, influencing activities, actors, roles, and functions within the value chain. Effective governance establishes coordinated and structured interactions among participants.

The value chain of the Lithium-Ion Battery (LIB) industry can be described as both producer-driven and buyer-driven. Producer-driven elements include raw material extraction, cell manufacturing, and battery pack integration, which are primarily driven by mining companies, battery manufacturers, and battery pack manufacturers, respectively.

Buyer-driven elements in the LIB industry involve demand and market trends, as well as design and application integration. Buyers, such as electric vehicle manufacturers and consumer electronics companies, influence the market by determining the specifications and requirements of LIBs. While producers drive manufacturing and raw material extraction, the direction and dynamics of the LIB industry are significantly influenced by buyers and their demands. Collaboration and alignment between producers and buyers are essential for developing competitive and market-responsive products, driving industry growth and innovation.

2.3.1 Definitions of Terms

Lithium-Ion Battery (LIB): A Lithium-Ion Battery (LIB) is a rechargeable battery commonly used in electric vehicles.

Value Chain Analysis: Value Chain Analysis is a strategic management tool used to analyze the activities and processes that a company or country undertakes to deliver a product or service to customers. It involves identifying the primary and support activities that add value to the final product, from the procurement of raw materials to the production, marketing, and distribution of the finished goods. The goal of value chain analysis is to identify opportunities for cost reduction, process improvement, and competitive advantage within the value chain.

Strategic Framework: A strategic framework is a structured approach or model that helps organizations develop and implement strategies to achieve their goals.

Ethiopia Competitiveness: Ethiopia Competitiveness refers to the ability of Ethiopia as a country to compete effectively in the global market and attract investments.

Electric vehicles (EVs) run on one or more electric motors rather than conventional internal combustion engines (ICEs) that burn fossil fuels. They rely on electricity as their main source of propulsion, which is stored in rechargeable batteries.

Value in the value chain is defined as the difference between the total cost of the final good or service and the price of the inputs and activities used to produce it. Each step along the value chain should work towards increasing the overall value of the finished product.

The value chain describes the full range of activities necessary to take a good or service from conception through the various stages of production (involving a combination of physical transformation and the input of different producer services), delivery to final consumers, final disposal after use, and recycling.

Value addition implies both value creation and value capture. Since every strategically significant activity requires an investment in resources, each link in the chain is expected to add value. A chain player's ability to compete and succeed depends on its position along the industry chain and its ability to create and capture value. The creation of value is a function of the ability to deliver high performance on the benefits that are important to the customer (Kothandaraman & Wilson, 2001). Creating value for customers that exceeds the cost of doing so is the ultimate goal of any generic strategy. Therefore, value, instead of cost, should be the basis for determining competitive position (Porter, 1985).

2.4 LIB's Value Chain

The commodity flow in the LIB's value chain encompasses several stages, ranging from raw material extraction to cell recycling. The Li-ion cell value chain represents a closed loop. The figure below provides a summary of the value chain, with the first four steps indicated as having the highest value added due to their complexity, accessibility, and demand for specific knowledge (Sharova et al., 2020). The analysis that follows will examine each stage of the value chain individually.

2.4.1 Overview of The Li-Ion Battery Cell Value Chain Stages

Table 1: Overview of the Li-ion battery cell value chain stages

Development	**Raw material**	**Processed material**	**Electrode**	**Cell assembly**	**Cell module**	**Battery pack**	**Recycling 2nd life**
							
Value adds per step	~ 80%	~ 50%	~ 40%	~ 50%	~ 25%	~ 30%	~ 10%
Key capacity	Access to mines for raw material	Process stability, material characterization	Continuous process, drying time	Process speed. Product variants	Automation degree, welding	Automation degree,	Process efficiency

Source:(Sharova et al., 2020)

2.5 The Various Stages in the LIB Value Chain

The lithium-ion battery value chain consists of several segments, which include the mining and processing of raw materials, the manufacturing of battery components, the assembly of battery cells and packs, and the recycling of used batteries. The value chain of LIBs can be broadly categorized into three key stages: upstream, midstream, and downstream (ATIC, 2018).

The upstream stage involves the extraction of raw materials and the production of processed materials. This stage is critical for securing the necessary inputs for battery production.

The midstream stage encompasses component production and cell manufacturing, which require specialized equipment and skilled labor. This stage focuses on the production of key components and the assembly of battery cells.

The downstream stage involves the assembly of LIBs into battery packs, the manufacturing of electric vehicles, and the recycling of end-of-life batteries. This stage is responsible for the final integration of batteries into various applications and the environmentally responsible disposal or recycling of used batteries.

Each stage of the lithium-ion battery value chain necessitates specialized equipment, expertise, and investment to ensure the smooth flow of activities and the production of high-quality batteries.

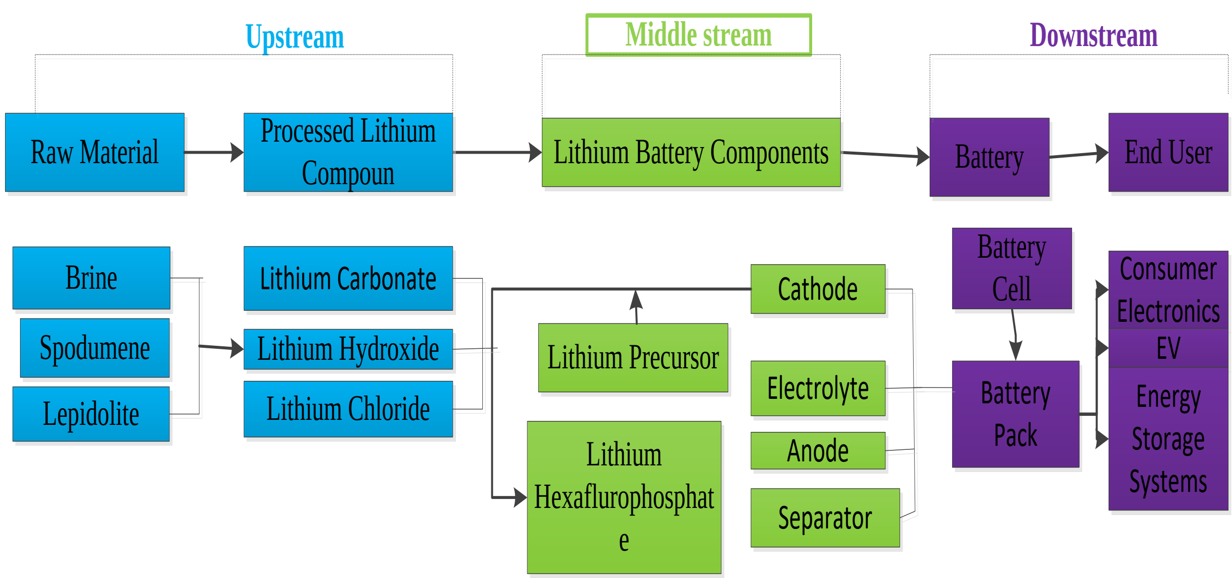


Figure 1; The lithium-ion battery industry chain

Source: (ATIC, 2018)

2.5.1 Downstream Stage of LIB's Value Chain

The downstream stage of the lithium-ion battery (LIB) value chain involves several activities. It includes the assembly of LIB cells into battery packs through manufacturing processes that ensure quality control and testing. These battery packs are then integrated into electric vehicles, providing the necessary power for their operation. Furthermore, the downstream stage also encompasses the end-of-life battery recycling process. Once LIBs reach the end of their useful life, they undergo recycling procedures to recover valuable materials and minimize environmental impact. This recycling process aims to maximize resource efficiency and reduce waste.

Overall, the downstream stage of the LIB value chain involves the crucial steps of assembling battery packs, integrating them into electric vehicles, and ensuring responsible recycling practices at the end of the battery's lifecycle.

2.5.1.1 Battery Pack Manufacturing

To create a complete battery pack, individual lithium-ion battery (LIB) cells need to be connected and assembled together. This process involves strict quality control measures and extensive testing procedures to ensure the reliability and quality of the battery packs. The responsibility for battery pack manufacturing can lie with either the automaker or the cell manufacturer. The cells are typically first housed together in module frames before being assembled into the final battery pack. During this process, the battery management system, electronics, and sensors are integrated with the modules, and everything is enclosed within the battery pack's final housing structure.

In Europe and North America, a third wave of new battery manufacturers is emerging, although currently many of them are in the planning or scaling-up stages. In response to recent supply chain challenges, both battery manufacturers and automakers are becoming more involved in the mining and processing of essential minerals to ensure access to production. If current policies, announcements, and investments materialize, it is projected that by the end of this decade, a quarter of battery production capacity will be located in Europe and the US (IEA, 2022).

2.5.1.2 EV Production

The battery packs are then integrated by automakers into electric vehicles (EVs). During this integration process, the battery packs are connected to the thermal systems, on-board charge module, high voltage distribution box, electric motor, and electric transmission of the EV. The specific integration process may vary depending on the vehicle's structure (International Energy

Agency (IEA), 2022). While existing automakers can retrofit and repurpose their vehicle assembly factories for EV production, automakers that solely focus on EVs may need to build new factories. In 2021, the top six original equipment manufacturers (OEMs) accounted for 52% of EV production, indicating a slight decline compared to 2020 when they accounted for 55% of total revenue. Among the top three EV producers in 2021 were Tesla (US), Volkswagen Group (Germany), and BYD (China), with BYD experiencing impressive growth. Notably, BYD surpassed several other companies to become the third-largest EV producer (International Energy Agency (IEA), 2022). It is important to highlight that China currently dominates the EV battery market. From the mining phase to each stage of EV battery production, China has a significant influence on the market (International Energy Agency (IEA), 2022).

2.5.1.3 End of life LIB Recycling

Battery cell recycling is receiving increasing attention due to concerns about the environmental sustainability of lithium-ion batteries. However, there is currently a lack of standardized processes that can effectively recover raw materials from batteries in a cost-effective manner (Sharova et al., 2020). Currently, the recycling of lithium-ion batteries is primarily limited to portable batteries, as there are still relatively few wastes electric vehicle batteries that have reached their end-of-life (Franco et al., 2014). Countries such as Europe, the USA, China, and Japan are dominant players in the recycling segment of the LIB value chain, with China leading the market and expected to obtain a monopoly position by 2030 (Gaylor Montmasson-Clair, 2021).

There are three main methods for recycling Li-ion batteries: pyrometallurgy, hydrometallurgy, and direct recycling. Hydrometallurgy is highly selective, efficient, and has low gas emissions, while pyrometallurgy allows for direct metal recovery and high productivity. However, pyrometallurgy requires intensive energy use and emissions control, while hydrometallurgical recycling requires chemicals, water, and wastewater treatment (Friedrich et al., 2017). These techniques focus on recovering valuable metals like nickel, cobalt, copper, and aluminum. China currently holds about half of the world's battery recycling capacity, and its dominant position is expected to continue with the announced capacity increase. While most battery recycling businesses are independent recyclers, original equipment manufacturers (OEMs), battery manufacturers, miners, and processors are also entering the market.

Direct recycling is a newer process that offers improved efficiency by preserving the embedded energy and economic value in cathode processing. It works well with cathodes that have lower levels of valuable metals, such as LFP. However, direct recycling is limited by its need for customization to specific cathode chemistries, and the recovered cathodes can only be used to produce the same type of battery. Nevertheless, new processing techniques are being developed to transform recycled chemicals into modern ones, such as from NMC333 to NMC811 (International Energy Agency (IEA), 2022). Recycling efficiency for various elements and selected methods for NMC and LFP chemistries

Table 2; Recycling efficiency LIB’s

Material	Combination of pyrometallurgical and hydrometallurgical processes (NMC and LFP)	Purely hydrometallurgical process (NMC only)	Purely hydrometallurgical process (LFP only)
Lithium	57 %	94 %	81 %
Nickel	95 %	97 %	NA
Manganese	0 %	~100 %	NA
Cobalt	94 %	~100 %	NA
Iron	0 %	NA	0 %
Phosphate	0 %	NA	0 %
Natural graphite	0 %	0 %	0 %

Source: (Sharova et al., 2020)

According to the table, the overall recycling rate for the metallic components of lithium-ion battery cells is approximately 50%, which is relatively low compared to other battery types such as lead-acid batteries, which have recycling rates exceeding 95% in Europe and the USA (source: International Energy Agency, 2014; Lead Association, sourced by Sharova et al., 2020).

As the energy density of cells increases, there is a greater need for stringent safety standards in the recycling process. Additionally, regulations for the transportation of used or defective cells over long distances are urgently required. It is also crucial to integrate recycling procedures into new production setups as part of a closed-loop system to ensure a reliable material supply and cost optimization. Standardized recycling routes that support different chemistries and are affordable and sustainable need to be established. Therefore, further research on new recycling techniques and improvements to existing ones are essential. Making industrialized recycling services available to Asian rivals could also be advantageous for European recycling businesses.

Policy mandates, such as extended producer responsibility for battery recycling, are driving the establishment of joint ventures between original equipment manufacturers (OEMs) and re-use and recycling businesses. For example, SK Innovation and KIA are collaborating on re-use and recycling initiatives, where used batteries are evaluated by KIA for potential use in stationary storage, and the remaining batteries are sent to SK Innovation's recycling process for material recovery. Renault, Veolia, and Solvay have formed a consortium with the objective of establishing a closed-loop for battery cells through re-use and recycling. BMW, Umicore, and Northvolt have also formed a consortium to develop a closed-loop system for battery cells. These initiatives and collaborations demonstrate the growing importance of sustainable battery recycling and the need for partnerships across the industry to establish efficient and environmentally friendly recycling practices.

2.5.2 Midstream stage of LIBs Value Chains

The midstream stage of the lithium-ion battery (LIB) value chain involves various processes related to the manufacturing and assembly of LIB components. This includes the production of separators, electrolytes, cathode and anode materials, and other specialized components that are crucial for battery and cell production. Currently, Asian nations, particularly China, dominate the production at every stage of the midstream LIB value chain. China has a strong hold on the entire supply chain, from mining of raw materials to anode material production. As a result, it is expected to continue dominating anode material production in the foreseeable future. Moreover, a majority of the top ten anode material production companies are based in China, which means that foreign investments by these Chinese companies play a significant role in anode production outside of China. It is worth noting that the cost of raw materials for producing graphite anodes is not currently high enough to stimulate substantial expansion of production. However, there are exceptions to this trend. For example, Nouveau Monde Graphite is building a plant in Canada that will produce both graphite anodes and active materials, indicating some potential for diversification in anode production.

Overall, the midstream stage of the LIB value chain remains heavily influenced by Asian nations, particularly China, which holds a dominant position in anode material production. However, there are emerging developments, such as the establishment of new production facilities in other countries, that could bring about a degree of diversification in the midstream segment of the LIB value chain.

Table 3: Manufacturing Capacity by Country for Various Battery Components

Country	Cathodes Manufacturing (3 M tons)	Anode Manufacturing (1.2 M tons)	Electrolyte Solution Manufacturing (339,000 tons)	Separator Manufacturing (1,987 M sq. m)
United States	----	10%	2%	6%
China	42%	65%	65%	43%
Japan	33%	19%	12%	21%
Korea	15%	6%	4%	28%
Rest of World	10%	---	17%	2%

Source: Bloomberg NEF, Battery Components Manufacturing Asset Map 2019, Accessed March 15, 2021., sourced by (FCAB, 2021)

2.5.2.1 Cell Component Production

The various highly specialized components that make up batteries are numerous, such as electrolytes, separators, and cathode and anode materials. The creation of these components requires sophisticated materials chemistry and engineering. The processing involved in producing high purity battery active materials is the most complicated. Raw materials like lithium, nickel sulfate, and hydrogen hydroxide undergo additional processing through specialized syntheses to create the active materials for the cathode and anode. Transition metal oxides, such as lithium cobalt oxide, lithium nickel cobalt, nickel manganese oxide, lithium iron phosphate (LFP), and aluminum oxide (NCA), are the most effective cathode active substances in Li-ion batteries.

The electrode manufacturing process consists of six steps: mixing the active and inactive components of the electrode to create a slurry, coating the slurry on the current collector, drying, calendaring, slitting, and final (vacuum) drying. Figure 4 illustrates these steps and their associated value-added.

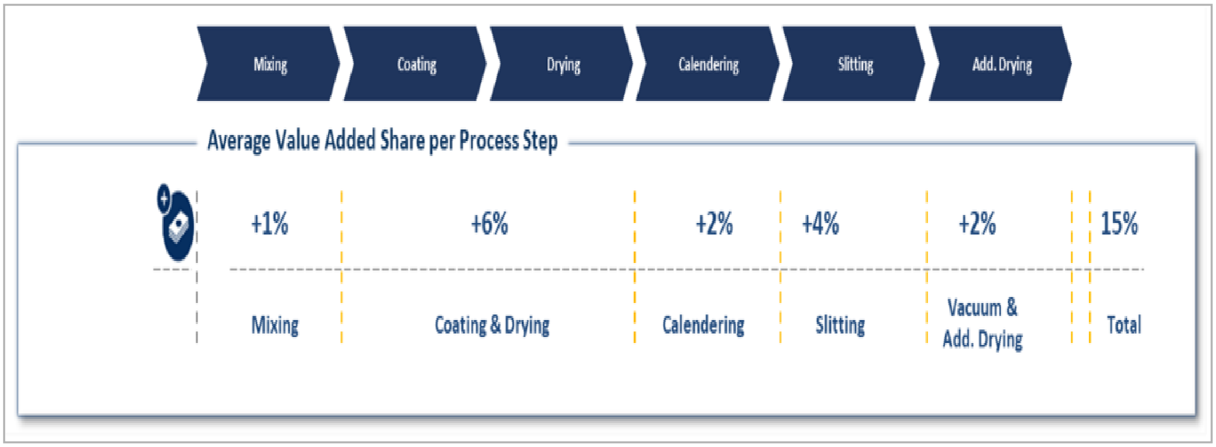


Figure 2; Overview of the electrode manufacturing process

Source: (Sharova et al., 2020)

The manufacturing of electrodes is a highly intricate process that requires precise environmental control and the setting of process variables to achieve uniform electrode thickness sheets. Electrode lines are established by well-known cell manufacturers, and several businesses, primarily from Japan, provide internally equipped electrodes. It is worth noting that there are a number of companies headquartered in Germany that supply machinery for electrode production lines, along with energy-efficient solutions.

Graphite, which can be natural or synthetic, serves as the primary active component of an anode. Given that graphite has been the predominant anode material for a long time, the production of graphite anode materials is more developed and established compared to cathode materials. However, both types of graphite require sophisticated processing. Natural flake graphite used in batteries is processed into spherical graphite to make it more homogeneous for use as an anode material. Synthetic graphite is produced using refined hydrocarbon materials such as coke. To enhance performance and increase energy density, small fractions of silicon are being incorporated into graphite anodes.

Microporous membranes, engineered to serve as separators, are frequently coated with ceramic and made of polyethylene or polypropylene to enhance security for electric vehicles (EVs).

Electrolytes consist of a salt and a solvent, and synthesis followed by mixing are necessary steps in their production.

In a lithium-ion cell, the cathode represents approximately 25% of battery costs and plays a crucial role in determining battery performance (Gaylor Montmasson-Clair, 2021).

By the end of this decade, a quarter of the production capacity for cathode materials is projected to be located in Europe and the US, assuming current policies, announcements, and investments materialize. Partnerships such as the one between Volkswagen and Umicore aim to increase Europe's capacity for producing cathode materials. Additionally, Redwood Materials and L&F have plans to construct a US factory that will produce cathode material for 5 million EVs annually by 2030, with similar plans for Europe. European cell manufacturer Northvolt also plans to produce over 100 GWh of its own cathode material annually (IEA, 2022).

Korea and Japan hold significant shares in the supply chain for cathode and anode materials after raw material processing. Korea accounts for 15% of cathode and 3% of anode material production capacity, while Japan accounts for 14% and 11%, respectively (IEA, 2022). Seven companies own 55% of the world's capacity to produce cathode materials, including important players such as Sumitomo (Japan), Tianjin B&M Science and Technology (China), Shenzhen Dynanonic (China), and Ningbo Shanshan (China) (IEA, 2022).

China dominates the entire supply chain for graphite anodes, accounting for 80% of the world's graphite mining. It is also the leading producer of cathodes, with 70% of cathode production and 80% of anode production for specialized materials (IEA, 2022).

The global production capacity of separators is highly concentrated, with five companies accounting for 50% of it. Three significant companies in this field are Zhuhai Enjie New Material Technology (China), Shanghai Putailai New Energy Technology (China), and SK IE Technology (Korea) (IEA, 2022).

Jiangxi Tinci Central Advanced Materials in China produces 35% of the world's electrolyte salt. Chinese firms Ningbo Shanshan, Shenzhen Capchem Technology, and Zhangjiagang Guotai-Huarong New Chemical Materials are among the top producers of electrolytes. It is worth noting that most businesses specializing in cell components production focus on manufacturing specific parts only (International Energy Agency (IEA), 2022).

The value chains of Lithium-ion Batteries (LIBs) in the cell component production segment depend on manufacturing technology and the quality of raw materials to add value. This segment encompasses the production of various constituent parts of LIB cells. To maintain the quality of components and prevent impurities and moisture from affecting their performance, production processes in this stage require tightly controlled clean and dry room conditions. Maintaining purity is crucial for LIB cells to function properly and have a long lifespan. Anode and cathode materials, separators, electrolytes, and other cell components are made using sophisticated processing techniques.

2.5.2.2 Cell Manufacturing

The manufacturing of electrodes and the assembly of battery cells are two major steps in the multi-step process of creating battery cells. While the cell designs may vary among manufacturers, the processes used for cell production are well-established, utilizing mature technologies that are similar across the industry. These processes require significant amounts of energy and are conducted in tightly controlled environments, free from impurities and moisture.

To reduce emissions during cell production, it is important to utilize electricity from low-carbon energy sources. The first step involves creating electrodes by combining cathode or anode active materials with binders, solvents, and additives before coating them onto aluminum (for cathodes) or copper (for anodes) foil current collectors. The electrodes are then rolled (calendared) and dried. Subsequently, the electrodes are stacked with a separator placed in between to form the cell (International Energy Agency (IEA), 2022).

Battery cell production is highly concentrated and capital-intensive, with the top three producers in 2021 accounting for 65% of global production: CATL (China), LG Energy Solution (Korea), and Panasonic (Japan). Established conglomerates with extensive experience in producing batteries for consumer electronics are predominantly found in Japan and Korea, where cells are manufactured (International Energy Agency (IEA), 2022).

China holds a significant competitive advantage in the sector, as it has the capacity to produce approximately 75% of the world's battery cells. Through concentrated efforts and substantial financial investments in the electric vehicle sector, China has gained a significant market share in battery cell production (International Energy Agency (IEA), 2022).

The cell manufacturing industry is dominated by a small number of companies, primarily located in Asia. Key factors that influence competitiveness in cell manufacturing include economies of scale and access to knowledge and intellectual property (Goodenough et al., 2021). Setting up a cell manufacturing facility incurs substantial costs, and it is projected that a facility in China in 2021 would cost approximately US$1.5 billion (Gaylor Montmasson-Clair, 2021).

There are currently three main LIB formats available, depending on the application: cylindrical, prismatic, and pouch formats (excluding button cells, which are typically non-rechargeable). Each format has its own advantages and disadvantages.

The formats are schematically shown in following figure: cylindrical (left), pouch (middle), prismatic (right)

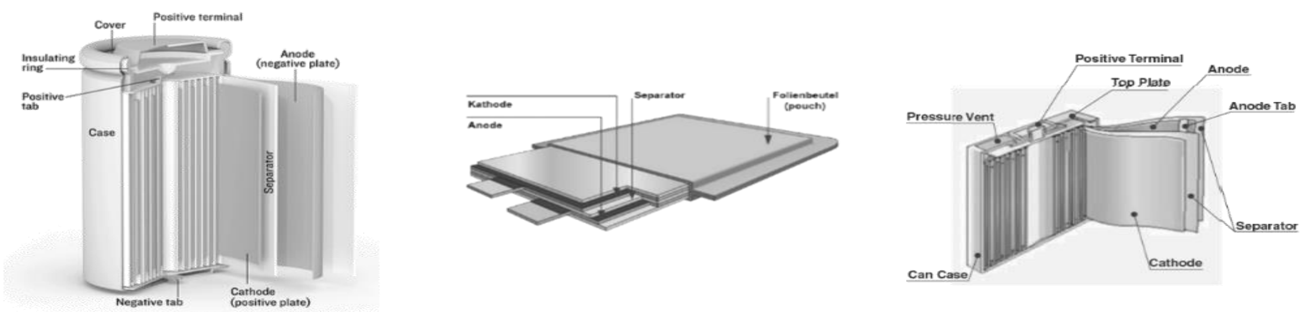


Figure 3; LIB cell formats

Source: (Achim Wiebelt, Tobias Isermeyer, 2009)

Prismatic cells are specifically designed for automotive applications, including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). These cells are well-suited for use in battery packs due to their ease of integration and high mechanical integrity. Prismatic cells are considered the safest cell format currently available in the market. However, they do have certain drawbacks. The housing for prismatic cells tends to be more expensive compared to other formats, and they generally have lower cell-level energy density when compared to cylindrical formats. Despite these limitations, prismatic cells remain a popular choice for automotive applications due to their safety features and ease of integration.

Table 4: Top cell manufacturers and machinery providers for cell assembly

Market Participants (HQ)	Equipment Manufacturers for cell assembly	Equipment Manufacturers for formation and aging
LG Chem (South Korea)	Hibar	Maccor
Panasonic (Japan)	Manz	Manz
SK Innovation (South Korea)	Trumpf	Bitrode
Samsung SDI (South Korea)	NAT	Digatron
BYD (China)	ATS	ATS
CALB (China	Harro Höfliger	PEC
CATL (China)	Jonas & Redmann	Chroma

Source: (Sharova et al., 2020)

While Asian players dominate the equipment manufacturing market for lithium-ion batteries, European producers also have the potential to contribute due to their strategically located production facilities. However, a major challenge is that most equipment manufacturers focus on specific process steps rather than providing complete assembly lines. This hurdle can be overcome through advancements in existing technologies, the introduction of innovative ideas, and close collaboration with Tier I and Tier II suppliers. Cell manufacturing, considered the most crucial step in the battery value chain, is projected to contribute up to 40 percent of the value creation in the battery industry by 2030. This highlights the significance of efficient and effective cell manufacturing processes (Schnell et al., 2018; Michaelis et al., 2020; Weimer et al., 2019).

2.5.3 Upstream EV LIB's Value Chain

The upstream stage of the lithium-ion batteries (LIBs) value chain encompasses the extraction of raw materials and the subsequent processing required for battery manufacturing. However, one significant challenge in this stage is the geographic concentration of battery metals, which makes the supply chain vulnerable to supply shocks and restrictions. Due to the limited number of regions or countries where these metals are abundant, any disruptions in the supply can have a significant impact on the availability and cost of raw materials necessary for LIB production. This highlights the importance of diversification and strategic resource management to mitigate potential risks in the upstream stage of the LIB value chain.

2.5.3.1 Raw Materials Extraction

During the raw material extraction stage of the lithium-ion battery value chain, lithium-rich ores and other raw materials necessary for battery production are mined and extracted. This stage involves a detailed evaluation of the value chain, including the assessment of raw material deposits, the demand for raw materials, the extraction process, and the importance of sustainable extraction practices.

Lithium-ion battery cells consist of various elements such as lithium, nickel, cobalt, manganese, aluminum, copper, silicon, tin, titanium, and carbon. These substances are obtained by mining raw materials from the Earth's crust or by recovering them from surface water sources. Some of these materials are considered "critical raw materials" (CRMs) due to their economic significance and high supply-risk factors (IEA, 2022).

One of the major challenges in raw material extraction is the accessibility of ore deposits, which are often distributed unevenly among resources. In particular, lithium, high-grade nickel, and cobalt, which are key components of cathode precursors, may face potential scarcity issues. Automotive original equipment manufacturers (OEMs) heavily rely on mining and material companies, which may demand significant margins, especially for scarce commodities. Additionally, the development of new mines, such as those for lithium and cobalt, can involve lengthy ramp-up times and challenging licensing procedures (Sharova et al., 2020).

Addressing these challenges requires sustainable and responsible extraction practices, as well as efforts to diversify the sources of raw materials. It is important for stakeholders in the lithium-ion battery value chain to collaborate and develop strategies to ensure a stable supply of raw materials while minimizing environmental impacts and promoting social responsibility.

Table 5: Overview of the materials availability for Li-ion cell production

	Raw material required	Demand vs. supply 2025	Risk
Lithium battery cell	Lithium	Potential shortage	Lead time for resource extraction
	Cobalt	Potential shortage	Only by product of other mining materials (Cu., Ni., Mn), inelastic offer
	Nickel	Potential shortage	Potential shortage of class 1 nickel
	Others (manganese, aluminum, graphite, and etc.)	No shortage	No shortage

Source: (Sharova et al., 2020)

The raw material extraction stage plays a critical role in the value chain of Li-ion battery cells, contributing approximately 80% of the value from ore extraction to refined metal salts. Having access to the right mines is crucial at this stage, and the players involved must have a deep understanding of the processes involved in extracting raw materials from ore deposits (Sharova et al., 2020).

When comparing current mining production to mineral reserves, there is significant untapped potential for diversification in the long term. Australia, for example, holds 22% of the world's nickel reserves and is already the largest producer of lithium. However, Australia's current production accounts for only 6% of the global total. In the case of cobalt, Australia has the second-largest reserves, representing almost 20% of the global total, despite contributing only 3% to current production (International Energy Agency (IEA), 2022).

These statistics highlight the importance of exploring and developing mining operations in countries with substantial mineral reserves. Diversifying the sources of raw materials can enhance the stability and resilience of the Li-ion battery value chain, reducing dependency on a few dominant regions and mitigating supply risks.

2.5.3.1.1 Lithium

Lithium is a highly valuable metal due to its small atomic mass and high electrochemical reactivity. Its unique chemical properties make it a crucial component in lithium-ion batteries (LIBs), which are known for their lightweight and high energy density. Lithium serves as an active material in the cathode and electrolytic solution of LIBs, enabling the storage and utilization of electrical charge. The name "lithium-ion" derives from the lithium ions that carry charge and facilitate the charging and discharging processes of the batteries. The demand for lithium is driven by its use in batteries that power various personal electronic devices and electric vehicles (EVs). EV LIBs, in particular, are expected to contribute significantly to the growth in lithium demand. Experts predict that the majority of future lithium consumption will come from LIBs used in EVs (LaRocca, 2020).

Lithium is extracted from two primary sources: hard rock and brine. Brines with high lithium content are found in saltwater deposits, predominantly in Chile, Bolivia, and Argentina in South America. These brine deposits often contain other valuable elements such as sodium, potassium, magnesium, and boron, which help offset the costs of pumping and processing brine. Australia is the leading producer of lithium from hard rock sources, specifically from spodumene ore. Australia accounts for more than half of the world's lithium production.

As unconventional lithium resources, like geothermal brine, are being explored, new extraction processes are being developed. Currently, the top five lithium producers contribute to approximately half of the global lithium supply. Some major lithium suppliers include Livent Corporation (United States and Australia), Allkem (Australia), Sociedad Química y Minera de Chile SA (Chile), Ganfeng Lithium Co., and Pilbara Minerals. It is worth noting that lithium extraction companies typically focus on chemical and mining industries, distinguishing them from other battery metal suppliers (International Energy Agency (IEA), 2021).

2.5.3.1.2 Global Production of Unprocessed Lithium Minerals

Mining operations typically utilize open-pit mines to extract lithium from rock deposits, while brine extractions involve distilling lithium salts in sun evaporation ponds. The subsequent processing of lithium brine concentrates into lithium carbonate is discussed in detail in the section on processed lithium compounds. Both types of resources, rock deposits and brines, are used for lithium in EVs. However, lithium from mine deposits is more affordable when producing EV LIBs.

The following table presents the production trends from 2014 to 2019 for raw (unprocessed) lithium minerals and EVs. During this period, raw lithium mineral production experienced a significant increase, while EV production only saw a slight increase due to declining battery prices. Australia is the primary producer of raw lithium, followed by Chile, which has multiple operations in the Atacama Desert near the borders with Argentina and Bolivia. Bolivia and Argentina also possess substantial lithium reserves and are rapidly expanding their production capacities. It is worth noting that Chile, Argentina, and Bolivia often undergo further processing before exporting their lithium materials. Additionally, China's brine and mineral extraction of lithium is a small but rapidly expanding industry. Global production history of unprocessed lithium minerals (raw stage 1 and raw stage 2) suppliers' countries by metric tons from 2014 to 2018.

Table 6: Global production of unprocessed lithium minerals

Country	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Australia	13,300	14,100	14,000	40,000	58,800	42,000
Chile	11,500	10,500	14,300	14,200	17,000	18,000
China	2,300	2,000	2,300	6,800	8,000	7,500
Argentina	3,200	3,600	5,800	5,700	6,400	6,400
Zimbabwe	900	900	1,000	800	1,600	1,600
All other	500	400	600	1,500	3,200	1,500
Total	31,700	31,500	38,000	69,000	95,000	77,000

Note: 2019 data are estimated by USGS. U.S. Production data have been withheld. Figures are in pure lithium content, which is 100 percent lithium.

Source: Jaskula, "Mineral Commodity Summary: Lithium," January 2020. Sourced by (LaRocca, 2020)

Table 7: Top lithium mining companies Company

Company name	**Mining location**	**Mining capacity (t/a)**	**Market share**
Albemarle	Australia, Chile, U.S.	73,000	31%
SQM	Chile,	50,000	21%
Tianqi	Australia	40,000	17$
FMC	Argentina	19,000	8%
Galaxy Resources	Australia	15,000	6%
Jiangxi Ganfeng	Australia	11,000	5%

Source: (Berman et al., 2018)

2.5.3.1.3 Lithium extraction process4.5.2.3 Lithium extraction process

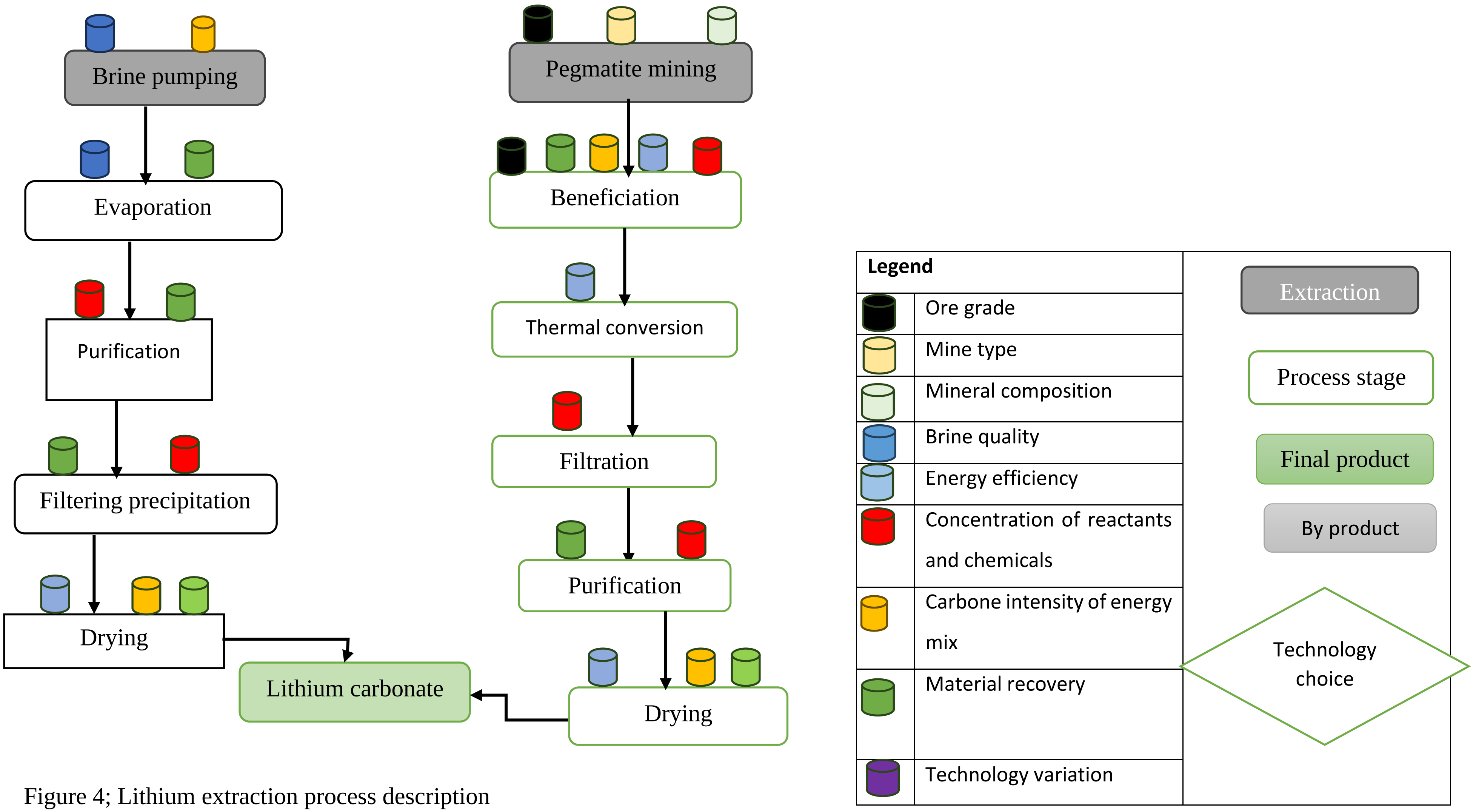


Figure 4; Lithium extraction process description

Source: (Manjong et al., 2021)

2.5.3.1.4 Cobalt

The extraction of cobalt involves three main processes: pyrometallurgy, hydrometallurgy, and vapor-metallurgy. Pyrometallurgy utilizes heat to separate metals based on their unique properties, such as density and melting point. This method is commonly used for sulfide ores. In hydrometallurgical processing, pressure acid leaching is the most frequently employed technique. The ore is slurried, pre-heated, and combined with a sulfuric acid solution at high temperature and pressure in order to extract cobalt. The metals are transformed into sulfate salts, which are then cleaned to obtain a clear cobalt solution. Laterite ores are processed using these methods at standard atmospheric pressure. Cobalt can also be recovered and refined from ore, matte, and concentrate. In vapor-metallurgy, the ore containing the extracted metal is vaporized by passing carbon monoxide and other gases, and the cobalt is deposited in a separate chamber (Farjana et al., 2019).

Cobalt is primarily extracted as a by-product of nickel (50%) and copper (44%) production. The Democratic Republic of the Congo (DRC) is the world's largest producer of cobalt, accounting for over 70% of global production. Refinement is mainly carried out by Chinese companies. The table below illustrates the major cobalt producers. Cobalt prices experienced a significant increase of over 300% between 2016 and 2018 due to the market's inability to meet the growing demand for electric vehicles and the concentration of reserves in specific regions. However, the prices declined in 2019 due to increased mining supply and the shift towards materials with lower cobalt content (source: Sanderson, (2019) sourced by Sharova et al., (2020)). While a new price increase cannot be ruled out due to a potential supply-demand mismatch. In the DRC, a significant portion (10-20%) of cobalt production comes from artisanal and small-scale mining operations (IEA, 2022).

Table 8; Top cobalt mining companies

Company name	Mining location	Mining capacity (t/a)	Market share
Glencore	DRC, Australia	42,200	30 %
China Molybdenum	DRC	16,800	12 %
Jinchuan	DRC	8,400	6 %
Norilsk Nickel	DRC	7,000	5 %

Source: (Berman et al., 2018)

2.5.3.1.5 Cobalt extraction process flow diagram

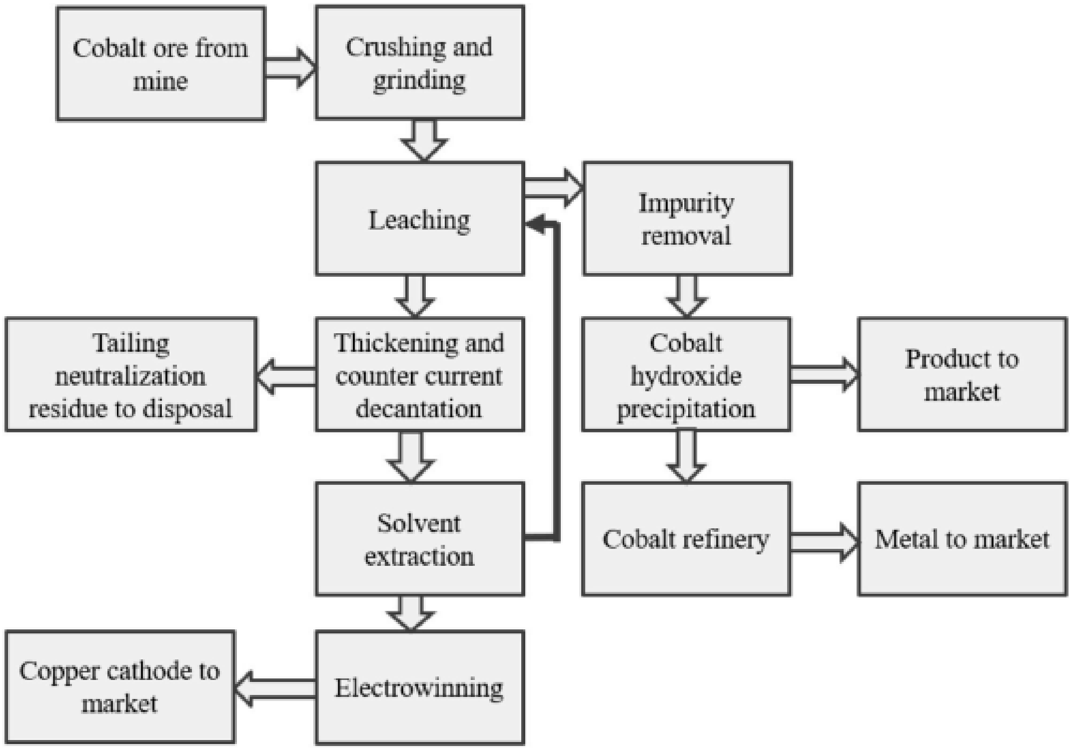


Figure 5; Cobalt extraction process flow diagram

Source; (Farjana et al., 2019)

2.5.3.1.6 Nickel

Nickel deposits can be categorized into two main types: sulphide and laterite deposits. Sulphide deposits, which generally contain higher-grade nickel, are primarily found in Russia, Canada, and Australia. These deposits are easier to process into nickel suitable for Class 1 batteries. On the other hand, laterite deposits are predominantly found in Indonesia, the Philippines, and New Caledonia and tend to have lower-grade nickel. Additional energy-intensive processing is required to produce nickel suitable for batteries from laterite deposits. Unlike lithium, the nickel market is less concentrated, with nine companies supplying half of the world's nickel production.

Key suppliers of nickel include Nickel Asia Corporation (Philippines), Glencore (Switzerland), Vale SA (Brazil), BHP Group (Australia), Jinchuan Group (China), and Tsingshan (China). Historically, the nickel market has been dominated by the steel industry. However, with the shift to nickel-rich cathode materials in batteries, the demand for nickel is expected to increase significantly. This is because only "first-class nickel" is suitable for battery production. Sulphide ore deposits, which account for only 40% of total nickel reserves, make the mining of high-purity nickel economically viable. The nickel market is relatively fragmented, with mining and refining often being handled by the same companies.

The supply of nickel is more diverse. While Indonesia provides the majority of Class 2 nickel, which represents around 40% of the global supply, only a small portion of it is currently used in EV battery production. Russia, being the third-largest nickel producer, accounts for approximately 20% of the world's supply of Class 1 battery-grade nickel (Sharova et al., 2020).

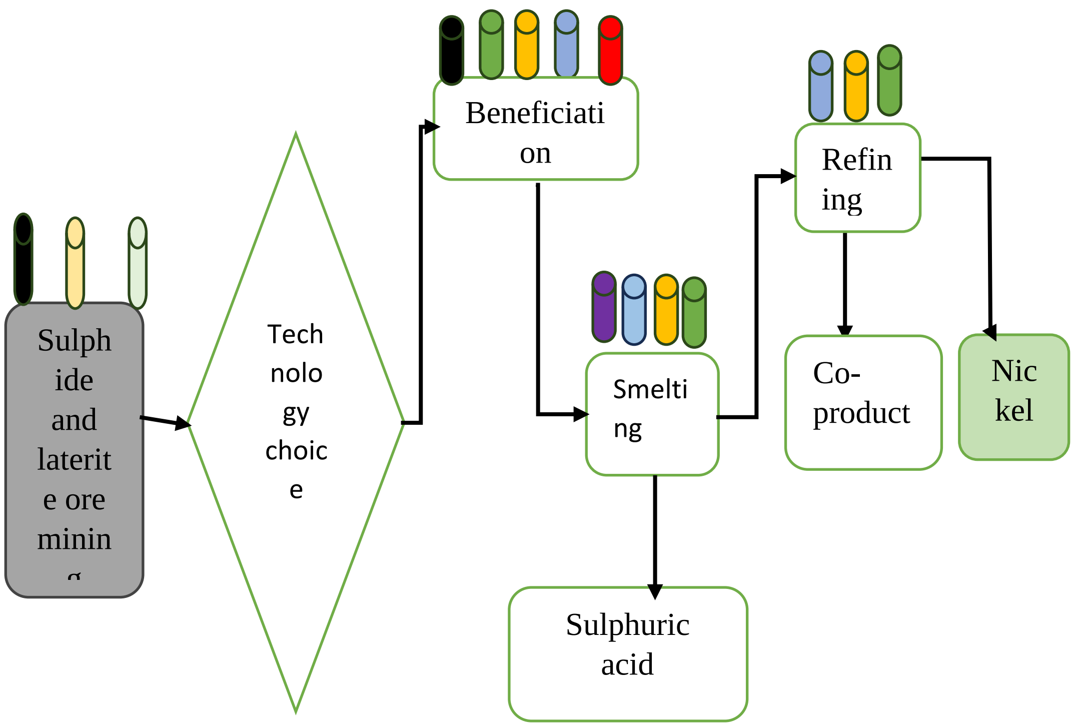
Africa has relatively few nickel reserves, with the East African Nickel Belt being the main source. However, BHP has agreed to invest USD 100 million in the KABANGA Nickel project in Tanzania, which is considered one of the world's largest nickel deposits. Similar to Bolivia's lithium resources, many nickel resources have been identified in Africa, but reported reserves are limited. This highlights the potential that modern geological surveys have in uncovering valuable resources in today's market (Goodenough et al., 2021).

Table 9; Top nickel mining companies

Company name	Mining location	Mining capacity (t/a)	Market share
Vale	Brazil, Canada, etc.	248,000	21%
Norilsk Nickel	Russia	201,000	17%
Glencore	South Africa	106,000	9%
Jinchuan Group	DRC, Zambia, South Africa, China	83,000	7%

Source: (Berman et al., 2018)

2.5.3.1.7 Nickel Extraction Process



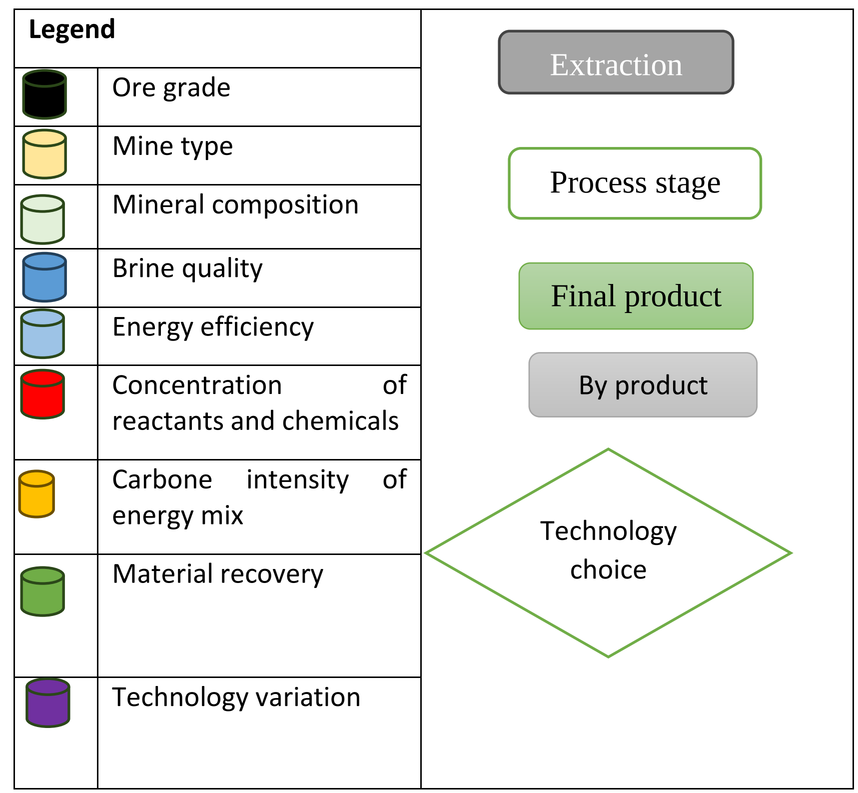


Figure 6; Nickel extraction process description

Source: (Manjong et al., 2021)

2.5.3.2 Raw Material Processing

To produce high-purity chemicals like lithium hydroxide and nickel sulfate, complex processing methods are required. The refining procedures for these raw materials are typically large-scale and technologically intensive, relying on processes like pyrometallurgy and hydrometallurgy, which involve heat or chemical treatment. The nature of the raw material determines the specific industrial processes used to transform the ore into the desired chemicals, such as lithium carbonate or hydroxide, or cobalt and nickel sulfate. Certain raw materials are better suited or exclusively used for battery precursor production. For example, lithium carbonate derived from lithium brine is suitable for general lithium demand but not for high-nickel Li-ion batteries. Lithium hydroxide, produced from spodumene hard rock sources, is better suited for high-nickel chemistries. Similarly, Class 1 nickel, which is most economically produced from nickel sulfides, is typically used to synthesize nickel sulfate for battery production. Additional processing is required to convert Class 2 nickel into Class 1 nickel (LaRocca, 2020).

Advancements in processing technologies are expanding the flexibility of nickel processing routes.

- High-pressure acid leaching (HPAL) allows for the production of Class 1 nickel from lower-grade laterite resources.
- Mixed hydroxide precipitate (MHP), an intermediate product in the nickel refining process, can be further refined into nickel sulfates at a lower cost using laterite resources.
- Nickel matte, a precursor for the metal used in batteries, can also be produced from laterite resources, although this method generates higher emissions compared to other methods.

China plays a dominant role in processing raw materials for lithium, cobalt, and graphite, accounting for over half of the world's production. The processing of raw materials is highly concentrated, with five major companies and their supply chains controlling three-quarters of the world's production capacity for lithium carbonate and hydroxide, for example. In some cases, mining companies handle both extraction and refining processes. For instance, Chinese mining company Ganfeng has expanded its operations to include processing and refining lithium, with a focus on increasing production of lithium hydroxide. In other cases, raw materials are exported to external parties for refining, with many processing firms in China, such as Chengxin Lithium Group or Zhejiang Huayou Cobalt, involved in the refining process. This is particularly true for

Australian spodumene, as only a few miners currently produce integrated supplies of lithium chemicals (International Energy Agency (IEA), 2022).

Manganese resources are widely dispersed; however, concerns about geographic supply concentration arise during the production of high-purity manganese sulfate. Currently, China holds approximately 90% of the world's production capacity for manganese sulfate, highlighting the need for additional diversified refining capacity. New manganese sulfate projects are emerging in Australia, Europe, Indonesia, and the United States to address this concern.

2.5.3.2.1 Processed Lithium Chemicals

Lithium intermediate forms, such as lithium carbonate and lithium hydroxide, are considered processed lithium compounds. These compounds, including lithium carbonate and lithium hydroxide, are used as inputs for the production of cathode materials or are further processed to create battery electrolytes. The choice of concentrating techniques depends on the original raw material and the desired final chemical compound, and it varies for lithium ores and brine concentrates. The accompanying figure illustrates the process of transforming naturally occurring materials into processed lithium chemicals, such as lithium carbonate and lithium hydroxide, and refining them into compounds like lithium chloride and lithium metal. These refined compounds are essential inputs in the manufacturing of LIBs (LaRocca, 2020).

Global production history of lithium from 2014 to 2019

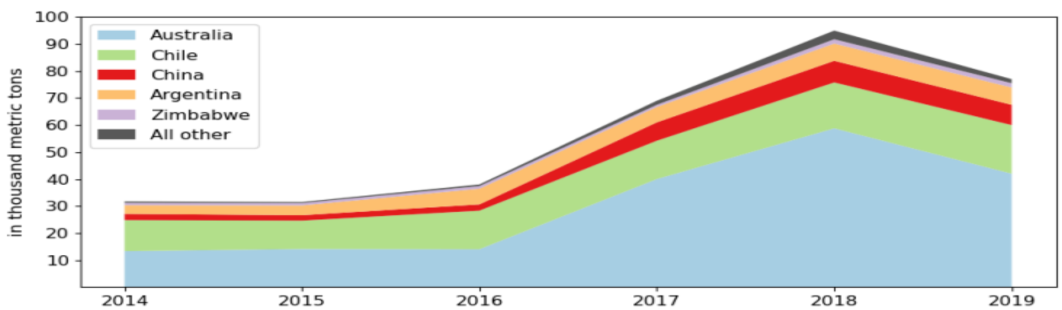


Figure 7; Global production of lithium (measured in pure lithium content),

Source: Jaskula, “Mineral Commodity Summary: Lithium,” 2020, source by (LaRocca, 2020)

Table 10: Lithium product forms

Form of lithium (process stage	Description	Source(s) type	Geographic sources
Unprocessed lithium minerals (raw stage 1)	Other mineral substances, not elsewhere specified or included	Mine extraction	Australia, China, Argentina, Zimbabwe
	Lithium rich salt concentrates	Brine extraction	Chile, Argentina
Processed lithium chemicals (raw stage 2)	Lithium carbonate	Lithium rich ores and salt concentrates	Chile, China
	Lithium oxide and hydroxide	Lithium rich ores or lithium carbonate	China
Refined lithium compounds	Chlorides, not elsewhere specified or included	Lithium carbonate	China, South Korea, Japan
	Other Fluorides, fluorosilicates, fluoroaluminates and other complex fluorine salts	Various lithium compounds, such as lithium chloride, lithium hydroxide, or lithium fluoride.	China, South Korea, Japan
	alkali metals, other than sodium	Lithium chloride	China, South Korea, Japan

Source: (LaRocca, 2020)

The process capability during the cathode production process plays a vital role in determining the chemical outcome, whether it is Li-carbonate or Li-hydroxide. The characteristics of the cathode material are directly influenced by the quality of the raw materials used.

The composition of the raw materials has a significant impact on the performance of the cathode, as it affects its overall quality and properties.

Table 11: Top cobalt refining companies

Company name	Mining location	Refining capacity (t/a)	Market share
Huayou	China	17,800	15 %
Freeport Cobalt	Finland	12,900	10 %
Jinchuan	China	12,700	10 %

Source: (Berman et al., 2018)

Table 12: Top nickel refining companies

Company name	Mining location	Refining capacity (t/a)	Market share
Vale	Brazil, Canada, etc.	236.000	21 %
Norilsk Nickel	Russia	212,000	19 %
Glencore	Canada	138,000	12 %

Source: (Berman et al., 2018)

2.6 Battery Metal Prices Increased Dramatically

Battery metal prices increased dramatically in early 2022, posing a significant challenge to the EV industry.

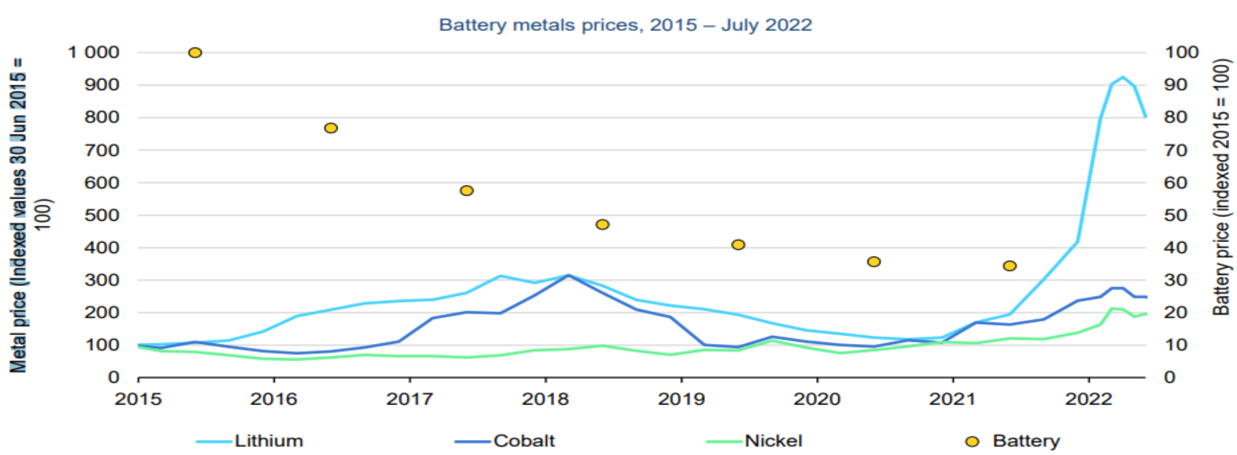


Figure 8; Battery metal prices

Sources: IEA analysis based on S&P Global, sourced by (IEA, 2022)

2.6.1 Projected Demand of Critical Material of LIB

The following figure shows the exponential increase in demand for critical materials driven by electric vehicles (EVs). It presents the projected demand for critical materials of lithium-ion batteries (LIBs) and anode/cathode materials to meet the anticipated demand in 2030 compared to the levels in 2021.

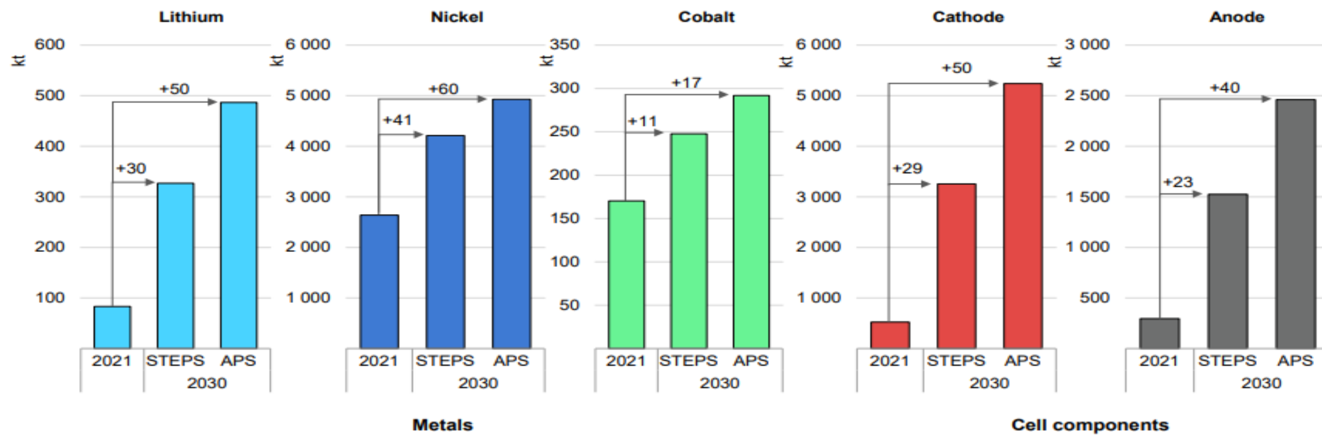


Figure 9; Projected demand of critical material of LIBs and anode/cathode

Sources: IEA analysis based on S&P Global. It is sourced by (International Energy Agency (IEA), 2022)

2.7 Review of Empirical Study

The study on the value chain of lithium-ion batteries and related opportunities in Europe suggests that Europe currently holds a small market share in the raw and processed materials, cell component, and cell manufacturing sectors. However, it is a market leader in the pack and vehicle manufacturing, as well as recycling segments. The European Union's automotive sector is expected to continue leading in EV production (Franco et al., 2014).

Another study focusing on South Africa explores the opportunities for developing the lithium-ion battery manufacturing value chain in the country. It suggests that mineral refining and battery production in South Africa are ready for scaling up. The study also mentions that the economic viability of cell production and recycling will be further investigated in the medium to long term (Gaylor Montmasson-Clair, 2021).

A study conducted in Australia highlights the country's new business opportunities in the lithium-ion battery value chain. Australia is the largest producer of lithium globally and possesses mineral reserves that contain 90% of the elements required for lithium-ion battery chemistry. The study emphasizes Australia's competitive advantage in the emerging lithium-ion battery market and the ongoing new energy revolution (ATIC, 2018).

In a study focusing on the global value chain of batteries and the technological challenges associated with electric vehicle mobility, it is suggested that lithium mining could provide a potential avenue for Brazil to participate in the battery global value chain. The presence of existing mining technology and expertise in Brazil, combined with substantial lithium reserves in neighboring South American countries, supports this suggestion (Jussani et al., 2017).

2.8 Literature Gap

Lithium-ion batteries (LIBs) are playing a crucial role in the global transition towards renewable energy and electric vehicles. Many countries are making significant investments in the LIBs value chain to meet the increasing demand. Ethiopia, in line with its 10-year plan for transport and logistics, also anticipates a rise in demand for LIBs (Transport Officials Eye Transition to Electronic Vehicles – Ethiopian Monitor, n.d.). Despite the potential for Ethiopia to become a key player in the LIBs value chain, there is a lack of research and comprehensive analysis on the subject.

A study conducted on the characterization of brines and evaporite deposits in Ethiopia identified significant lithium reserves associated with potassium in the northern part of the Danakil Depression and selected areas of the Main Ethiopian Rift lakes (Bekele & Schmerold, 2020). However, there is currently no research available on the value chain of LIBs in Ethiopia. It is important to conduct a comprehensive analysis to understand Ethiopia's competitive advantage and develop a strategy in the LIBs value chain. Such a study would inform policymakers, attract investment, promote economic growth, and meet the future local and global demand for LIBs in the electric vehicle industry.

2.9 Conceptual Framework of LIB value chain.

The conceptual framework for conducting the Lithium-Ion Battery (LIB) Value Chain Analysis in Ethiopia focuses on assessing the country's competitiveness and developing a strategic framework to leverage its competitive advantages. The framework encompasses four key components: Value Chain Analysis, Competitiveness Assessment, and Strategic Framework Development.

1. Value Chain Analysis:

The first component involves a comprehensive analysis of the LIB value chain, encompassing the upstream, midstream, and downstream stages. This analysis aims to understand the flow of activities, actors involved, and value creation at each stage. It examines the extraction of raw materials, processing of materials, battery component manufacturing, and the final production of LIBs. The Value Chain Analysis provides insights into the critical stages where Ethiopia can enhance its competitiveness and capture value within the LIB industry.

2. Competitiveness Assessment:

The second component focuses on assessing Ethiopia's competitiveness within the LIB value chain. This assessment examines various factors that influence competitiveness, including access to raw materials, technological capabilities, infrastructure, skilled labor, market access, and policy and regulatory frameworks. By conducting a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis and applying frameworks such as Porter's Five Forces, the competitiveness assessment identifies Ethiopia's strengths, weaknesses, opportunities, and threats in the LIB industry. It enables a clear understanding of the country's competitive position and areas for improvement.

3. Strategic Framework Development:

The third component involves developing a strategic framework tailored to Ethiopia's competitive advantages. This framework outlines the specific actions and interventions required to enhance Ethiopia's competitiveness in the targeted segments of the LIB value chain. It considers aspects such as policy and regulatory reforms, infrastructure development, research and development initiatives, technology transfer, human capital development, and international collaborations. The strategic framework aims to create an enabling environment that attracts investments, fosters innovation, promotes sustainable practices, and maximizes Ethiopia's potential in the LIB industry.

By following this conceptual framework, Ethiopia can gain a comprehensive understanding of its position in the LIB value chain, leverage its competitive advantages, and establish a strong presence in the global LIB market. The framework provides a roadmap for policymakers, industry stakeholders, and investors to guide decision-making, allocate resources effectively, and drive the sustainable development of Ethiopia's LIB industry.

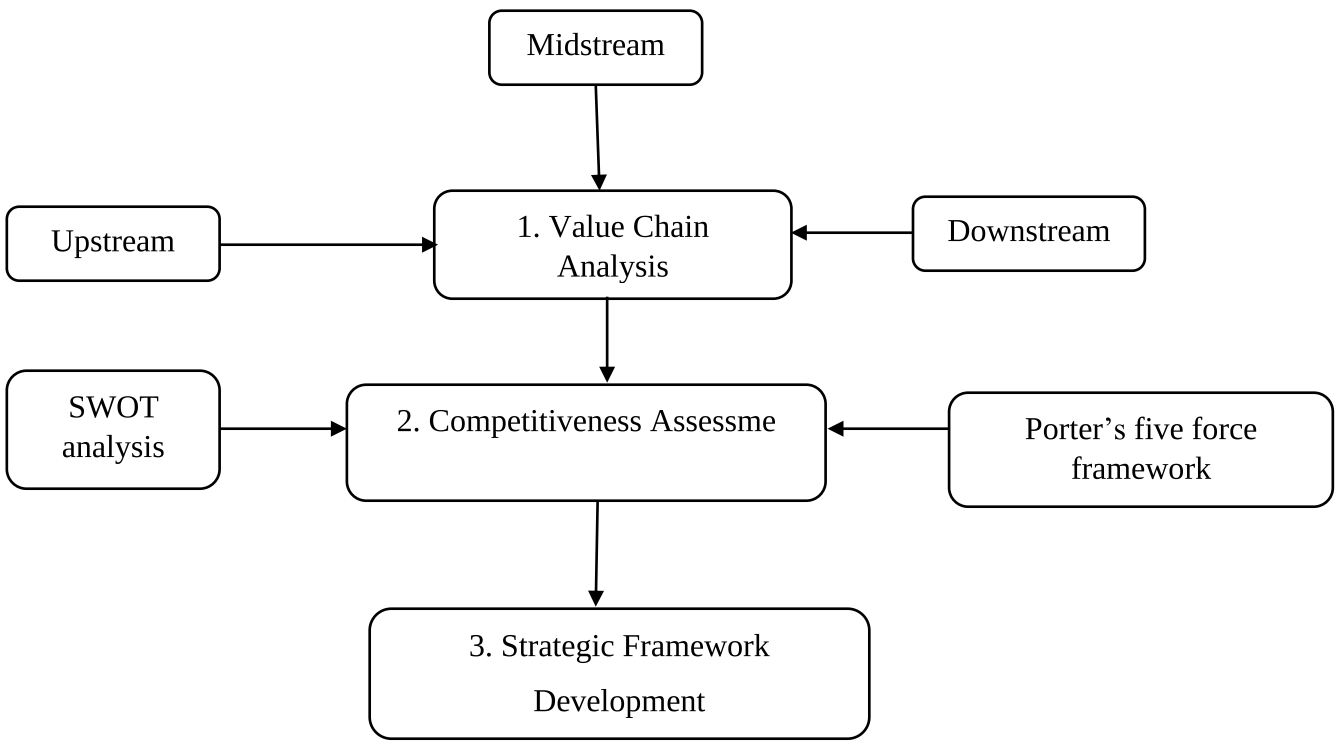


Figure 10; Conceptual Framework of lithium-ion battery value chain.

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 Research Design

The research design master plan outlines how the study on Ethiopia's competitiveness in the Lithium-Ion Batteries (LIBs) value chain will be conducted. It involves several key components and methodologies to address the research questions and gather valuable insights. A global value chain map of LIBs is used as a visual representation and analytical tool. This map helps to understand the different stages, actors, and processes involved in the production, distribution, and end-of-life of LIBs. It provides insights into market segments, participants, functions, and interconnections, allowing for a comprehensive understanding of industry dynamics.

A focused group is formed, comprising relevant stakeholders and experts in the field. This group includes influential individuals and institutions such as the Minister of Mines, the Geology Institute of Ethiopia, the Minerals Industry Development Institute, and the Manufacturing Industry Development Institute. Their expertise and perspectives are sought to gain insights into Ethiopia's potential and capabilities in LIB production.

SWOT analysis is employed to assess Ethiopia's strengths, weaknesses, opportunities, and threats in the LIBs value chain. This analysis examines internal and external factors that influence Ethiopia's position in the industry, providing valuable insights into its competitive advantage.

Porter's Five Forces analysis is applied to thoroughly examine the competitive environment surrounding Ethiopia's involvement in the LIBs value chain. This analysis assesses the bargaining power of suppliers and buyers, the threat of new entrants, the threat of substitutes, and the intensity of competitive rivalry. It helps identify potential challenges and opportunities in the industry.

The focused group discussion plays a crucial role in verifying the selected segments and evaluating Ethiopia's competitive advantage. Their insights and feedback contribute to the robustness and accuracy of the study. Any methodological or analytical gaps identified during the review are addressed, ensuring the reliability of the analysis.

Overall, the research design master plan incorporates the global value chain map, the expertise of the focused group, SWOT analysis, and Porter's Five Forces analysis to provide a comprehensive analysis of Ethiopia's potential and capabilities in the LIBs value chain. The review conducted by the focused group enhances the study and ensures its accuracy and reliability.

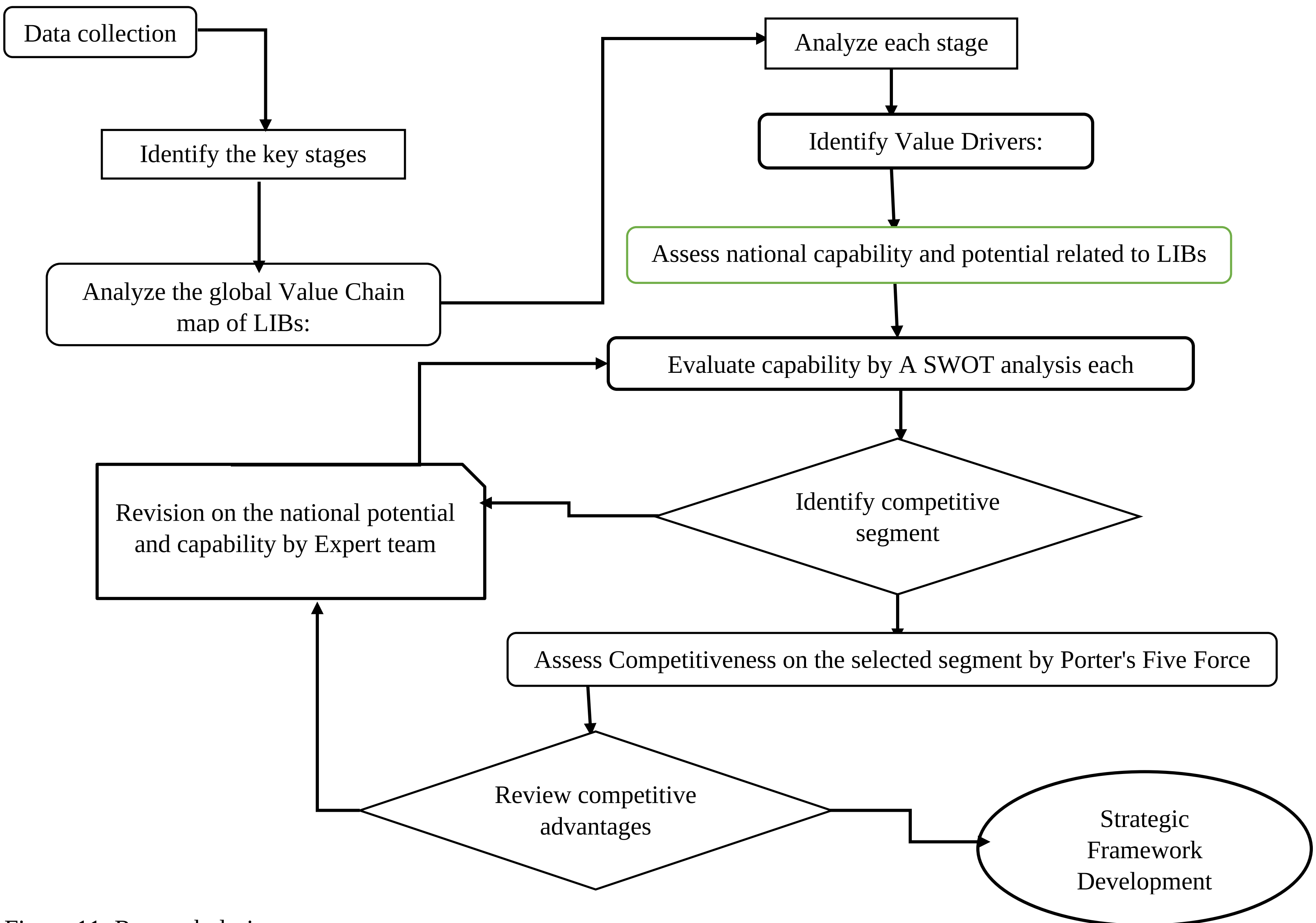


Figure 11; Research design

3.3 Importance of Value Chain Analysis

Value chain analysis plays a crucial role in understanding the strengths and gaps within the lithium-ion battery (LIBs) value chain. By reviewing existing literature, reports, and data on the global LIBs industry, valuable insights can be gained regarding the different stages, key players, trends, and challenges in the value chain (Kaplinsky & Morris, 2002).

The use of value chain analysis as an analytical tool is important in understanding the overall trends of industrial reorganization and identifying change agents and leverage points for policy and technical interventions. It helps provide a holistic view of the LIBs industry and enables stakeholders to make informed decisions and interventions.

In the context of rapid globalization, value chain analysis becomes even more critical for several reasons. Firstly, the expanding global distribution of component production emphasizes the significance of systemic competitiveness. Understanding the various stages and players in the value chain is crucial to maintaining competitiveness in the global market.

Secondly, successful entry into international markets requires specific circumstances. By conducting a value chain analysis, businesses can identify the necessary factors and conditions for successful market entry, allowing them to strategically position themselves in the global arena.

Lastly, to maximize the benefits of globalization, it is important to comprehend the dynamic factors across the entire value chain. This understanding enables businesses to effectively participate in global markets and achieve sustained income growth. By analyzing the value chain, organizations can identify areas of opportunity, address challenges, and develop strategies to leverage globalization effectively (Kaplinsky & Morris, 2002).

In summary, value chain analysis is a crucial tool for understanding the strengths and gaps in the LIBs value chain. It helps stakeholders gain insights into the industry, identify trends and challenges, and make informed decisions and interventions. In an era of rapid globalization, value chain analysis is essential for achieving systemic competitiveness, successful market entry, and optimal utilization of global markets for sustained income growth.

3.4 Dimensions of LIB Value Chain

A value chain analysis is crucial for identifying the strengths and gaps in the lithium-ion battery supply chain. By analyzing the various stages and components of the supply chain, from material extraction to battery cell and pack manufacturing, organizations can gain insights into their competitive edge in both domestic and global Li-ion markets.

Starting with material extraction, understanding the sources and availability of key raw materials such as lithium, cobalt, nickel, and others is essential. This involves assessing the geographical distribution, reserves, and potential supply risks associated with these materials. Additionally, evaluating the sustainability and environmental impact of material extraction is becoming increasingly important in the industry.

Moving along the supply chain, assessing the processing and refining of raw materials is crucial. This includes understanding the technologies and processes involved in converting raw materials into battery-grade chemicals, such as lithium carbonate or nickel sulfate. Analyzing the efficiency, scalability, and cost-effectiveness of these processes can help identify areas for improvement and optimization.

The manufacturing stage is another key aspect of the supply chain. Analyzing the capabilities, capacities, and technological advancements in battery cell and pack manufacturing is necessary to stay competitive. Factors such as production efficiency, quality control, and innovation in battery manufacturing techniques play a significant role in determining the competitiveness of organizations in the Li-ion market.

Furthermore, logistics and distribution are important considerations in the supply chain analysis. Assessing transportation networks, warehousing capabilities, and delivery systems helps optimize the flow of materials and finished products. Analyzing the efficiency of supply chain management, including inventory management and coordination with suppliers and customers, can enhance competitiveness and responsiveness to market demands.

Lastly, a comprehensive value chain analysis should also consider factors such as regulatory frameworks, policy incentives, and sustainability initiatives. Understanding the legal and regulatory landscape, along with government support and incentives, can have a significant impact on the competitiveness of the Li-ion supply chain.

In summary, conducting a value chain analysis of the lithium-ion battery supply chain enables organizations to identify their strengths and gaps. It provides insights into material extraction, processing, manufacturing, logistics, and regulatory aspects, all of which contribute to their competitive edge in the domestic and global Li-ion markets. By identifying areas for improvement and strategic interventions, organizations can enhance their position in the supply chain and drive their competitiveness in the growing Li-ion industry.

3.5 Description of the Study Area

The study aims to assess Ethiopia's position and potential within the lithium-ion battery (LIB) value chain, considering its competitive advantages, challenges, and opportunities. It covers several aspects of the LIB value chain, including:

1. Raw Material Sourcing: Evaluating Ethiopia's access to crucial raw materials such as lithium, cobalt, nickel, graphite, and others. The study assesses the availability, reliability, and long-term viability of these resources within the country.

2. Manufacturing: Analyzing Ethiopia's current manufacturing capabilities and infrastructure for LIB production. This involves assessing the availability of factories capable of manufacturing battery cells and packs, as well as evaluating the level of production and technological adoption.

3. Competitiveness: Conducting a comparative analysis of Ethiopia's competitiveness within the global LIB value chain. The study levels Ethiopia against other countries or regions known for LIB production, considering factors such as cost competitiveness, technological expertise, regulatory environment, and government support.

By examining these topics, the research aims to provide insights into Ethiopia's potential for establishing a competitive LIB value chain. This has the potential to contribute to job growth and meet the future demand for LIBs in electric vehicles, thereby facilitating the transition to clean energy technologies.

The study intends to provide valuable information to policymakers, investors, and industry stakeholders, enabling them to make informed decisions and develop strategies to foster the growth of the LIB value chain in Ethiopia.

.3.6 Data Type, Sources and Collection Method

The study collected primary data from key stakeholders such as the Minister of Mines, Minister of Transport and Logistics, and the Ministry of Industry/Manufacturing Industry Development Institute. The primary data collection focused on gathering information about the availability of raw materials related to LIB manufacturing, future local demand for LIBs, and the existing manufacturing capabilities and infrastructure for LIB production in Ethiopia. These sources provided valuable insights into the specific context and conditions within the country.

In addition to primary data, the study also relied on secondary data sources, including literature, reports, books, and financial databases, to gather information on the global lithium-ion battery industry. These secondary data sources were used to gain a comprehensive understanding of various aspects of the LIB value chain, including stages, key players, trends, production processes, technological complexity, market mapping, and future global demand. By leveraging existing knowledge and research, the study could build upon the collective understanding of the LIB industry and incorporate relevant insights into the analysis.

The combination of primary and secondary data collection allowed the study to have a comprehensive and well-informed analysis of Ethiopia's potential and capabilities within the LIB value chain. The primary data provided specific and contextual information from key stakeholders, while the secondary data enriched the analysis with broader industry knowledge and insights.

3.7 Ethical Consideration

The researcher was committed to upholding the highest ethical standards throughout the research process. The following ethical considerations were carefully taken into account:

1. Informed Consent: Prior to their participation, all individuals involved in the study, including stakeholders and participants in the focused group discussion, were fully informed about the purpose, procedures, and potential risks and benefits of the study. They provided voluntary consent to participate and were aware of their right to withdraw at any time.

2. Confidentiality: The researcher ensured the confidentiality of all data collected during the study. Measures were implemented to protect the privacy and anonymity of participants. Data was stored securely and access was limited to authorized personnel only.

3. Data Accuracy and Integrity: The researcher took utmost care to ensure the accuracy and integrity of the data collected. Rigorous research methodologies and techniques were employed to minimize biases and errors. Data sources were critically evaluated for reliability, and data analysis was conducted with transparency and adherence to established standards.

4. Use of Existing Data and Intellectual Property: The researcher respected copyright laws and intellectual property rights when utilizing existing data, reports, and resources. Proper acknowledgments and citations were given to the original sources to ensure that credit was appropriately attributed.

5. Impartial Reporting: The researcher-maintained objectivity and impartiality in the reporting of findings and conclusions. The study aimed to present a balanced and accurate assessment of Ethiopia's competitiveness in the LIB value chain, without favoring any particular stakeholder or interest group.

Overall, the researcher was committed to conducting the study ethically, ensuring the rights and well-being of participants, and upholding the integrity and credibility of the research process and its outcomes.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Introduction

This chapter examines the concept of barriers to entry and their impact on Ethiopia's participation in the lithium-ion battery (LIB) value chain. It focuses on key governance factors and various drivers that influence each segment of the value chain. The chapter takes into account Ethiopia's capabilities and potentials to evaluate its current position in the global LIB value chain and assess its competitiveness.

The chapter also identifies a specific segment within the value chain where Ethiopia should concentrate its efforts. This involves analyzing Ethiopia's strengths, weaknesses, opportunities, and threats in relation to that particular segment. By understanding these factors, Ethiopia can strategically position itself to leverage and expand its competitive advantages.

To achieve this, a strategic framework is proposed to guide Ethiopia's engagement in the LIB value chain. This framework provides a roadmap for the country to capitalize on its strengths, address its weaknesses, seize opportunities, and navigate potential challenges. It outlines the necessary steps and actions to enhance Ethiopia's competitiveness and maximize its benefits from participating in the LIB value chain.

By exploring barriers to entry, assessing Ethiopia's position, and providing a strategic framework, this chapter aims to support policymakers and stakeholders in making informed decisions and guiding Ethiopia's engagement in the LIBs value chain. It seeks to pave the way for Ethiopia to leverage its capabilities and potentials, contributing to the country's economic growth and meeting the increasing demand for LIBs in the global market.

4.2 The Three Important Components to Assess the LIB Value Chain

The value chain of lithium-ion batteries (LIBs) encompasses three essential components: barriers to entry, governance factors, and different types of value chains (Kaplinsky & Morris, 2000). When examining barriers to entry, it becomes crucial to understand the governance factors that influence the LIB value chain. These factors include government policies, regulations, economic conditions, technological advancements, infrastructure development, and resource availability.

Each segment within the value chain, such as raw material extraction, battery manufacturing, component assembly, and recycling, is impacted by these governance factors, which can vary across nations based on their capabilities and potentials.

Barriers to entry refer to the challenges and obstacles that new entrants face when attempting to participate in the LIB value chain. These barriers can include high capital requirements, technological complexity, intellectual property rights, access to key resources, and established market dominance by existing players. By analyzing the governance factors, policymakers and industry stakeholders can gain insights into the regulatory environment, government support, investment incentives, and infrastructure development needed to overcome these barriers and promote the growth of the LIB value chain.

Different types of value chains can exist within the LIB industry, reflecting variations in geographic location, specialization, and market dynamics. For example, some countries may focus on raw material extraction and supply, while others may specialize in battery manufacturing or recycling. Understanding these different types of value chains allows for a comprehensive analysis of the global LIB industry and the roles played by various nations.

By considering barriers to entry, governance factors, and different types of value chains, policymakers and industry players can make informed decisions to strengthen their position in the LIB value chain. This analysis helps identify strategic opportunities, address challenges, and foster an environment conducive to innovation, investment, and sustainable growth in the LIB industry.

4.2.1 Assessing the Downstream Stage

The downstream stage of the lithium-ion battery (LIB) value chain includes various segments, such as battery pack manufacturing, integration into electric vehicles (EVs), and end-of-life battery recycling. Battery pack manufacturing involves assembling individual battery cells into larger modules and packs that are suitable for use in EVs and other applications. This segment requires specialized expertise and facilities to ensure the proper configuration and integration of the battery cells to meet the performance and safety requirements of the intended use. Once the battery packs are manufactured, they are integrated into EVs during the vehicle assembly process. This involves installing the battery packs, along with the necessary electrical and control systems, to power the vehicle's electric propulsion system. This segment requires collaboration between battery manufacturers, EV manufacturers, and other automotive suppliers to ensure seamless integration and optimal performance.

The end-of-life battery recycling segment focuses on the proper disposal and recycling of used or damaged LIBs. This is an important aspect of the value chain as it addresses environmental concerns and helps recover valuable materials for reuse. Recycling processes involve the collection, dismantling, and separation of battery components, followed by the recovery of metals and other materials for recycling or reprocessing. Proper recycling practices are crucial to minimize waste and environmental impact, and to promote a circular economy for LIBs.

The downstream stage of the LIB value chain plays a critical role in the overall lifecycle of LIBs, from manufacturing to usage to end-of-life management. It involves multiple stakeholders, including battery manufacturers, EV manufacturers, automotive companies, recycling facilities, and regulatory bodies. Collaboration and coordination among these stakeholders are necessary to ensure the efficient and sustainable operation of the downstream segments and to maximize the value and environmental benefits of LIBs.

4.2.1.1 Barriers to Entry in Battery Pack Manufacturing Segment

In the battery pack manufacturing stage of the lithium-ion battery (LIB) value chain, there is intense competition among experienced industries for market share, and a few nations and businesses dominate this segment. The production of battery packs requires advanced technological knowledge and expertise, encompassing areas such as electrical systems, thermal management, and safety procedures. The ability to manufacture high-quality battery packs with superior performance is crucial for value creation at this stage.

Building a strong manufacturing infrastructure is also essential. This includes establishing facilities, technologies, and materials necessary for large-scale production. Often, significant capital investments are required to construct and maintain advanced manufacturing facilities that can meet the demands of battery pack production. Developed nations and established companies are prominent in this segment of the LIBs value chain due to the complexity of technology, manufacturing infrastructure, and production processes involved.

For Ethiopia to participate effectively in the battery pack manufacturing stage, the country needs to focus on leveraging technology effectively. This can be achieved through investments in research and development, fostering partnerships with international entities, and providing specialized training to develop a skilled workforce with expertise in battery pack manufacturing processes and technologies. Access to testing facilities is also crucial to ensure competence, efficiency, and safety in battery pack production. Establishing testing facilities from scratch can be resource-intensive, so exploring partnerships, collaborations, or regional cooperation can provide Ethiopia with access to these facilities.

By addressing these factors, including technological know-how, manufacturing infrastructure, and testing facilities, Ethiopia can increase its participation in the battery pack manufacturing stage of the LIBs value chain. This strategic approach will contribute to the development of a competitive and sustainable LIB industry in the country, fostering economic growth and attracting investment in the clean energy sector.

4.2.1.2 Barriers to Entry in EV Production

It is evident that large companies and developed nations have a significant presence in the lithium-ion batteries (LIBs) value chain segment dedicated to the production of electric vehicles (EVs). The production process, manufacturing infrastructure, supply chain integration, and level of technological complexity all play crucial roles in value creation at this stage. The production of electric vehicles involves various processes, such as chassis assembly, battery pack incorporation, electrical system installation, and the utilization of cutting-edge technologies. Expertise in EV-specific technologies and manufacturing methods is required for these processes. Efficient production of high-quality electric vehicles with innovative features and performance is essential for value creation in this stage.

Furthermore, the establishment of a robust manufacturing infrastructure is vital. Adequate facilities, machinery, and resources are necessary for effective and large-scale EV production. The manufacturing infrastructure should be capable of meeting the unique requirements of electric vehicles, including battery pack integration, charging systems, and advanced electronics. Integration of the supply chain is another critical factor, involving the coordination and integration of various systems and components sourced from different suppliers. A smooth and reliable supply chain is crucial for the timely production and delivery of electric vehicles.

For Ethiopia to participate in this stage, the effective utilization of technology becomes a crucial component. This can be achieved by developing a skilled workforce with expertise in EV production processes and technologies through investments in research and development, fostering partnerships with international collaborators, and providing specialized training. Access to testing facilities is also essential to ensure quality control and compliance with safety standards. Testing facilities are utilized to verify the effectiveness, reliability, and safety of electric vehicles. Ethiopia can explore options such as partnerships, collaborations, or regional cooperation to gain access to testing facilities or establish their own, which may require significant investment.

By addressing these factors, including technological know-how, manufacturing infrastructure, supply chain integration, and testing facilities, Ethiopia can enhance its participation in the electric vehicle production stage of the LIBs value chain. This has the potential to stimulate economic activity, create new job opportunities, and drive technological advancements in the field of sustainable transportation.

4.2.1.3 Barriers to Entry in End-of-life LIB Recycling Segment

In the recycling segment of the lithium-ion battery (LIB) value chain, value creation and value addition depend on two main factors: the collection rate of used batteries and the recycling efficiency in extracting valuable materials. Currently, the recycling of LIBs primarily focuses on portable batteries, as the volume of waste electric vehicle batteries reaching their end-of-life is still limited. However, to effectively engage in this stage of the value chain, several factors come into play.

Technological expertise is crucial for developing efficient and environmentally friendly recycling processes. This involves knowledge of separation techniques, chemical processes, and recovery methods for valuable metals and materials. Developing expertise in these areas will ensure that the recycling process is optimized for maximum resource recovery and minimal environmental impact.

Supply chain integration is also important in the recycling segment. Establishing partnerships with battery manufacturers, collection networks, and recycling facilities is necessary to ensure a consistent flow of used batteries for recycling. Collaborating along the supply chain facilitates the efficient recovery of valuable materials and promotes a circular economy approach.

Building a robust recycling infrastructure and capabilities is essential. This includes the establishment of recycling plants and facilities equipped with advanced technologies for battery dismantling, material recovery, and waste management. Adequate investment in infrastructure and equipment is necessary, as recycling LIBs can be capital-intensive. The technological complexity of the recycling process also necessitates the availability of testing facilities to ensure the quality and safety of the recycled materials.

By focusing on developing technological expertise, establishing supply chain networks, and investing in recycling infrastructure, Ethiopia can effectively engage in the recycling segment of the LIBs value chain. Collaborating with international partners, adopting best practices, and leveraging regional cooperation will support the development of a sustainable and efficient end-of-life battery recycling industry.

Addressing these factors will not only contribute to a more circular and sustainable LIBs value chain but also increase recycling rates, reduce environmental impact, and minimize reliance on primary raw materials. It is important to keep in mind that the competitive landscape can evolve over time as other nations and businesses strive to increase their capabilities in the LIBs value chain. Continuous innovation and improvement will be crucial for Ethiopia to maintain a competitive edge in the recycling segment.

4.2.1.4 The Key Governor Factors in the Downstream

LIBs Value Chain	Key governance factors
Downstream stage	❑ Advanced technological knowledge is crucial for producing high-quality battery packs, electric vehicle (EV) production, and recycling with optimal performance. ❑ The complexity of the technology, manufacturing infrastructure, and production processes heavily influence the value creation and value addition in this stage and it requires capital-intensive investments in advanced facilities ❑ Supply chain integration involves establishing partnerships to ensure a consistent flow of used batteries for recycling, electric vehicle (EV) production.

4.2.1.5 Types of driven in Downstream stage of LIB value chain

In the downstream stage of the lithium-ion battery (LIB) value chain, there are various activities related to battery pack manufacturing, the production of electric vehicles (EVs), and the recycling segment. This stage is characterized as buyer-driven, meaning that the activities and dynamics are primarily influenced by the demand and requirements of the end-users, such as automotive manufacturers and consumers.

Battery pack manufacturing involves the assembly and integration of battery cells, electronics, and other components into a complete battery pack. This process requires advanced technological knowledge and expertise in electrical systems, thermal management, and safety procedures. The goal is to produce high-quality battery packs that meet the performance and safety standards required for EVs.

The production of electric vehicles encompasses various processes, including chassis assembly, battery pack incorporation, and electrical system installation. These processes require specialized knowledge in EV-specific technologies and manufacturing methods. The goal is to manufacture electric vehicles with innovative features, high performance, and reliability.

The recycling segment of the LIB value chain focuses on the end-of-life management of LIBs. This includes the collection, dismantling, and recycling of used batteries to recover valuable materials. Currently, the recycling of LIBs is more focused on portable batteries, but as the volume of end-of-life EV batteries increases, there will be a greater need for recycling infrastructure and processes specific to EV batteries. The recycling segment aims to extract valuable materials from used batteries and minimize environmental impact through sustainable waste management practices.

In the downstream stage, buyer-driven dynamics play a significant role. Automotive manufacturers and consumers drive the demand for battery packs and EVs, which influences the production processes, technological advancements, and quality standards in the industry. Additionally, there is growing awareness and emphasis on the importance of end-of-life management and recycling of LIBs to ensure sustainability and resource efficiency (Producer and Buyer-Driven Value Chains _ The Geography of Transport Systems, n.d.).

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Overall, the downstream stage of the LIB value chain is crucial for meeting the demand for EVs, producing high-quality battery packs, and promoting sustainable practices in the recycling of LIBs. It requires close collaboration between automotive manufacturers, battery pack manufacturers, and recycling facilities to ensure the smooth flow of activities and the development of innovative and environmentally friendly solutions.

4..2.2 Assessing the Midstream Stage

The midstream stage of the lithium-ion battery (LIB) value chain primarily involves LIB cell manufacturing and cell component production, including separators, electrolytes, cathode and anode materials, and other specialized components.

LIB Cell Manufacturing: LIB cell manufacturing refers to the process of assembling the individual components, such as cathode, anode, electrolyte, and separator, into a complete LIB cell. This involves precise manufacturing techniques, such as coating, stacking, and sealing, to create the cell structure. Cell manufacturing also includes the implementation of quality control measures to ensure the performance, safety, and reliability of the LIB cells.

Separators: Separators are thin, porous membranes placed between the cathode and anode in a LIB cell. They facilitate the flow of lithium ions while preventing electrical short circuits. Separators are typically made of materials like polyethylene or polypropylene and undergo specialized manufacturing processes, including pore size control and surface treatment, to ensure optimal performance and safety.

Electrolytes: Electrolytes play a crucial role in facilitating the movement of lithium ions between the cathode and anode during charge and discharge cycles. The production of electrolytes involves formulating specific chemical compositions and purifying them to ensure stability and ion conductivity. Different types of electrolytes, such as liquid, gel, or solid-state, may be used depending on the LIB cell design.

Cathode and Anode Materials: Cathode and anode materials are responsible for storing and releasing lithium ions during charge and discharge cycles. These materials undergo various processes, including synthesis, coating, and drying, to achieve the desired characteristics. Cathode materials typically include metal oxides like lithium cobalt oxide, lithium nickel manganese cobalt oxide, or lithium iron phosphate, while anode materials often consist of carbon-based materials such as graphite or silicon.

Other Specialized Components: In addition to separators, electrolytes, cathode, and anode materials, other specialized components are involved in LIB cell production. These may include current collectors, binders, additives, and packaging materials. Current collectors ensure efficient electron flow within the cell, binders hold the active materials together, additives improve cell performance and safety, and packaging materials provide protection and sealing.

The midstream stage requires advanced manufacturing techniques, strict quality control measures, and adherence to safety standards. Efficient cell manufacturing processes are crucial to produce high-performance LIB cells with consistent quality and reliability. Continuous research and development efforts are also essential to enhance the performance, energy density, and lifespan of LIB cells and their components. By effectively carrying out cell manufacturing and component production, the midstream stage contributes to the overall performance and functionality of LIBs, enabling their application in electric vehicles industries.

4.2.2.1 Barriers to Entry in Cell Component Production Segment

Competition in the cell component production segment of the lithium-ion battery (LIB) value chain is intense due to the demand for high-quality and reliable components. To be successful in this stage, several factors need to be considered:

Technological Expertise: Developing advanced manufacturing processes and techniques requires expertise in electrochemistry, materials science, and LIB-specific manufacturing methods. Continuous research and development efforts are necessary to stay at the forefront of technology and innovation in cell component production.

Supply Chain Integration: Establishing strong and reliable supply chains is crucial for sourcing raw materials, machinery, and other necessary components. Collaborating with suppliers and ensuring a steady flow of superior materials is essential for producing high-quality cell components.

Manufacturing Infrastructure: A robust manufacturing infrastructure is necessary to meet the complex requirements of cell component production. This infrastructure includes specialized tools, settings, and quality control procedures to maintain consistent component fabrication. Significant investments in infrastructure development, research and development, and specialized equipment are typically required.

Testing Facilities: Access to testing facilities is vital for quality assurance and control throughout the manufacturing process. Testing helps verify the quality and performance of cell components, ensuring they meet the necessary requirements. Establishing or having access to testing facilities enables thorough testing and validation of components.

For Ethiopia to participate in the cell component production stage of the LIBs value chain, investments in infrastructure development, research and development, and specialized equipment are necessary. By addressing these factors, Ethiopia can develop a skilled workforce with advanced battery technology skills, foster economic growth, and facilitate technology transfer. Additionally, partnerships and collaborations with international players in the LIB industry can help Ethiopia leverage their expertise and gain access to advanced technologies. This collaboration can support knowledge transfer and the development of a competitive cell component production industry within the country. By focusing on these factors and fostering a supportive environment for cell component production, Ethiopia can enhance its participation in the LIB value chain, contribute to the growth of the battery industry, and drive economic development.

4.2.2.2 Barriers to Entry in Cell Manufacturing

The value creation and value addition in the cell manufacturing segment of the Lithium-ion Batteries (LIBs) value chain depend on manufacturing technology and the purity of raw materials. Several factors contribute to the success of this stage:

Technological Know-How: The fabrication of LIBs cells requires sophisticated processing methods, including electrode preparation, assembly, and encapsulation procedures. Technological expertise is crucial in developing and implementing these manufacturing processes efficiently. Continuous innovation and improvement in cell manufacturing processes drive competitiveness and cost optimization.

Supply Chain Integration: Ensuring a reliable supply chain is essential for obtaining high-quality raw materials and components throughout the cell manufacturing process. Collaboration with suppliers and the establishment of trustworthy supply chains enable a steady flow of materials and resources required for cell fabrication. A secure supply chain helps maintain consistency and reliability in cell production.

Manufacturing Infrastructure: A robust manufacturing infrastructure is necessary to support cell manufacturing operations. Specialized tools, facilities, and quality assurance procedures are required to maintain desired production conditions and ensure consistent cell production. Significant investments are often required to establish the necessary infrastructure and maintain a competitive edge.

Testing Facilities: Access to testing facilities is crucial for verifying the effectiveness, reliability, and safety of the cells. Testing ensures strict quality assurance and control throughout the manufacturing process. Having access to testing facilities enables thorough validation and compliance with industry standards.

To increase participation in the cell manufacturing stage of the LIBs value chain, Ethiopia would need to address these factors. This includes investments in infrastructure development, research and development, and specialized equipment. Building a skilled workforce with expertise in cutting-edge battery technologies can be achieved through training programs and knowledge transfer initiatives. By fostering a supportive environment and addressing these factors, Ethiopia can promote economic growth, technology transfer, and enhance its position in the LIBs value chain. Collaboration with international partners, leveraging regional cooperation, and adopting best practices can also support Ethiopia in developing a competitive cell manufacturing industry and contributing to the growth of the LIBs market.

4.2.2.3 The Key Governor Factors in the Midstream Stage of the LIBs Value Chain

LIBs Value Chain	Key governance factors
Midstream Stage	▪ The complexity of the technology, manufacturing infrastructure, supply chain integration, and production processes heavily influence the value creation and value addition in this stage and it requires capital-intensive investments in advanced facilities. ▪ Access to testing facilities are crucial factors in this stage. ▪ The production process is energy-intensive

4.2.2.4 Types of Driven in Midstream Stage

The midstream stage of the Lithium-ion Batteries (LIBs) value chain is characterized by producer-driven activities, focusing on LIB cell manufacturing and cell component production. This stage involves the production and assembly of various components that are integral to the functioning of LIBs. Some of the key components produced in this stage include separators, electrolytes, cathode and anode materials, and other specialized components.

LIB cell manufacturing is a complex process that involves the assembly of individual cells, which are the basic units of a battery. It requires specialized knowledge and expertise in areas such as electrode preparation, cell assembly, and encapsulation techniques. Advanced manufacturing technologies and processes are employed to ensure the production of high-quality and reliable LIB cells.

In addition to cell manufacturing, the midstream stage also encompasses the production of various cell components. Separators, which act as a physical barrier between the cathode and anode, are essential for the safe and efficient operation of LIBs. Electrolytes, which facilitate the flow of ions between the electrodes, are also produced in this stage. Cathode and anode materials, which store and release ions during charge and discharge cycles, are manufactured to meet specific performance requirements.

The midstream stage is characterized by producer-driven activities, with companies specializing in LIB manufacturing and component production. These companies invest in research and development to improve the performance, efficiency, and safety of LIB cells. Continuous innovation and advancements in manufacturing processes are key drivers of value creation in this stage (Producer and Buyer-Driven Value Chains _ The Geography of Transport Systems, n.d.).

Efficient supply chain management and integration play a crucial role in the midstream stage. Collaboration with suppliers for raw materials, equipment, and other components is essential to ensure a steady and reliable flow of inputs. Quality control and testing processes are implemented to maintain high standards and meet customer requirements.

Overall, the midstream stage of the LIBs value chain focuses on producer-driven activities related to LIB cell manufacturing and cell component production. It requires specialized knowledge, advanced manufacturing technologies, efficient supply chain management, and a commitment to continuous improvement to meet the demands of the growing LIB market.

4.2.2 Assessing the Upstream Stage

The upstream stage of the Lithium-ion Batteries (LIBs) value chain encompasses the activities related to raw material extraction and raw materials processing, which are essential for battery manufacturing. In this stage, the focus is on sourcing and acquiring the key raw materials required for LIB production, including lithium, cobalt, nickel, graphite, and other crucial materials. The raw materials are typically obtained from various sources such as mining operations, brine deposits, or recycling processes.

Raw material extraction involves the extraction of minerals or other resources from the earth, which contain the desired elements needed for LIB production. This includes mining operations for lithium, cobalt, and nickel ores, as well as the extraction of graphite from natural deposits. Once the raw materials are extracted, they undergo processing to obtain the desired chemical composition and purity required for LIB manufacturing. This processing stage may involve various techniques such as crushing, grinding, flotation, leaching, and other separation methods to separate and refine the raw materials. The quality and availability of raw materials play a crucial role in the overall performance and sustainability of LIBs. Factors such as the location and accessibility of mineral deposits, mining practices, environmental considerations, and social impacts are important considerations in the upstream stage. Additionally, the upstream stage also includes the development of technologies and processes for more sustainable and responsible sourcing of raw materials. This includes efforts to reduce the environmental footprint of mining operations, promote ethical practices, and support initiatives for recycling and reuse of materials.

Efficient supply chain management is crucial in the upstream stage to ensure a reliable and sustainable flow of raw materials to meet the demands of LIB manufacturing. Collaboration with suppliers, adherence to environmental and social standards, and the development of long-term sourcing strategies are key aspects of this stage.

Overall, the upstream stage of the LIBs value chain focuses on raw material extraction and processing, which form the foundation for battery manufacturing. It involves sourcing and processing raw materials in a sustainable and responsible manner to support the growing demand for LIBs in electric vehicles industries.

4.2.3.1 Barriers to Entry on Upstream Stage

The value creation and value addition in the raw material extraction stage of the Lithium-ion Batteries (LIBs) value chain are determined by several factors, including access to deposits, extraction methods, infrastructure, technology, and specialized knowledge. Access to deposits plays a crucial role in the value creation of raw material extraction. The availability and quality of lithium, cobalt, nickel, and other critical materials determine the feasibility and viability of extraction. Meeting the increasing demand for LIBs can be challenging if there is a limited availability of these deposits.

Infrastructure, technology, and specialized knowledge are essential for efficient raw material extraction. Different extraction techniques are employed based on the characteristics of the deposit. For example, lithium brines can be extracted with less capital expenditure and infrastructure complexity compared to cobalt and nickel. The number of companies involved in this stage is relatively small due to the specific expertise required for efficient extraction operations.

While competition may be less intense in the raw material extraction segment, significant investments are still needed for infrastructure, machinery, and processing facilities. Access to testing facilities is also crucial to ensure the quality and suitability of the extracted materials for LIB production.

To participate in the raw material extraction stage, Ethiopia would need to focus on developing the necessary knowledge, infrastructure, and technologies. This can be achieved through knowledge transfer, partnerships with foreign entities, and investments in research and development. Sustainable and ethical mining practices should be emphasized to ensure environmental stewardship and social responsibility.

In the raw material processing stage, value creation and value addition depend on the refinery processes used to convert raw materials into the necessary chemicals for LIB production. The processes are often extensive and technologically complex, involving techniques such as pyrometallurgy or hydrometallurgy. Skilled labor with expertise in metallurgy, chemical engineering, and industrial processes is required for effective processing.

Competition in the raw material processing segment is increased by the involvement of experienced companies with effective supply chains and refining processes. Access to testing facilities is crucial to ensure the quality and purity of the refined materials. Integration of the supply chain is important for a reliable and continuous supply of high-quality materials.

Ethiopia would need to invest in infrastructure, skilled workforce development, and refining technologies to participate in the raw material processing stage. Collaboration with seasoned businesses and international partners can facilitate the adoption of new technologies. By addressing these factors, Ethiopia can actively participate in the LIBs value chain's raw material extraction and processing stages. This has the potential to stimulate economic activity, create job opportunities, and establish a reliable supply of raw materials and refined chemicals for LIB manufacturing.

4.2.3.2 The Key Governor in the Upstream Stage of the LIB Value Chain

LIBs Value Chain	Key governance factors
Upstream Stage	➢ Availability and accessibility of key minerals are determining the foundation and competitiveness. ➢ Reliable access to lithium deposits is a key factor. ➢ Comprehensive knowledge of the raw material extraction and processing from ores. ➢ skilled labor and testing facilities are essential.

4.2.3.3 Types of Driven in Upstream Stage

The upstream stage of the Lithium-ion Batteries (LIBs) value chain is producer-driven and encompasses activities such as mining and extraction of raw materials, as well as the production of processed materials (Producer and Buyer-Driven Value Chains _ The Geography of Transport Systems, n.d.). One of the primary activities in the upstream stage is the mining and extraction of raw materials like lithium, cobalt, and nickel. These raw materials are essential for LIB production and are typically found in specific geological formations or deposits. The mining process involves locating and accessing these deposits, extracting the raw materials from the earth, and preparing them for further processing.

Once the raw materials are extracted, they undergo processing to obtain refined and processed materials that are used in LIB production. For example, lithium can be processed into lithium carbonate or lithium hydroxide, which are key components of LIBs. The processing methods vary depending on the specific raw material and desired end product, and may involve chemical processes, purification, and other refining techniques.

The value creation and value addition in the upstream stage of the value chain depend on factors such as the availability and quality of raw material deposits, the efficiency and effectiveness of mining and extraction processes, and the ability to produce high-quality processed materials. Technology and expertise in mining, extraction, and processing play a crucial role in optimizing value creation at this stage.

It is important for countries and companies involved in the upstream stage to consider sustainable and responsible practices in mining and extraction, ensuring environmental protection, and promoting the welfare of local communities. Ethical considerations and compliance with environmental regulations are vital to maintain the long-term viability and sustainability of the raw material supply chain.

Overall, the upstream stage of the LIBs value chain is critical for securing a reliable supply of raw materials and producing processed materials necessary for LIB production. Through efficient and responsible mining and processing practices, countries and companies can contribute to the growth and sustainability of the LIB industry.

4.3 Ethiopia Currently Stands in the Global Lithium-Ion Battery Value Chain

Drawing from the insights gathered during the focused group discussion, it becomes evident that Ethiopia's industry is presently facing challenges in competing with established major players in the manufacturing of LIB cells. At present, the Ethiopian minerals associated with the LIB industry are not optimize serving the LIB value chain. The dominance of leading firms, leveraging economies of scale, substantial production volumes, and innovative intellectual property, positions them significantly ahead in the value chain. However, a closer examination reveals a more nuanced picture when considering battery manufacturing and battery component production. Additionally, the automotive sector poses notable entry barriers.

The findings indicate that Ethiopia's current position in LIB cell manufacturing is not on par with the major industry players. Factors such as limited infrastructure, technological gaps, and limited access to key raw materials hinder the country's ability to compete effectively. The economies of scale achieved by established firms allow them to benefit from cost advantages and production efficiencies, making it challenging for emerging players like Ethiopia to enter this segment successfully. However, the situation takes a different turn when examining battery manufacturing and battery component production. Ethiopia shows some potential in these segments due to its growing expertise in electronics manufacturing, skilled labor force, and favorable investment incentives. By focusing on these areas, Ethiopia can capitalize on its existing strengths and work towards developing a competitive edge. This strategic approach would allow Ethiopia to participate more effectively in the LIB value chain and reduce the dependency on external sources for LIB cells.

In addition to the challenges faced in the manufacturing sector, the automotive sector presents significant entry barriers for Ethiopia. Established automotive companies hold a strong market position and possess substantial brand recognition, advanced technology, and established supply chains. This makes it difficult for new entrants, including Ethiopia, to break into this sector without significant investment, technological advancements, and strategic partnerships.

To address these barriers, Ethiopia needs to develop a comprehensive strategy that encompasses multiple facets. This includes strengthening the mineral-related industries, enhancing technological capabilities, fostered research and development efforts, improving infrastructure, and establishing collaborations with international partners. Furthermore, the government should consider implementing supportive policies, investment incentives, and capacity-building programs to attract domestic and foreign investments in the LIB industry.

Overall, based on the findings of the focused group discussion, Ethiopia currently faces challenges in competing with major players in LIB cell manufacturing. However, opportunities exist in battery manufacturing and battery component production, where Ethiopia can leverage its existing strengths. The automotive sector presents formidable entry barriers, requiring strategic investments and partnerships. To overcome these challenges and enhance competitiveness, Ethiopia should adopt a comprehensive approach that includes infrastructure development, technological advancements, policy reforms, and collaboration with industry leaders. By doing so, Ethiopia can position itself as a significant participant in the LIB value chain.

4.4 Ethiopia's Potential and Capabilities Related to LIB

Ethiopia possesses abundant mineral resources that play a crucial role in the growth of lithium-ion batteries (LIBs), giving it a valuable competitive advantage. Notably, Ethiopia has significant reserves of lithium, a key element in the production of LIBs. This availability of raw materials presents undeniable advantages for Ethiopia's participation in the LIB value chain. Lithium constitutes more than 80% of the essential components in LIB chemistry (Sharova et al., 2020).

In Ethiopia, various raw materials essential for LIB manufacturing, including lithium, cobalt, nickel, and graphite, can be found in abundance. Geological observations in the Danakil depression confirm the USGS model's predictions of lithium enrichment in brines. Research findings indicate higher lithium content in the northern part of the Danakil depression. The estimated lithium content associated with the potash horizons in Danakil reaches approximately 3 million tons with a 50% recovery rate. The production process for lithium primarily involves evaporating the end brines and separating lithium from other elements, resulting in reduced costs and eliminating the need for it in additional processing facilities (Bekele & Schmerold, 2020).

4.4.1 Ethiopia's main reserves related to lithium-ion batteries

Table 13; Ethiopia's main reserves related to LIB's

The type of mineral	Amount of stock that has been studied in	Location/Remark
Copper	50,000,000	✓ 8587 tons of proven reserves have been issued to the Company for production;
Lithium	419,116	✓ From Kenticha granites-pegmatite ✓ Requires detailed study
Nickel	17,000,000	✓ Although there are conditions indicating the existence of the mineral in different places, it needs further research;

Manganese	Not quantified	✓ Even if there is no quantitative information, there are conditions indicating the existence of the mineral in different places, so it needs further research.
Phosphate	181,000,000	✓ Apart from this, although the size of the stockpile has not been disclosed, it is assumed that there is a wide range of resources, so it requires further research.
Graphite	460,000	✓ Although the size of the stockpile has not been disclosed, it is believed to be extensive and requires further study.

Source: Minister of Mines, 2023

China has identified Ethiopia as one of six lithium-rich countries in Africa for strategic partnership, as reported by the Financial Times. This crucial mineral is in high demand by international automakers due to its essential role in the production of batteries for electric vehicles. Currently, there is a significant gap between supply and demand, allowing producers to generate attractive profit margins. The average cost of a ton of lithium has exceeded $50,000 this year, estimated to be five to ten times the production cost. Forecasts suggest that the demand for lithium will remain high, with supply needing to increase by a factor of 42 by 2050 to support the transition to clean energy (Opalo, 2023).

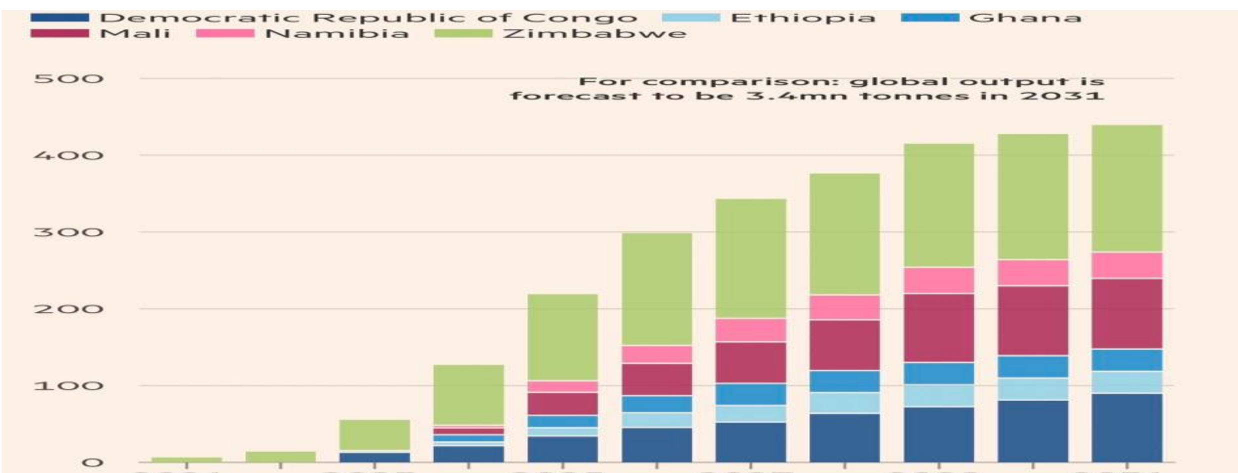

Figure 12; China’s focus for lithium in African nations

Source; | Financial Times (Opalo, 2023)

Ethiopia's abundance of mineral resources, particularly lithium, provides a significant advantage for its engagement in the LIB value chain. With the growing demand for LIBs in various industries, including electric vehicles, Ethiopia has the potential to capitalize on its resources and become a prominent player in the global lithium market. However, it will be crucial for Ethiopia to develop appropriate infrastructure, attract investments, and foster technological advancements to fully leverage this competitive advantage.

4.5 Ethiopia's Competitiveness in the Lithium-Ion Batteries Value Chain

As mentioned previously, the LIB value chain is characterized by intense competition and poses considerable entry barriers, particularly in the mid and downstream segments. These barriers are primarily due to the dominant position of a small number of companies, often originating from a select group of countries. Furthermore, the value chain is constantly evolving and being disrupted by cutting-edge technological advancements, which further contributes to the dynamic nature of the market.

To assess Ethiopia's potential and capabilities in LIB production, valuable insights were gathered through a focused group discussion. The discussion aimed to analyze Ethiopia's strengths, weaknesses, opportunities, and threats (SWOT analysis) within the LIBs value chain. This approach allowed for a comprehensive understanding of the country's internal factors that could influence its participation in the industry. By identifying and leveraging its strengths and addressing weaknesses, Ethiopia can effectively position itself in the value chain.

The insights obtained from the focused group discussion played a crucial role in verifying the selected segment for Ethiopia's engagement in the LIBs value chain. The discussion considered Ethiopia's capabilities, potential, and competitive advantages to determine the most suitable segment where the country can excel. This approach ensures that Ethiopia can focus its resources and efforts on a specific area that aligns with its strengths, increasing its chances of success in the competitive market.

4.5.1 SWOT Analysis of Ethiopia's Engagement in the LIBs Value Chain:

SWOT analysis insights were the Ethiopia's potential and capabilities in LIB value chain Utilizing SWOT analysis, the study provided valuable insights into Ethiopia's strengths, weaknesses, opportunities, and threats concerning its potential and capabilities within the LIBs value chain. It identifies the main challenges and success factors of each stage of the li-ion cell value chain, and evaluated the main players in terms of production capacity and experience and other factors

4.5.1.1 Upstream Stage

Strengths:

Mineral Resources in Abundance: Ethiopia's access to important mineral resources such as lithium, cobalt, graphite, and nickel provides a strong foundation for its participation in the upstream stage of lithium-ion batteries (LIBs) manufacture. These minerals are essential components in the production of LIBs, and Ethiopia's abundance of these raw materials offers a valuable competitive advantage in the global LIB value chain. By leveraging its natural resources, Ethiopia can attract investment and establish itself as a reliable and competitive source of these crucial materials. This can lead to the development of a robust upstream sector, encompassing activities such as mining, extraction, and processing of raw materials, which are critical for the production of high-quality LIBs.

Moreover, having access to these important minerals domestically reduces dependency on external suppliers and minimizes potential supply chain disruptions, enhancing Ethiopia's resilience in the LIBs value chain. Additionally, it opens up opportunities for technology transfer, innovation, and partnerships with international players in the industry, further strengthening Ethiopia's position in the upstream stage.

Low-Cost Raw Material Extraction: the presence of lithium-rich brine resources in Ethiopia offers a distinct competitive advantage in the upstream stage of lithium-ion battery (LIB) production. Brine deposits are a valuable source of lithium, and extracting lithium from brines can be a cost-effective and accessible method compared to traditional hard rock mining. The extraction of lithium from brine involves drilling wells and constructing evaporation ponds or processing facilities. This method generally requires less infrastructure complexity and capital investment compared to other mining methods. As a result, Ethiopia can benefit from lower production costs and potentially higher profit margins, making it more competitive in the global LIB value chain.

Furthermore, the accessibility of lithium-rich brine resources within the country reduces dependency on imported raw materials, contributing to the development of a self-sustaining and resilient LIB industry. This independence from external suppliers can mitigate supply chain risks and enhance Ethiopia's ability to meet growing global demand for LIBs. By capitalizing on its access to brine resources, Ethiopia can strategically position itself as a key player in the upstream stage of LIB production. It can attract investments, foster technology transfer, and establish itself as a reliable source of lithium for LIB manufacturers worldwide. This, in turn, can drive economic growth, create job opportunities, and accelerate the country's transition to cleaner energy technologies.

Weaknesses:

Limited infrastructure can pose significant challenges for Ethiopia's participation in the lithium-ion battery (LIB) value chain, particularly in the upstream stage where raw material extraction is crucial. Inadequate transportation, logistics, and energy infrastructure can hinder the efficient extraction, processing, and transportation of raw materials like lithium, cobalt, nickel, and graphite, which are essential for LIB manufacturing.

Insufficient transportation infrastructure can lead to difficulties in accessing remote mining areas where valuable mineral deposits might be located. This can result in higher transportation costs and delays in the supply chain, affecting the overall competitiveness of the LIB production process. Additionally, a lack of well-developed logistics networks may hinder the timely and cost-effective movement of raw materials from mining sites to processing facilities and eventually to LIB manufacturing plants.

Moreover, energy infrastructure is essential for the energy-intensive processes involved in raw material extraction and processing. Adequate and reliable energy supply is required for drilling, evaporation, and refining processes used in lithium extraction from brine, for example. A shortage of reliable energy supply could lead to inefficiencies and increase operational costs.

Opportunities:

a. Abundance of Critical Materials

The advantages of Ethiopia's access to brine deposits for lithium extraction in the upstream phase of the lithium-ion batteries (LIBs) value chain. Brine deposits offer a relatively easier and more affordable method of extracting lithium compared to conventional hard rock mining. This implies that Ethiopia may not require as much complex and capital-intensive upstream infrastructure. By focusing on creating the necessary infrastructure for brine extraction, such as drilling wells and constructing processing facilities, Ethiopia can leverage its inherent advantages and establish a competitive edge in the upstream stage of the LIBs value chain. This strategic approach can attract investment and position Ethiopia as a reliable source for essential materials like lithium, cobalt, graphite, and nickel, contributing to economic growth and development.

The potential of utilizing brine deposits and adopting effective extraction techniques to reduce technology and capital requirements for lithium extraction, thus strengthening Ethiopia's competitiveness in the upstream phase of the LIBs value chain.

b. Growing Global Demand: The global demand for lithium-ion batteries (LIBs) is on the rise, primarily driven by the increasing adoption of electric vehicles (EVs) and the growing use of renewable energy sources. Ethiopia's abundance of essential mineral resources, including lithium, cobalt, nickel, and graphite, positions the country well to capitalize on this global trend and play a significant role in meeting the surging demand for LIBs. The transition to clean energy and sustainable transportation solutions has led to a surge in the production and usage of LIBs. Electric vehicles are becoming more popular due to their environmental benefits and advancements in battery technology, which have extended driving ranges and reduced charging times. Additionally, renewable energy sources like solar and wind power are being integrated into power grids, creating a need for energy storage solutions like LIB to balance the intermittency of these sources.

Ethiopia's access to plentiful mineral resources, particularly lithium, is a crucial advantage in this context. As the major component of LIBs, lithium is a sought-after material for battery manufacturers worldwide. By leveraging its domestic resources, Ethiopia can reduce its reliance on imported LIBs and become a significant player in the global LIB market.

The growing demand for LIBs offers an excellent opportunity for Ethiopia to foster economic growth, attract foreign investments, and create new job opportunities in the LIB value chain. By strategically developing its domestic capabilities in LIB manufacturing, the country can position itself as a reliable supplier of batteries for both domestic and international markets.

However, to fully realize this potential, Ethiopia must address various challenges and invest in developing its LIB industry. As mentioned earlier, improving infrastructure, building a skilled workforce, fostering research and development, and forming strategic partnerships are all essential steps to enhance Ethiopia's competitiveness in the global LIB value chain.

Moreover, it is crucial for Ethiopia to adopt sustainable and responsible practices in its mineral extraction and LIB production processes. By prioritizing environmental and social considerations, Ethiopia can gain a reputation as a responsible and ethical player in the global LIB industry, further enhancing its competitiveness and attractiveness to international partners.

Ethiopia's abundant mineral resources, especially lithium, present a significant opportunity for the country to meet the growing global demand for lithium-ion batteries. By capitalizing on this advantage and addressing challenges proactively, Ethiopia can position itself as a key player in the LIB value chain and contribute to the global transition towards cleaner and more sustainable energy and transportation solutions.

C. Job Creation and Economic Growth: Developing the upstream stage can stimulate economic growth by creating employment opportunities, attracting foreign direct investment, and generating revenue through mineral exports. Ethiopia can leverage these opportunities to diversify its economy and reduce dependency on traditional sectors.

Threats:

Global Competition: The upstream stage of LIB production, which involves the extraction and processing of raw materials like lithium, cobalt, nickel, and graphite, is characterized by fierce competition. Established players in the global market, such as Australia, Chile, and China, have a dominant position in the supply of these critical minerals and already control a significant portion of the market.

Australia is one of the world's largest lithium producers, with extensive lithium reserves and well-developed mining infrastructure. Chile is another major player, known for its vast lithium brine resources and long-standing experience in lithium extraction. China, on the other hand, is a key player in the production of various raw materials needed for LIBs, including cobalt, nickel, and graphite. These countries have established strong supply chains, economies of scale, and technological expertise, giving them a competitive advantage in the upstream stage of LIB production. They have invested significantly in mining and processing facilities, enabling them to extract and supply these minerals more efficiently and at a lower cost.

For Ethiopia to compete effectively in this highly competitive market, it will need to overcome several challenges. Limited infrastructure, as previously mentioned, could pose difficulties in transporting raw materials from extraction sites to processing facilities and export points. Additionally, establishing a robust and efficient mining and processing infrastructure for lithium and other minerals will require substantial investments. Furthermore, global demand for these minerals is expected to increase rapidly as the demand for LIBs continues to grow. This increasing demand will intensify competition among suppliers, making it even more critical for Ethiopia to develop a strategic approach to become a significant player in the global market.

Price Volatility: Market changes can have a significant impact on the cost and availability of raw materials used in LIB production, such as cobalt and lithium. Fluctuations in the global market can influence Ethiopia's participation in the upstream stage of the LIB value chain.

Several factors can contribute to market changes for these raw materials:

1. Supply and Demand Dynamics: The demand for LIBs, particularly for electric vehicles continues to grow rapidly. As a result, the demand for raw materials like cobalt and lithium is also increasing. Any imbalances in supply and demand can lead to price volatility.

2. Technological Advancements: Advances in technology and manufacturing processes can affect the consumption patterns of raw materials in LIB production. For instance, researchers and manufacturers are constantly exploring alternative materials or more efficient use of existing materials, which can impact the demand for specific minerals.

3. Geopolitical Factors: Political and economic developments in major supplier countries, like Australia, Chile, and China, can affect the availability and pricing of raw materials. Export restrictions, trade disputes, or changes in regulations can disrupt supply chains and influence prices.

4. Environmental Concerns: The extraction of certain raw materials, such as cobalt and lithium, can be associated with environmental challenges. As environmental regulations tighten, companies may face additional costs in complying with sustainable mining practices, potentially affecting the overall cost of raw materials.

5. Technological Breakthroughs: Advances in recycling and refining technologies can influence the availability of secondary raw materials. Improved recycling processes can reduce the dependence on primary raw material extraction, leading to changes in market dynamics.

For Ethiopia's participation in the upstream stage, it will be crucial to closely monitor these market changes and adapt accordingly. Ensuring a competitive advantage will require addressing challenges, enhancing efficiency, and diversifying strategies to navigate through fluctuations in raw material costs.

4.5.1.2 Midstream Stage

Strengths:

Ethiopia's significant potential for producing renewable energy, especially through hydropower, can offer a crucial advantage in supporting the energy-intensive midstream step of LIB production. Hydropower is a clean and sustainable energy source that can be harnessed to power various stages of the LIB value chain, including the midstream processes involved in cell manufacturing and cell component production. To fully leverage its renewable energy potential, Ethiopia must continue to invest in the development and expansion of its hydropower infrastructure. Additionally, establishing partnerships with renewable energy experts and private sector companies can facilitate the integration of clean energy into LIB production processes.

By capitalizing on its renewable energy resources, Ethiopia can enhance its competitiveness in the midstream stage of the LIB value chain, contribute to a more sustainable battery industry, and strengthen its position as a significant player in the global LIB market.

Skilled Labor Force: Ethiopia's young and expanding population can be a valuable asset for the development and expansion of the midstream stage of the LIB value chain. The availability of a skilled and specialized labor pool is essential for successfully implementing the intricate manufacturing processes involved in LIB cell manufacturing and cell component production.

To fully capitalize on the potential of its young labor force, Ethiopia must invest in education and training programs that align with the specific needs of the midstream stage. Collaboration between the government, educational institutions, and industry stakeholders can help bridge the skills gap and create a workforce that meets the demands of the LIB value chain.

By harnessing the potential of its young population, Ethiopia can bolster the midstream stage of the LIB value chain, enhance its competitiveness in the global market, and pave the way for sustainable economic growth and development.

Weaknesses:

a. Technological Complexity: Advanced manufacturing techniques used in the midstream stage of the LIB value chain require specialized skills, knowledge, and expertise, as well as access to cutting-edge technologies and equipment. Ethiopia may face several challenges in acquiring and developing these essential technology skills:

1. Knowledge and Expertise: Acquiring the necessary knowledge and expertise for advanced manufacturing techniques in LIB production can be a time-consuming process. It requires skilled professionals who are well-versed in areas such as materials science, electrochemistry, and engineering. Developing a strong talent pool with expertise in these fields may require significant investments in education and training programs.

2. Access to Specialized Tools and Equipment: Advanced manufacturing techniques often rely on specialized tools and equipment that may not be readily available in Ethiopia. Acquiring or importing these tools can be costly and may involve navigating import regulations and customs procedures.

3. Patent and Intellectual Property Issues: Some advanced manufacturing techniques used in LIB production may be protected by patents and intellectual property rights. Ethiopia may need to negotiate licensing agreements or collaborate with international partners to gain access to these technologies while respecting intellectual property rights.

4. Capital-Intensive Projects: Implementing advanced manufacturing processes can be capital-intensive, requiring significant investments in research, development, and infrastructure. Securing the necessary funding for such projects may pose a challenge for Ethiopia, especially if it competes with established players with more financial resources.

b. Supply Chain Integration: Setting up a reliable and efficient supply chain is crucial for success in the midstream stage of the LIB value chain. This stage involves the production and assembly of

LIB components, and a well-functioning supply chain is essential to ensure the timely availability of equipment, components, and raw materials for manufacturing.

c. Limited Market Reach:

Developing export capabilities and expanding market reach can be a challenge for Ethiopia in the midstream stage of the LIB value chain. Due to its relatively smaller domestic market compared to larger economies, Ethiopia may face some hurdles in accessing global markets for LIB components and batteries

Opportunities:

Investing in the midstream stage of the LIB value chain and processing essential minerals into battery components and intermediate goods can significantly enhance Ethiopia's economic prospects and create higher-value products. By engaging in value addition at this stage, Ethiopia can unlock several advantages:

1. Strengthening Comparative Advantage: Processing essential minerals into higher-value battery components and intermediate goods allows Ethiopia to move up the value chain and develop a competitive advantage in producing specialized and advanced products. This can position Ethiopia as a more attractive destination for investment and partnerships in the LIB industry.

2. Employment Opportunities: Developing the midstream stage involves setting up manufacturing facilities, research centers, and skilled workforce training. This would create new employment opportunities across various sectors and help in tackling unemployment and promoting economic growth.

3. Domestic Value Retention: Value addition in the midstream stage ensures that more of the value generated from the raw materials remains within the country. Instead of solely exporting raw materials, Ethiopia can retain a larger share of the profits through processing and producing higher-value products domestically.

4. Diversification of the Economy: Expanding the midstream stage allows Ethiopia to diversify its economy beyond the extraction of raw materials. By moving into

manufacturing and value addition, the country becomes less reliant on a single commodity and can build resilience against market fluctuations.

5. Technology and Knowledge Transfer: Investing in advanced manufacturing processes and research and development in the midstream stage can lead to technology and knowledge transfer to local industries. This can foster innovation, enhance industrial capabilities, and support the growth of other related sectors.
6. Attracting Foreign Investment: Developing a robust midstream stage can attract foreign direct investment from companies seeking to establish a presence in Ethiopia's growing LIB industry. Foreign investments can bring in expertise, capital, and access to global markets, accelerating the country's industrial development.
7. Sustainable Development: A strong midstream stage with value addition can promote sustainable development. By utilizing renewable energy sources for production and employing environmentally friendly practices, Ethiopia can contribute to the global efforts towards sustainable and green industries.

To fully harness the benefits of value addition in the midstream stage, Ethiopia must adopt a comprehensive approach that includes infrastructure development, policy support, research and development, and collaboration with international partners. By seizing the opportunities in the midstream stage, Ethiopia can establish itself as a significant player in the global LIB industry and contribute to the country's overall economic growth and development.

Threats:

Intense Global Competition; the global competition in the midstream stage of LIB production is intense, and Ethiopia will face significant challenges in establishing a competitive position. Established companies from nations like China, South Korea, and the United States have a strong presence in the LIB industry and possess well-established manufacturing capacities. These companies have years of experience, advanced technology, and well-developed supply chains, giving them a significant advantage in the market

Technological advancement: competitiveness in the midstream stage of LIB manufacturing requires Ethiopia to continually invest in technological advancements and improve its industrial capacity. As technology rapidly evolves, embracing innovation and staying on the cutting edge will be crucial for sustaining a strong position in the market.

4.5.1.3 Downstream Stage:

Strengths:

Emerging Domestic Market: developing the downstream stage of LIB manufacturing can be a strategic move for Ethiopia to meet the increasing local market demand for renewable energy sources and electric automobiles. By establishing a robust downstream sector, Ethiopia can not only fulfill its domestic needs but also potentially position itself as a key player in the regional market

Sustainable Energy Transition: Ethiopia's participation in the downstream stage of the value chain, particularly in the manufacturing of battery packs and electric vehicles, can contribute significantly to the country's transition to sustainable energy and the adoption of electric vehicles (EVs).

Weaknesses:

Limited Market Reach: Ethiopia's domestic market for downstream LIB goods may be relatively small compared to more developed nations. This poses a challenge for the country to expand its market reach and build export capabilities in the downstream stage of the LIB value chain.

Technological Complexity: The downstream stage of the LIB value chain requires advanced technological skills for complex systems integration and product development. To participate successfully in this stage, Ethiopia may need to invest in research and development (R&D) to enhance its technological capabilities. Several factors contribute to the need for R&D investment:

1. Product Innovation: The downstream stage involves the production of battery packs and electric vehicles, which require continuous innovation to meet the evolving demands of consumers and industry standards. Investing in R&D allows Ethiopia to develop cutting-edge technologies and features that differentiate its products in the market.
2. System Integration: Integrating battery packs into electric vehicles and ensuring seamless operation is a complex process that demands technological expertise. R&D investments

can help Ethiopian companies gain proficiency in system integration, leading to more reliable and efficient electric vehicles.

3. Safety and Compliance: Electric vehicles must meet rigorous safety and regulatory standards to be viable in the market. R&D efforts can focus on developing safety features and ensuring compliance with international regulations, enhancing the reputation of Ethiopian products.

4. Performance Optimization: Improving the performance of LIBs and electric vehicles is crucial for customer satisfaction and market competitiveness. R&D investments can lead to advancements in battery technology, energy efficiency, and range optimization.

5. Cost Reduction: R&D efforts can also focus on cost reduction strategies to make Ethiopian downstream products more price-competitive. Achieving economies of scale and refining manufacturing processes can help lower production costs.

6. Skill Development: Investing in R&D contributes to the skill development of the local workforce, providing them with expertise in advanced technologies and fostering a culture of innovation and problem-solving.

Opportunities:

Ethiopia's rising urbanization and population present a significant opportunity for the downstream stage of the LIB value chain. As the population grows and urban centers expand, there is an increasing demand for renewable energy sources and electric vehicles (EVs) to address environmental concerns and promote sustainable development. Ethiopia can capitalize on this growing market demand by focusing on the downstream stage and meeting domestic needs for LIBs.

1. Meeting Domestic Demand: As the population and urban centers grow, the demand for renewable energy sources and EVs will increase. By developing the downstream stage, Ethiopia can produce battery packs and EVs locally, catering to the rising demand for clean energy solutions within the country.

2. Urban Transportation: With increasing urbanization, there will be a greater need for sustainable transportation options. Electric vehicles offer a viable solution to address air

pollution and reduce carbon emissions in cities. By producing EVs locally, Ethiopia can contribute to sustainable urban transportation.

3. Access to Renewable Energy: Ethiopia's potential for producing renewable energy, particularly through hydropower, presents a unique advantage for the downstream stage. By utilizing renewable energy sources for LIB production, the country can further enhance the sustainability of its value chain.

4. Job Creation: Developing the downstream stage can lead to job creation in the manufacturing and assembly of battery packs and electric vehicles. This can provide employment opportunities for the growing urban population, contributing to economic growth and social development.

5. Export Opportunities: As the demand for renewable energy and electric vehicles grows globally, Ethiopia can position itself as a supplier of sustainable solutions. By producing high-quality LIBs and EVs for export, the country can diversify its economy and generate foreign exchange earnings.

Threats:

Global Competition: The downstream stage of LIB production is highly competitive, with well-established producers from countries like China, the United States, and Germany dominating the market. These nations have advanced manufacturing capabilities, technological expertise, and established supply chains, giving them a significant advantage in the downstream stage. As Ethiopia seeks to participate in the downstream stage, it will face fierce competition from these established players

Market Demand Variability: Consumer preferences, governmental regulations, and economic conditions play a critical role in shaping the market for downstream LIB products, especially electric automobiles. To successfully participate in the downstream stage, Ethiopia must carefully evaluate these factors and make informed decisions to align its offerings with market demand and regulatory requirements.

Table 14: Summarization of the SWOT analysis

Stage	Upstream stage	Midstream	Downstream
Strengths	➢ Abundant mineral resources ➢ Low-cost raw material extraction for lithium brines	➢ Access to renewable energy sources ➢ Youth Labor Force	➢ Emerging domestic market ➢ Sustainable energy transition
Opportunities	➢ Job creation and economic growth ➢ Growing global demand ➢ Not capital intensive ➢ Simple technology ➢ High value creation	➢ Increase Local Value Addition: ➢ Collaboration and technology transfer	➢ Domestic Market Growth: ➢ Export potential ➢ Renewable energy integration ➢ Export potential
Weaknesses	➢ Limited infrastructure and logistical challenges	➢ Manufacturing infrastructure ➢ Technological complexity ➢ Technological Expertise ➢ Supply chain integration ➢ Patent right issues ➢ Capital intensive	➢ Limited market reach ➢ Technological complexity ➢ Patent right issues ➢ Capital intensive

Threats	➯ Global competition ➯ Market demand variability	➯ Intense global competition ➯ Rapid technological upgradation	➯ Global competition ➯ Market demand variability
Competitive advantage	High	Low	Low

After conducting a comprehensive SWOT analysis and considering Ethiopia's prospects and strengths, it becomes evident that the upstream stage in the LIBs value chain holds a significant competitive advantage for the country. Ethiopia possesses great potential in the upstream sector, further bolstered by the increasing global demand for LIBs and the opportunity to harness renewable energy sources. Currently, Ethiopia enjoys a competitive edge in this stage of the value chain.

The upstream sector in the LIBs value chain operates as a producer-driven value chain, granting the advantage of controlling the price of raw materials and possessing high bargaining power. This positions Ethiopia favorably, allowing it to leverage its abundant resources and actively influence market prices for raw materials. With control over these crucial inputs, Ethiopia can shape the dynamics of the value chain and fortify its competitive position.

To fully capitalize on the opportunities in the upstream stage and establish a prominent position in the global LIBs market, Ethiopia needs to address its limitations and overcome existing obstacles. Key areas requiring attention are limited infrastructure and logistical challenges. Improving transportation networks and power supply will enhance the efficiency and effectiveness of upstream operations. Additionally, overcoming logistical challenges related to the transportation and distribution of raw materials will ensure a seamless flow within the value chain.

By addressing these limitations and surmounting obstacles, Ethiopia can maximize its competitive advantage in the upstream stage. This will enable the country not only to meet the growing global demand for LIBs but also to capitalize on the potential of renewable energy sources. Ethiopia's commitment to sustainable practices and renewable energy aligns well with the global shift towards clean energy solutions, positioning it favorably to capture a significant share of the LIBs market.

In conclusion, the upstream stage in the LIBs value chain offers a highly competitive advantage for Ethiopia, as supported by the SWOT analysis and the country's prospects and strengths. By addressing limitations and overcoming obstacles, particularly in terms of infrastructure and logistics, Ethiopia can fully exploit the opportunities and establish a prominent position in the global LIBs market. As a producer-driven value chain, Ethiopia's control over raw materials and strong bargaining power will significantly contribute to its success in the upstream sector.

Furthermore, by leveraging renewable energy sources, Ethiopia can align itself with the growing global demand for sustainable energy solutions and solidify its position in the LIBs market.

4.5.2 Identify Specific Segment for Ethiopia in the Upstream Stage

Ethiopia is in a favorable position to excel in the extraction and processing tasks required for the production of LIBs due to the abundance of essential materials, particularly lithium. As a crucial ingredient in battery production, lithium holds immense significance, and Ethiopia's lithium reserves, especially in the Afar region, present a tremendous opportunity for sustainable extraction and supply. The performance and efficiency of LIBs are heavily influenced by lithium, making it a key component of these batteries. In fact, lithium constitutes more than 80% of the essential elements in lithium-ion battery chemistry, underscoring its substantial value (Sharova et al., 2020). With such rich lithium resources, Ethiopia can potentially play a crucial role in the global LIBs industry, meeting the increasing demand for these batteries and contributing to the advancement of sustainable energy solutions.

Ethiopia's valuable mineral resources extend beyond lithium and also include significant reserves of graphite and nickel, which are crucial components in the manufacturing of electrodes for LIBs. While lithium and nickel are especially essential in the creation of LIBs, all these minerals require substantial investments in infrastructure, technology, and knowledge for their extraction and processing. When it comes to extracting lithium, brines offer a more straightforward method, requiring less complex infrastructure and lower capital investments compared to cobalt and nickel. These factors make Ethiopia's lithium brine resources particularly advantageous for participating in the LIB value chain.

Lithium, nickel, cobalt, graphite, and manganese are the five essential components of batteries, with lithium, cobalt, and nickel being the most crucial metals for Li-ion batteries. Despite the abundance of these metals in the Earth's crust, their availability depends on mine output rates, and the current pace of building new mines is insufficient to meet the growing demand for batteries (IEA, 2022).

Considering the significant value of these critical metals in the final product, the focus will now shift to their role and importance in LIBs. Specifically, the researcher will delve into the key materials, including lithium. In LIB cells, the amount of lithium in the active material varies depending on the type of battery cathode, ranging from 4.1% to 8.4%. Despite its relatively low content share compared to other minerals, lithium plays an essential role in these batteries. For electric vehicle (EV) LIBs, the two most common cathode material types are nickel-manganese-cobalt (NMC) and nickel-cobalt-aluminum (NCA), with Figure 13 below illustrating the lithium composition share in selected LIB cathodes by volume (LaRocca, 2020).

Ethiopia's abundant reserves of lithium, graphite, and nickel present valuable opportunities for the production of LIBs. These critical materials are vital for electrode manufacturing and play essential roles in the performance and efficiency of LIBs. While lithium extraction from brines offers advantages in terms of infrastructure and capital investment, the overall importance of these minerals underscores Ethiopia's potential to contribute significantly to the global LIB value chain.

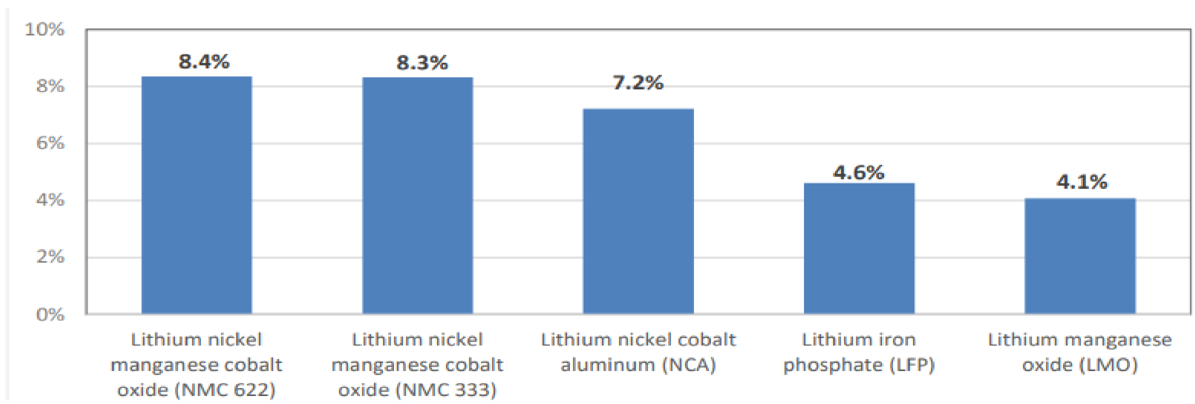

Figure 13; Lithium composition share in selected LIB cathodes, by volume

Source: Argonne National Laboratory, 2018, source by (LaRocca, 2020)

The figure clearly indicates that the volume of lithium in different types of LIBs is significant, ranging from 41% to 84%. This highlights the crucial role of lithium as one of the primary components, enabling the functionality and performance of these batteries. Understanding the composition and distribution of lithium within LIB cathodes is vital for optimizing battery design and maximizing efficiency.

Based on the focused group's recommendation, considering the simplicity of extraction and the value of lithium in LIBs, Ethiopia should prioritize the extraction of lithium brines over graphite and nickel at this time. By focusing on lithium extraction, Ethiopia can capitalize on its readily available resources and gain a competitive advantage in the upstream stage of the LIB value chain.

However, it is essential for Ethiopia to keep in mind the future potential of extracting and processing nickel and graphite as well. These minerals are equally crucial in LIB production, and as Ethiopia's capabilities and infrastructure grow, exploring their extraction and processing would further enhance the country's participation in the global LIB market.

Overall, Ethiopia's strategic approach to prioritize lithium brine extraction while keeping an eye on the potential for future extraction of nickel and graphite aligns well with its strengths and the demands of the evolving LIB industry. By maximizing its lithium resources and strategically planning for the future, Ethiopia can solidify its position in the LIB value chain and contribute significantly to the growing demand for LIBs worldwide.

4.5.2.1 Lithium Brine Extraction Process of the Danakil Depression

Large volumes of potassium-bearing brines are pumped onto multistage evaporation ponds as part of the solution mining process for potash in the Danakil Depression. During the evaporation process, lithium that was mobilized during potassium solution mining could be extracted as a secondary byproduct (Bekele & Schmerold, 2020). As shown in Figure 6, the lithium extraction process typically involves pumping brine to a series of ponds at the surface, each of which can be thousands of acres in size. In these ponds, lithium and other salts are concentrated through passive solar evaporation, which may take a year or longer. The lithium concentration in the water reaches a level of 6,000 mg/kg, and any non-lithium components that were not eliminated in the previous evaporative concentration steps are then precipitated using chemical reagents, primarily slaked lime ($Ca(OH)_2$). The remaining lithium-enriched solution is transported to a processing facility where any remaining undesirable components are eliminated using additional non-evaporative techniques, which are typically proprietary and may include reagent addition, filtration, solvent extraction, and ion exchange. To create lithium carbonate (Li_2CO_3) or lithium hydroxide ($LiOH \cdot H_2O$), the purified, lithium-concentrated brine undergoes chemical treatment with soda ash (Na_2CO_3).

Despite operators' efforts to improve their procedures, evaporative brine processing typically only recovers about 50% of the original lithium content of the native brine (Warren, 2021). However, the secondary byproduct of lithium extraction from potassium-bearing brines presents a valuable opportunity for countries like Ethiopia with significant lithium resources. By optimizing the lithium extraction process and implementing efficient techniques, Ethiopia can enhance its competitiveness in the upstream stage of the LIB value chain and contribute to meeting the growing global demand for LIBs.

4.6 Porter's Five Forces Framework

Porter's Five Forces framework provides a useful tool for analyzing the competitive dynamics and potential competitive advantage of a country or industry. In the case of Ethiopia's potential participation in the raw material extraction and processing segment of the LIBs value chain, the framework can shed light on the country's competitive position.

1) **Threat of New Entrant**, Ethiopia's access to brine deposits for lithium extraction provides a significant advantage in the upstream stage of the lithium-ion batteries (LIBs) value chain. Brine extraction offers a relatively simpler and more cost-effective method compared to conventional mining techniques, which reduces the barriers to entry for new competitors like Ethiopia. With brine deposits, the need for extensive infrastructure and capital investment is minimized, making it more feasible for Ethiopia to participate in the upstream stage. This advantage allows Ethiopia to leverage its available resources and potentially establish itself as a competitive player in the global lithium market.

   Furthermore, the threat of new competitors in the upstream stage is reduced due to the specific nature of brine deposits. Unlike traditional mining, where established players may hold a dominant position, brine extraction offers opportunities for new entrants to establish themselves in the market. By focusing on the extraction and processing of lithium brines, Ethiopia can capitalize on its inherent advantages and pave the way for greater participation in the LIBs value chain. To fully realize this potential, Ethiopia should continue to invest in technology, knowledge transfer, and sustainable practices to optimize lithium extraction and processing. Overall, Ethiopia's access to brine deposits for lithium extraction provides a favorable outlook for its participation in the upstream stage of the LIBs value chain, and the lowered entry hurdles enhance its competitive position in the global market.

2) **Bargaining Power of Suppliers**: Ethiopia's access to lithium-containing brine deposits provides a strategic advantage in the upstream phase of the lithium-ion batteries (LIBs) value chain. As a potential source of this essential chemical, Ethiopia gains considerable bargaining power as a supplier in the global market. The availability of crucial commodities, such as lithium, plays a vital role in determining the bargaining position of suppliers. With its access to brine deposits for lithium

extraction, Ethiopia can offer a steady supply of this critical material. A reliable and consistent supply of lithium is highly valuable to LIB manufacturers, especially considering the increasing demand for LIBs in various industries, including electric vehicles and renewable energy.

3) **Bargaining Power of Buyers**: it is a crucial aspect of the bargaining power in the upstream stage of the lithium-ion batteries (LIBs) value chain. While Ethiopia's potential as a lithium supplier can provide it with considerable negotiating power, it is essential to consider other factors that can influence buyers' decisions. Buyers in the upstream stage, such as LIB manufacturers, rely on a steady and reliable supply of essential components like lithium to ensure the continuous production of LIBs. Ethiopia's access to lithium-containing brine deposits can give it an advantage in terms of supplying this critical material to the market.

4) **Threat of Substitutes:** the significance of staying informed about market trends and technological advancements in the upstream stage of the lithium-ion batteries (LIBs) value chain. While LIBs currently dominate the energy storage market across various industries, it is essential for Ethiopia to be proactive in preparing for potential future replacements or advancements in energy storage technologies. Solid-state batteries, as an example, are one of the emerging technologies that hold promise for energy storage. As technology evolves, solid-state batteries may offer advantages in terms of safety, energy density, and charging rates compared to traditional LIBs.

5) **Competitive Rivalry:** Ethiopia's competitive advantage in the upstream stage of the lithium-ion batteries (LIBs) value chain. Access to brine reserves for lithium production gives Ethiopia a strategic edge in this highly competitive market. However, as you rightly mentioned, it is crucial for Ethiopia to be vigilant and proactive in navigating the challenges posed by other participants in the industry.

Table 15: Summarization of Porter's Five Forces analysis

Porter's Five Forces framework	DICTRIPTION
Threat of New Entrants	✓ The threat of new entrants to Ethiopia's involvement in the upstream stage is relatively low, considering its potential access to brine deposits for lithium extraction.
Bargaining Power of Suppliers	✓ Ethiopia's potential access to brine deposits containing lithium gives it a strategic advantage as a supplier, potentially enhancing its bargaining power in the global LIBs market.
Bargaining Power of Buyers	✓ Ethiopia can leverage its potential as a lithium supplier to negotiate favorable terms with buyers, but it needs to ensure a competitive advantage in terms of quality, cost-effectiveness, and sustainability.
Threat of Substitutes	✓ The threat of substitutes in the upstream stage is currently low, as lithium-ion batteries are the dominant energy storage solution. Ethiopia should monitor market trends, invest in R&D, and adapt to emerging technologies to mitigate future threats.
Competitive Rivalry	✓ Competition in the upstream stage exists among countries with access to critical materials. Ethiopia's potential access to brine deposits provides a competitive advantage, but it should focus on sustainable practices, strong supply chains, and reliability to differentiate itself.

Finally, given its potential access to brine reserves, Ethiopia has promising chances in the upstream stage of the LIBs value chain. Ethiopia can take the lead in the market by concentrating on cost-effectiveness, dependability, and sustainability. Ethiopia will be better able to respond to emerging trends and establish its position in the industry by spending money on R&D and keeping an eye on market trends. To utilize and to expand those competitive advantages the following actionable strategy is proposed.

By combining the insights from the focused group discussion, SWOT analysis, and Porter's Five Forces analysis, Ethiopia can gain a holistic understanding of its position in the LIBs value chain.

This comprehensive evaluation allows Ethiopia to identify its competitive advantages, mitigate potential threats, capitalize on opportunities, and develop strategies to enhance its participation in the dynamic LIB market.

The highly competitive nature of the LIB value chain, coupled with evolving technological advancements, presents entry barriers for new firms. The insights gathered from the focused group discussion, employing SWOT analysis and Porter's Five Forces analysis, have provided valuable insights into Ethiopia's potential and capabilities in LIB production. By leveraging its strengths and addressing weaknesses, Ethiopia can strategically position itself in the value chain and navigate the competitive landscape effectively.

4.7 Existing Ethiopia's Policy and Strategy Related LIB Industry

At present, Ethiopia lacks a clear strategy concerning the Lithium-ion Battery (LIB) industry and technology within its mining and industry sector policies. According to experts' opinions, the Ethiopian government has yet to establish a comprehensive framework that addresses the specific needs and opportunities presented by the LIB industry. This absence of a defined strategy poses challenges for the country's mining sector, which holds the potential for lithium extraction, a critical component in battery production.

To capitalize on the growing demand for lithium-ion batteries globally and leverage its mineral resources, Ethiopia would benefit from formulating a cohesive and forward-thinking approach. This strategy should encompass both the mining sector, focusing on responsible and sustainable extraction practices, as well as the industry sector, targeting the development of a robust and competitive battery manufacturing ecosystem. By actively engaging with stakeholders, including mining companies, technology experts, policymakers, and international partners, Ethiopia can cultivate an environment conducive to the growth of the LIB industry. This involves establishing clear policies and regulations that promote investment, research and development, and local skill development.

Overall, a well-defined strategy addressing the LIB industry and technology within Ethiopia's mining and industry sector policies is imperative to unlock the nation's potential in this rapidly expanding field. By embracing sustainable practices, fostering partnerships, and promoting innovation, Ethiopia can emerge as a key player in the global LIB market, driving economic growth, technological advancement, and energy transition in the country.

4.7.1 Strategic Framework for Ethiopia's Engagement in the LIBs Value Chain

The strategic framework has been developed to effectively address the weaknesses and threats identified during the SWOT analysis and Porter's Five Forces framework. Its primary objective is to leverage and expand the competitive advantages within specific segments of the lithium-ion battery (LIB) value chain. The framework encompasses short-term, midterm, and long-term goals, addressing multiple aspects of the value chain, including lithium extraction, material refining, and LIB component manufacturing. The ultimate aim is to enhance Ethiopia's competitiveness and meet the growing demand for LIBs both domestically and globally, especially for electric vehicles.

The short-term goals of the strategic framework focus on immediate actions that can be taken to address the identified weaknesses and mitigate threats. These may include targeted investments in infrastructure development, technology acquisition, and skill enhancement programs. By addressing these areas, Ethiopia can lay a strong foundation for its participation in the LIB value chain. In the midterm, the strategic framework aims to strengthen Ethiopia's position in specific segments of the value chain. This may involve the establishment of strategic partnerships with international players, research and development initiatives to foster innovation, and the implementation of favorable policies and regulations to attract investments. By strategically focusing on key segments, Ethiopia can enhance its competitiveness and ensure a sustainable presence in the LIB market. In the long term, the framework envisions Ethiopia becoming a major player in the LIB industry, capable of meeting both local and global demand. This requires long-term investments in human capital development, research and innovation centers, and advanced manufacturing facilities. Additionally, the framework emphasizes the importance of sustainable practices, including the utilization of renewable energy sources in LIB production.

By following this strategic framework, Ethiopia can overcome its weaknesses and address potential threats while capitalizing on its competitive advantages. The framework provides a roadmap for the development of the LIB value chain, enabling Ethiopia to become a significant contributor to the global electric vehicle industry and support the transition towards clean energy.

I. Objective of the strategy:

The objective of the strategy is:

a) Establish a competitive advantage in the extraction and processing of lithium and other critical minerals

b) Establish a reliable and sustainable source of essential materials by creating a strong sustainable mining practices and environmental protection

c) Encourage the establishment of refining industry and cell component manufacturers.

1) Short-Term Objectives (Lithium Extraction):

Lithium extraction from brines is a primary concern in the near future. To facilitate strategic planning and decision-making, conducting a resource assessment will provide crucial details about Ethiopia's lithium reserves. This assessment will offer valuable insights into the quantity, quality, and accessibility of lithium brine deposits, enabling informed decisions on the scale and feasibility of extraction operations. Moreover, understanding the country's lithium reserves will aid in attracting investments, formulating policies, and fostering partnerships for sustainable and efficient lithium extraction. By conducting a comprehensive resource assessment, Ethiopia can position itself as a reliable and competitive player in the global lithium market, contributing significantly to the growing demand for lithium-ion batteries and clean energy solutions.

a) Resource Evaluation:

A thorough evaluation of Ethiopia's lithium brine reserves is essential to ascertain their quantity, quality, and viability from an economic standpoint. The evaluation should include the following key steps:

1. Geological Survey: Conduct a comprehensive geological survey of potential lithium brine-bearing regions, such as the Danakil Depression, to identify and map the locations of lithium-rich brine deposits.

2. Lithium Content Analysis: Collect samples from the identified brine deposits and analyze them to determine the lithium content in the brine. This analysis will provide crucial data on the concentration of lithium in the brine reserves.

3. Quantity Estimation: Based on the geological survey and lithium content analysis, estimate the total quantity of lithium present in the identified brine reserves. This will help in understanding the overall resource potential of Ethiopia's lithium brine deposits.

4. Economic Viability: Evaluate the economic viability of extracting lithium from the brine reserves. Consider factors such as extraction costs, processing costs, infrastructure requirements, and potential market prices for lithium. This analysis will help determine if the extraction and processing operations are financially feasible.

5. Environmental Impact Assessment: Conduct an environmental impact assessment to understand the potential environmental effects of lithium extraction from brine reserves. This assessment is crucial to ensure sustainable and responsible mining practices.

6. Technology and Infrastructure Assessment: Assess the existing technology and infrastructure in Ethiopia to determine if they are suitable for efficient lithium extraction and processing. Identify any gaps or requirements for further development.

7. Market Demand and Competition Analysis: Analyze the current and projected global demand for lithium and assess the competition in the lithium market. This analysis will provide insights into Ethiopia's potential market position and competitiveness.

8. Policy and Regulatory Framework: Evaluate the existing policies and regulations related to lithium extraction and mining in Ethiopia. Identify any regulatory barriers or incentives that could impact the economic viability of lithium brine extraction.

By conducting a thorough evaluation of Ethiopia's lithium brine reserves, policymakers, investors, and stakeholders will gain a comprehensive understanding of the country's potential in the lithium market. This knowledge will inform strategic planning and decision-making to harness Ethiopia's competitive advantage and contribute to the growth of the lithium-ion battery industry.

b) Investing in the development of infrastructure and technology

I. In order to facilitate the effective extraction of essential minerals, mining infrastructure should be established. This includes drilling wells, building processing facilities, and building storage facilities.

II. Invest in cutting-edge mining equipment and technologies to streamline extraction procedures, boost output, and reduce environmental impact.

III. Encourage research and development initiatives to improve extraction methods, look into creative resource recovery techniques, and make sure sustainable mining practices are used.

IV. To ensure effective supply chain management, upgrade your transportation and logistics systems.

V. Improve the energy network to support the production of LIBs and the integration of renewable energy sources

c) Regulation and Policy:

I. Create and implement clear, transparent mining regulations and policies that support ethical mining practices, safeguard the environment, and guarantee the equitable distribution of benefits.

II. Simplify the licensing process and offer mining companies incentives to make investments in Ethiopia's upstream LIB value chain.

III. Create legal frameworks that support the growth of local content, the transfer of technology, and the development of Ethiopia's capacity.

IV. Promote communication between stakeholders in the government, academia, and industry.

V. Promote the protection of intellectual property rights to encourage technological transfer and innovation.

d) Research and Development

Encourage R&D activities to boost technological innovation and capability.

i. Conduct research on LIB technology and materials in cooperation with academic institutions, research centers, and international partners.

ii. For the characterization and performance assessment of LIBs, invest in cutting-edge testing facilities and laboratories.

iii. Support research and development initiatives in the LIB industry with funding and incentives.

iv. Encourage the transfer of technology and support the commercialization of research findings.

2) Midterm Goals (Critical Materials Extraction):

The strategic framework suggests broadening Ethiopia's focus to include the extraction of other crucial materials in the interim.

a) **Resource Assessment:** To determine Ethiopia's ability to extract other essential components used in lithium-ion batteries (LIBs) such as cobalt, graphite, and nickel, a comprehensive assessment of the country's mineral resources and mining capabilities is necessary.

1. Cobalt:

Ethiopia is known to have significant cobalt resources, particularly in the northern Tigray region. A thorough geological survey and mineral exploration would be required to identify specific cobalt deposits and estimate the quantity and quality of cobalt reserves. Additionally, an assessment of the existing mining infrastructure and technology for cobalt extraction would be essential to determine the country's ability to extract and process this critical component for LIBs.

2. Graphite:

Ethiopia has known graphite deposits in various regions, including the Amhara and Oromia regions. Similar to cobalt, a geological survey and mineral exploration would be needed to assess the quantity and quality of graphite reserves. Additionally, an evaluation of the existing mining and processing capabilities for graphite extraction would be crucial to determine Ethiopia's potential in supplying this essential material for LIBs.

3. Nickel:

Nickel is another vital component used in the cathodes of LIBs. Ethiopia is known to have nickel deposits, and a thorough assessment of these reserves is necessary to determine the country's potential in nickel extraction. Geological surveys and mineral exploration would help estimate the quantity and quality of nickel reserves. Moreover, an evaluation of the existing mining infrastructure and technology for nickel extraction would be essential in understanding Ethiopia's ability to supply this critical material for LIBs.

Furthermore, the economic viability of extracting and processing these essential components would also need to be considered. Factors such as extraction costs, processing technology, environmental impact, and market demand for the components would play a significant role in determining Ethiopia's ability to compete in the global supply chain of LIB materials.

It is essential for Ethiopia to conduct detailed resource assessments and invest in research, technology, and infrastructure development to fully harness its potential in extracting and supplying cobalt, graphite, nickel, and other essential components for the growing lithium-ion battery industry. Additionally, fostering partnerships with international players and adopting sustainable mining practices will enhance Ethiopia's competitiveness in the global LIBs value chain.

b) Enhance the infrastructure: To support the extraction and transportation of other essential materials for the lithium-ion battery (LIB) industry, Ethiopia should prioritize enhancing its infrastructure. Strong infrastructure is crucial for efficient and cost-effective mining operations, as well as the smooth transportation of extracted materials to processing facilities and markets.

Here are some key steps that Ethiopia should take to enhance its infrastructure:

1. Transport and Logistics: Invest in the development and improvement of transportation networks, including roads, railways, and ports, to facilitate the movement of raw materials from mining sites to processing plants and export points. Well-maintained and efficient transport systems can significantly reduce transportation costs and delivery times.

2. Energy Infrastructure: Ensure a reliable and sustainable energy supply to support mining and processing operations. Access to affordable and consistent energy is essential for the extraction and refining processes involved in producing essential components for LIBs.

3. Processing Facilities: Establish modern and efficient processing facilities close to mining sites to minimize transportation distances and costs. Adequate processing facilities enable Ethiopia to add value to the extracted materials before they are supplied to the LIB market.

4. Technology and Automation: Embrace technological advancements and automation in the mining and processing sectors. The adoption of modern technologies can improve efficiency, productivity, and safety in the extraction and refining processes.

5. Water Management: Implement effective water management practices, especially for brine extraction, to ensure the responsible and sustainable use of water resources. Proper water management is essential for lithium extraction from brines.

6. Environmental Considerations: Ensure that infrastructure development takes environmental protection and sustainability into account. Responsible mining practices and infrastructure development can help mitigate negative environmental impacts.

7. Skilled Workforce: Invest in skill development and training programs to build a skilled workforce capable of operating and maintaining modern mining and processing equipment.

8. Stakeholder Collaboration: Foster collaboration with relevant stakeholders, including private companies, international partners, and government agencies, to attract investment and share knowledge and expertise in infrastructure development.

By prioritizing infrastructure enhancement, Ethiopia can create a conducive environment for the extraction and transportation of essential materials used in LIBs. This, in turn, will strengthen its position in the global supply chain and contribute to the country's economic growth and development in the burgeoning lithium-ion battery industry.

c) Investment Promotion: To establish a welcoming investment environment and attract foreign direct investment (FDI) in the extraction of crucial materials for the lithium-ion battery (LIB) industry.

Ethiopia should take the following strategic measures:

Investment Incentives: Offer attractive investment incentives, such as tax breaks, customs duty exemptions, and accelerated depreciation allowances, to foreign investors interested in the mining and extraction of essential materials. These incentives can lower the initial costs and improve the return on investment for potential investors.

Regulatory and Policy Stability: Ensure a stable and predictable regulatory environment with clear and consistent policies related to mining and foreign investment. A stable regulatory framework instills confidence in investors, reducing perceived risks and encouraging long-term commitments.

Investor Support Services: Establish investor support services, such as investment promotion agencies or one-stop investment centers, to assist potential investors with information, project approvals, and other administrative procedures. Streamlining processes can make it easier for investors to enter the market.

Transparent Licensing and Permitting: Implement transparent and efficient licensing and permitting processes for mining activities. Clarity in procedures and timelines reduces bureaucratic hurdles and enhances investor confidence.

Land Access and Ownership: Ensure clear and secure land access and ownership rights for foreign investors engaging in mining activities. Transparent land tenure systems help avoid conflicts and disputes over land rights.

Infrastructure Development: Improve infrastructure, including transportation networks and energy supply, as mentioned earlier, to support mining operations. Reliable infrastructure enhances the attractiveness of the investment location.

Access to Finance: Facilitate access to finance for foreign investors by collaborating with international financial institutions and promoting partnerships with local banks. Access to funding options can help investors with capital-intensive projects.

Environmental and Social Responsibility: Demonstrate a commitment to environmental and social responsibility in mining operations. Ensure compliance with international standards for sustainable mining practices and responsible mineral extraction.

Collaborate with Industry Leaders: Foster collaborations with established industry players and international companies experienced in the mining and extraction of essential materials. Partnerships can bring in expertise, technology transfer, and market access.

Capacity Building: Invest in developing local human capital and expertise in the mining sector. Training and skill development programs can create a skilled workforce capable of contributing to the success of mining projects.

By implementing these measures, Ethiopia can create an enabling environment that attracts foreign direct investment in the extraction of crucial materials. A welcoming investment climate will not only boost the country's participation in the LIB value chain but also contribute to economic growth, job creation, and technology transfer.

3) **Building capacity and developing skills:** access to a skilled and diverse workforce is crucial for the development of the innovation-heavy lithium-ion battery (LIB) value chain in Ethiopia. The LIB industry demands a wide range of skills and qualifications to cover various aspects of research, development, and manufacturing.

   To foster a skilled workforce, Ethiopia can implement the following strategies:

   1. Technical and Vocational Training: Establish technical and vocational training programs focused on the specific skills required in the LIB industry. These programs can provide training for operators, technicians, mechanics, and electricians to support manufacturing and assembly processes.
   2. Higher Education and Research Institutes: Collaborate with universities and research institutes to develop specialized educational programs in LIB-related fields. This can include advanced degrees and research opportunities for graduates, especially in areas like materials science, electrochemistry, and battery engineering.
   3. Skills Development Centers: Create specialized skills development centers that focus on providing hands-on training and practical knowledge related to LIB R&D and manufacturing processes.
   4. International Partnerships: Engage in international partnerships with countries or institutions with expertise in the LIB industry. These partnerships can facilitate technology transfer, knowledge sharing, and training opportunities for Ethiopian professionals.
   5. Incentives for Researchers and Professionals: Offer incentives and attractive packages to encourage skilled researchers, engineers, and PhD graduates to work in the LIB sector in Ethiopia. This can include competitive salaries, research grants, and career advancement opportunities.
   6. Industry-Academia Collaboration: Foster collaboration between academia and industry to bridge the gap between theoretical knowledge and practical applications. This can lead to relevant research projects and more industry-relevant educational programs.

7. Workforce Mobility Programs: Establish workforce mobility programs that allow professionals from other countries to work in Ethiopia's LIB industry temporarily. This can facilitate knowledge transfer and skill enhancement.

8. Continuous Learning and Professional Development: Encourage continuous learning and professional development opportunities for the existing workforce in the LIB sector. This can be achieved through workshops, seminars, and training programs.

9. Emphasis on STEM Education: Promote Science, Technology, Engineering, and Mathematics (STEM) education at the school level to create a strong foundation of skills and interest in related fields.

10. Talent Attraction and Retention: Implement initiatives to attract talented individuals to the LIB industry in Ethiopia and retain skilled professionals through attractive career prospects and opportunities for growth.

By focusing on developing a skilled and qualified workforce, Ethiopia can strengthen its position in the LIB value chain and become a competitive player in the global battery industry. A well-trained workforce will drive innovation, ensure high-quality production, and contribute to the country's economic development and sustainable growth.

3) Long-Term Objectives (Manufacturing and Refining):

Exactly, the long-term objectives of Ethiopia's strategic framework for the lithium-ion battery (LIB) value chain include not only extracting essential materials like lithium, cobalt, graphite, and nickel but also moving up the value chain by producing LIB parts and refining these extracted materials. By refining the extracted materials locally, Ethiopia can add more value to its resources, making them more competitive in the global market. This step will reduce dependency on exporting raw materials and enable the country to participate in the higher value-added segments of the LIB industry. It will also create opportunities for job growth, technology transfer, and knowledge accumulation in the LIB value chain.

Producing LIB parts locally will further enhance Ethiopia's competitiveness and position in the LIB value chain. Manufacturing LIB components like cathodes, anodes, electrolytes, and separators within the country will not only meet domestic demand for batteries but also allow Ethiopia to export finished LIB products. This will contribute to economic growth, diversification of exports, and the development of a robust battery manufacturing ecosystem.

Moving towards more advanced stages in the value chain, such as refining and manufacturing LIB parts, will require investments in research and development, technology acquisition, and human capital development. Collaboration with international partners and existing industry players can play a significant role in building the necessary capabilities.

Overall, the strategic framework's long-term objectives to produce LIB parts and refine extracted materials will empower Ethiopia to unlock the full potential of its resources, increase competitiveness, and contribute to the global LIB market while promoting sustainable and responsible practices throughout the value chain.

a) Investing in manufacturing facilities to produce LIB components like cathodes, anodes, and electrolytes will enhance your manufacturing capabilities.

b) Enhancing the integration of the supply chain will ensure a seamless flow of goods from raw materials to finished products.

c) Prioritize continuous innovation by investing in R&D projects to advance extraction methods, improve efficiency, and reduce costs.

I. Market expansion and international cooperation:

To support the growth of the LIB industry, broaden market access and encourage international cooperation.

a) Develop strategies to enter potential export markets after identifying them.

b) Participate in international partnerships and collaborations to gain access to markets, technology, and distribution systems.

c) Participate in international LIB industry forums, conferences, and exhibitions to promote Ethiopia's capabilities and draw buyers and investors.

d) Encourage regional integration and collaboration to strengthen the LIB value chain in Africa.

e) Market Monitoring**:** Keep abreast of market developments, including new technologies and shifts in LIB demand, and adjust the strategic framework as necessary.

f) Analyze the market's level of competition and find ways for Ethiopia to stand out by implementing sustainable business methods, dependable supply chains, and high-quality goods.

II. Partnerships and Collaboration:

a) International Collaboration: To promote technology transfer, knowledge sharing, and capacity building, works with international partners, industry alliances, and research organizations.
b) Partnerships between the public and private sectors should be encouraged in order to promote investment, innovation, and skill development.

III. Environmental and social sustainability.

a) Give environmental protection and resource management top priority by putting strict environmental standards and monitoring systems in place.

b) Promote social responsibility by involving local communities, upholding their rights, and offering them opportunities and benefits through ethical mining methods.

c) Encourage initiatives to lessen the negative effects of mining on the environment, such as land rehabilitation, biodiversity preservation, and water resource management.

IV. Monitoring and Evaluation:

To track progress and make wise decisions, establish a reliable monitoring and evaluation system:

a) Create key performance indicators (KPIs) to gauge how well the strategy framework is working.

b) Consistently evaluate the way policies are being put into practice, the growth of the infrastructure, the research being done, and market penetration.

c) Conduct impact analyses to determine the socioeconomic and environmental advantages of the LIB sector.

d) Refine the strategy and make the necessary adjustments using data-driven insights.

Overall, the proposed strategic framework provides a comprehensive roadmap for Ethiopia's engagement in the LIBs value chain. This strategic framework identifies key areas that it should concentrate on. By putting these strategies into practice, Ethiopia can gain a competitive edge, draw in investment, generate jobs, and support sustainable economic growth and development while making the most of its plentiful critical mineral resources.

Table 16: Strategic Stakeholders and Activities with Timelines

Stakeholder	Short-Term Objectives (Lithium Extraction)	Midterm Goals (Critical Materials Extraction)	Long-Term Objectives (Manufacturing and Refining)
Universities	✓ Conduct research on LIB technology and materials in cooperation with academic institutions, research centers, and international partners. (Resource evaluation, R&D)	✓ Develop educational curricula and vocational training programs focused on manufacturing LIBs and extracting lithium in collaboration with colleges, technical schools, and job training programs. (Building capacity and developing skills)	✓ Collaborate with industry partners to bridge the skills gap and promote knowledge transfer. (Continuous innovation, Cooperation with manufacturers and international partners)
Government Agencies	✓ Conduct a thorough evaluation of Ethiopia's lithium brine reserves to ascertain their quantity, quality, and viability. (Resource evaluation)	✓ Simplify the licensing process and offer incentives to mining companies for investments in Ethiopia's upstream LIB value chain. (Investment promotion)	✓ Implement strict environmental standards and monitoring systems to ensure environmental protection and resource management. (Value-added processing, Market diversification)
Conducive Institutions	✓ Enhance infrastructure to support the extraction and transportation of essential	✓ Enhance the infrastructure to support the extraction and transportation of	✓ Set up refinery facilities to process and purify essential materials according to industry

	materials. (Investing in infrastructure and technology)	other essential materials. (Enhancing infrastructure)	standards. (Value-added processing)
Investors	✓ Invest in the development of mining infrastructure, including drilling wells, processing facilities, and storage facilities. (Investing in infrastructure and technology)	✓ Invest in the extraction of crucial materials used in LIBs, such as cobalt, graphite, and nickel. (Resource assessment)	✓ Invest in manufacturing facilities to produce LIB components and increase manufacturing capabilities. (Investment in manufacturing facilities)

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the value chain analysis, SWOT, and Porter's five force analysis, several key findings emerge regarding Ethiopia's competitiveness in the lithium-ion batteries (LIBs) value chain. The country's abundance of mineral resources, including lithium, cobalt, graphite, and nickel, provides a solid foundation for its participation in the LIBs value chain. Ethiopia holds a competitive advantage in the extraction of lithium due to its access to brine deposits, which require less complex infrastructure and financial investment compared to other mining techniques. This advantage positions Ethiopia to meet the increasing global demand for LIBs, particularly in the electric vehicle and renewable energy sectors.

Furthermore, Ethiopia's potential to play a significant role in the LIBs market aligns with the global trends towards electric vehicles and renewable energy sources. The growth of the upstream segment of the LIBs value chain can contribute to economic diversification, attract foreign direct investment, and create job opportunities, bolstering the nation's economy. Ethiopia's renewable energy potential, particularly in hydropower, supports the energy-intensive midstream stage of LIB production. By utilizing these renewable energy sources, Ethiopia can develop a sustainable and environmentally friendly LIBs industry.

Collaboration and technology transfer with established LIB producers can significantly enhance Ethiopia's technological capabilities and provide access to global markets and delivery systems. Additionally, the developing domestic market for electric vehicles and renewable energy sources offers an opportunity for downstream growth in the LIBs value chain. Ethiopia can foster this growth by focusing on local value addition, promoting the use of renewable energy and electric vehicles, and reducing reliance on traditional sectors.

In conclusion, Ethiopia has the potential to establish a strong presence in the global LIBs market, particularly in the upstream stage. To fully realize this potential, the country must address its constraints, such as inadequate infrastructure, technological complexity, and supply chain integration. By doing so, Ethiopia can position itself as a key player in the fast-growing LIBs industry and contribute to the global transition towards clean energy solutions.

5.2 Recommendations

This can be accomplished by giving the extraction and processing of lithium from brine deposits top priority when investing in infrastructure. Due to its competitive advantage in the upstream stage, Ethiopia will benefit from this. In order to promote technology transfer, knowledge sharing, and capacity building in the midstream and downstream stages, collaboration and partnerships with reputable LIB's producers are also essential. Additionally, in order to meet international standards and increase market access, certification and testing facilities for LIBs must be established. Ethiopia can produce higher-value battery components and intermediate goods, creating more employment opportunities and keeping more of the value created domestically by concentrating on local value addition and investing in the midstream stage.

Driving the development of the downstream stage and reducing reliance on traditional sectors will require encouraging the use of renewable energy sources and electric vehicles on the domestic market. The expansion of the LIBs value chain and the creation of a favorable business environment will be supported by enhancing research and development efforts and strengthening coordination among government agencies, stakeholders in the private sector, and educational institutions.

Those suggestions should be considered and into practice, Ethiopia will be able to make the most of its advantages, get rid of its disadvantages, seize chances, and counter threats while gaining an edge in the global LIBs market. The transition to a greener and more energy-efficient future will be aided by this, which will also promote economic growth. The following activities should be into account in order to utilize and to expand competitive advantages in the selected segment of the LIBs value chain.

Table 17: The recommendation for Ethiopia's engagement in the LIBs value chain

Short-Term Objectives (Lithium Extraction)	**Midterm Goals (Critical Materials Extraction)**	**Long-Term Objectives (Manufacturing and Refining)**
Conduct a comprehensive resource assessment for lithium brine reserves.	Conduct R&D projects for other essential materials (cobalt, graphite, nickel).	Establish manufacturing facilities for LIB components (cathodes, anodes, etc.).
Prioritize investment in infrastructure for efficient lithium extraction.	Strengthen supply chain integration for smooth flow of materials.	Develop a robust battery manufacturing ecosystem with sustainable practices.
Formulate policies and attract FDI, fostering partnerships with experts.	Establish strategic partnerships for technology transfer and capacity building.	Foster local value addition, producing higher-value battery components.
Establish certification and testing facilities for quality assurance.	Invest in skill enhancement and workforce development.	Enhance R&D efforts for innovation and technological advancements.

By implementing these objectives in the short, midterm, and long term, Ethiopia can capitalize on its competitive advantages, promote a sustainable LIB industry, and become a prominent player in the global market.

5.3 Future Research area

1. Technological Advancements: on LIB technology

Research emerging technologies and innovations in the LIB sector globally and consider how they might be used and adopted in Ethiopia. This research can concentrate on improvements in LIB materials, manufacturing procedures, energy storage systems, and recycling technologies.

2. Sustainable Supply Chain for LIB Materials

Investigate methods to develop a sustainable and responsible supply chain for LIB Materials. It includes Lithium, Cobalt, and Graphite. Analyze the negative effects that LIB production has on the environment and society, and look into ways that responsible sourcing, recycling, and circular economy strategies can be used to reduce these effects.

3. Market Dynamics and Demand Forecasting for LIB products

Forecasting market dynamics and future LIB demand in a number of industries, including consumer electronics, renewable energy storage, and the transportation of electric vehicles. Examine market trends, price swings, and consumer preferences to find market niches and potential growth opportunities for Ethiopian LIB producers.

4. Environmental Impact Assessment linked to the production, consumption, and disposal of LIB

Conduct a thorough analysis of the environmental effects linked to the production, consumption, and disposal of LIB in Ethiopia. Develop strategies for reducing adverse effects on the environment by employing sustainable manufacturing techniques, waste management, and end-of-life recycling.

More knowledge can be gained by addressing these potential research areas in order to support the long-term development and competitiveness of Ethiopia's in the LIB industry as well as the global transition to clean energy and sustainable development.

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Appendix A: Focused Group Discussion

Conducting a Focused Group Discussion on Lithium-Ion Battery Value Chain Analysis: Assessing Ethiopia's Competitiveness and strategic framework

1. Objectives:

The objectives of the Focused Group Discussion on Lithium-Ion Battery Value Chain Analysis: Assessing Ethiopia's Competitiveness and strategic framework are as follows:

a) Assess Ethiopia's current position and competitiveness in the global lithium-ion battery value chain.

b) Identify the strengths and weaknesses of Ethiopia's lithium-ion battery industry in terms of production, technology, infrastructure, and supply chain.

c) Evaluate the potential for Ethiopia to attract investment and develop a competitive lithium-ion battery value chain.

d) Examine the role of government policies and regulations in fostering the growth of the lithium-ion battery industry in Ethiopia.

e) Explore the opportunities and challenges faced by Ethiopia in developing a sustainable and environmentally friendly approach to lithium-ion battery production.

f) Discuss the potential economic and social benefits of developing a strong lithium-ion battery value chain in Ethiopia.

g) Identify strategies and initiatives to enhance Ethiopia's competitiveness in the lithium-ion battery value chain.

h) Examine the implications of emerging technologies and trends in the lithium-ion battery industry on Ethiopia's competitiveness.

i) Assess the potential for collaboration and partnerships with international players in the lithium-ion battery industry.

j) Discuss the role of research and development in enhancing Ethiopia's competitiveness in the lithium-ion battery value chain.

k) Explore ways to leverage Ethiopia's renewable energy resources to support the growth of the lithium-ion battery industry.

l) Discuss financing options and opportunities for supporting the development of Ethiopia's lithium-ion battery value chain.

m) Examine the potential for promoting the adoption of electric vehicles systems to drive domestic demand for lithium-ion batteries in Ethiopia.

2. Forming focused group:

To ensure a comprehensive analysis, a focused group consisting of relevant stakeholders and experts was formed. The group included influential individuals and institutions such as the Minister of Mines (2 experts), the Geology Institute of Ethiopia (2 experts), the Minerals Industry Development Institute (2 experts), and Manufacturing Technology and Engineering Industry Research And Development Center (2 experts). Their valuable insights were sought regarding Ethiopia's potential and capabilities in lithium-ion battery production, ensuring a well-rounded perspective.

3. Date and Place:

The discussion was held on May 16, and May 23, 2023, at 9 am, at the Minister of Mines, 5th floor. The venue was chosen to provide a suitable environment for group interactions and conducive to productive discussions.

4. Discussion Guide:

The following discussion questions were prepared to cover key aspects of the lithium-ion battery value chain and Ethiopia's competitiveness. These open-ended questions encouraged participants to share their insights, experiences, and recommendations:

a) What are the key components of the lithium-ion battery value chain?

b) How does Ethiopia currently fit into the global lithium-ion battery value chain?

c) What are the strengths and weaknesses of Ethiopia's competitiveness in the lithium-ion battery value chain?

d) What is the current state of lithium resources and mining in Ethiopia?

e) What is the capacity and capability of Ethiopia's lithium-ion battery manufacturing industry?

f) What are the major challenges faced by Ethiopia in developing a competitive lithium-ion battery value chain?

g) What are the potential opportunities for Ethiopia to enhance its competitiveness in the lithium-ion battery value chain?

h) What policies and initiatives should Ethiopia consider to attract investment and promote local production in the lithium-ion battery sector?

i) How can Ethiopia ensure a sustainable and environmentally friendly approach to lithium-ion battery production?

j) What role can research and development play in enhancing Ethiopia's competitiveness in the lithium-ion battery value chain?

k) How can Ethiopia develop a skilled workforce to support the growth of the lithium-ion battery industry?

l) What lessons can be learned from other countries that have successfully developed a competitive lithium-ion battery value chain?

m) How can Ethiopia foster collaboration and partnerships with international players in the lithium-ion battery industry?

n) What are the potential economic and social benefits of developing a strong lithium-ion battery value chain in Ethiopia?

o) How can Ethiopia leverage its renewable energy resources to support the growth of the lithium-ion battery industry?

p) What are the implications of emerging technologies and trends in the lithium-ion battery industry for Ethiopia's competitiveness?

q) How can Ethiopia ensure a fair and sustainable supply chain for lithium-ion battery materials?

r) What are the financing options available to support the development of Ethiopia's lithium-ion battery value chain?

s) What role can government policies and regulations play in fostering the growth of the lithium-ion battery industry in Ethiopia?

t) How can Ethiopia promote the adoption of electric vehicles to drive demand for lithium-ion batteries domestically?

5. Introduction:

The focused group discussion began by providing an overview of the objectives and guidelines for the discussion. The importance of open and constructive dialogue was emphasized, ensuring that all participants had an equal opportunity to share their perspectives.

6. Facilitating the Discussion:

As the facilitator, the researcher guided the discussion, following the objectives and utilizing the discussion guide. Active participation from all participants was encouraged to ensure a comprehensive and insightful discussion. The discussion remained focused, with time management to cover all relevant topics.

7. Analyzing and Interpreting the Data:

Careful review of the discussions and notes was conducted by the researcher. The data was analyzed, and the participants' opinions were considered to identify common themes, trends, and key insights regarding Ethiopia's competitiveness in the lithium-ion battery value chain. Both individual perspectives and collective viewpoints were taken into account.

8. Findings Summarization:

The findings from the focused group discussion highlighted key insights regarding Ethiopia's competitiveness in the lithium-ion battery value chain. These included the strengths and weaknesses of the industry, challenges faced, potential opportunities, policy considerations, research and development implications, workforce development, lessons from other countries, collaboration and partnerships, economic and social benefits, renewable energy leverage, emerging technologies' implications, sustainable supply chain, financing options, and the role of government policies and regulations. The summarized findings provided a comprehensive understanding of Ethiopia's current position and potential in the lithium-ion battery industry.

9. Validating and Sharing the Findings:

The summary report was shared with the participants to validate the accuracy of the information presented. Feedback and additional insights provided by the participants were incorporated into the report, ensuring its completeness and accuracy.

10. Utilizing the Findings:

The findings from the focused group discussion were utilized to inform decision-making processes, policy development, strategy formulation, and future initiatives related to Ethiopia's competitiveness in the lithium-ion battery value chain. The recommendations derived from the findings were integrated into actionable plans, with continuous monitoring and assessment of the industry's progress.