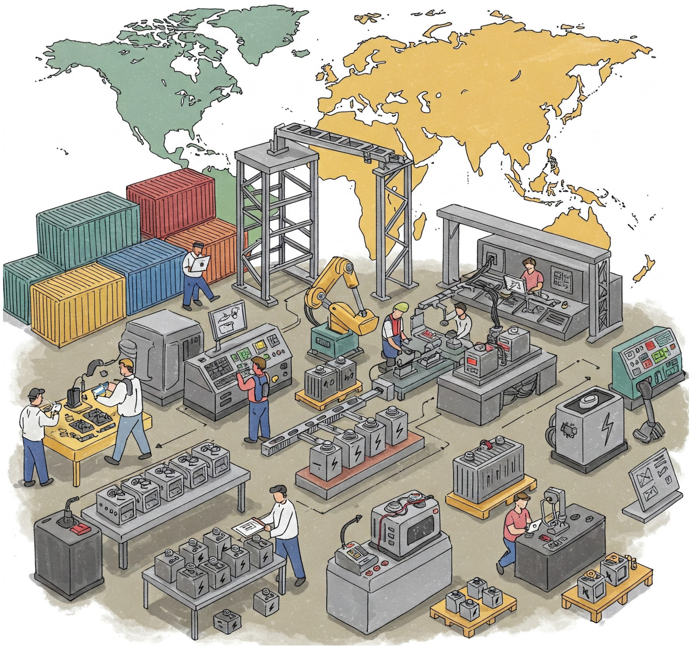

Outsourcing Electrode Manufacturing: A Technical and Economic Evaluation

Strategic Considerations for Slurry Mixing, Electrode Coating, Calendering, and Slitting at NOVO Energy

Master's Thesis in Production Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

The demand for lithium-ion batteries (LIBs) has been continuing to grow, and that is the reason why battery manufacturers like NOVO Energy face a strategic decision: whether to continue producing electrodes in-house or to outsource their production. This thesis investigated the decision by exploring both the technical and economic implications of outsourcing electrode manufacturing in the context of LIB production. The study used academic literature and expert interviews to assess four strategic scenarios: fully In-house production, fully Outsourcing, Gradual Vertical Integration, and Parallel Make-and-Buy.

Each scenario was analyzed through the lens of key industry factors like cost efficiency, scalability, quality control, and intellectual property protection. Outsourcing can offer short-term benefits like lower initial investment and possibly faster ramp-up, but it also has drawbacks related to long-term control over processes and maintaining the product quality consistency. On the other hand, keeping production in-house brings tighter integration and long-term competitiveness but needs more upfront resources and causes higher early-stage risk.

The thesis suggested a staged approach that combines Gradual Vertical Integration and Parallel Make-and-Buy based on the findings. By starting with external suppliers for the electrodes and then transitioning to in-house production over time, NOVO Energy can manage risks and costs while aiming towards a controlled and scalable production model.

Keywords: In-house Production, Outsourcing, Lithium-ion Batteries, Electrode Manufacturing, Production Strategy, Scenario Analysis, Technical Factors, Economic Analysis.

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We would like to begin by thanking NOVO Energy for the opportunity to collaborate on the project with them this spring semester. We would like to thank everyone at NOVO Energy who has taken the time to answer all our questions and share their experiences with us this spring semester. We would also like to acknowledge our supervisors from NOVO Energy, Carlo Novarese and Lukasz Gryga, for guiding us through the project and providing us with significant industry experience throughout the whole project. Thank you for always being there, checking in on us even when we did not know we needed it. Your guidance and encouragement meant the world. A heartfelt thank you to Pooyan Seddighzadeh for inspiring our topic and giving us the opportunity to collaborate with NOVO Energy. Your support at the very beginning set the tone for everything that followed.

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Tina Balouchzadeh & Amanda Kristensson, Gothenburg, 2025-06-13

Declaration of AI Tools and Technologies

During the construction of this thesis, Grammarly, Quillbot, and ChatGPT were all different AI-powered programs used. All the tools were used exclusively to enhance grammar, spelling, language clarity, and sentence fluency. Their function was limited to linguistic refinement and did not influence the development of ideas, critical analysis, or original arguments presented in this thesis. All intellectual content, research findings, and conclusions are the result of independent academic work. The tools were used responsibly to uphold the integrity, authenticity, and academic standards of this thesis. In addition, the AI tool Gemini was used to generate the frontage picture.

Acronyms

EV	Electric Vehicle
LIB	Lithium-ion Battery
NMP	N-methyl-2-pyrrolidone
SEI	Solid-Electrolyte Interphase
OCV	Open Circuit Voltage
EOL	End of Line
ACIR	Alternating Current Internal Voltage
DCIR	Direct Current Internal Resistances
CapEx	Capital Expenditures
OpEx	Operational Expenditures
EU	European Union
IRA	Inflation Reduction Act
GDIP	Green Deal Industrial Plan
IP	Intellectual Property
ALIB	Automotive Lithium-Ion Battery
IATA	International Air Transport Association
UN	United Nations
RD	R&D: Research and Development
ICT	Information and Communication Technologies
TCE	Transactional Cost Economy
RBT	Resource-based Theory
CM	Contract Manufacturer
OEM	Original Equipment Manufacturer
COGS	Cost of Goods Sold
OEE	Overall Equipment Efficiency
DOE	Design of Experience

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1

Introduction

This chapter aims to provide an overview of the areas in focus for this thesis and the reasons behind the studied problems. The chapter includes background, problem formulation, aim, research questions, and delimitations. Moreover, an introduction to the analyzed company and the chosen study area will be presented.

1.1 Background

The need for effective and affordable battery manufacture has grown dramatically as a result of the global shift toward electrification and sustainable energy solutions (Mauler et al., 2021). Batteries have become critical components in enabling the widespread adoption of electric vehicles (EVs) and supporting renewable energy storage solutions, driving a paradigm shift in how energy is stored and utilized. In 2023, the International Energy Agency reported that one in every five cars sold in the world was electric and that shows just how fast the shift toward electrification is happening (International Energy Agency, 2024). This peak in demand has caused a lot of pressure on battery manufacturers, and pushed them to rapidly scale up their production, lower costs, and keep getting updated at a speed that few industries have ever seen.

Although there are these opportunities, the lithium-ion battery (LIB) manufacturing industry faces numerous challenges. Rising costs of raw materials such as lithium, cobalt, and nickel, coupled with the environmental impact of their extraction, have emphasized the need for sustainable and efficient production processes (Ramasubramanian et al., 2024). Furthermore, maintaining high quality, scalability, and operational efficiency remains a challenging task for manufacturers who are competing in this rapidly evolving industry.

The following thesis is conducted in collaboration with NOVO Energy AB, a joint venture between Volvo Cars and Northvolt (NOVO Energy, 2025). NOVO Energy is a Swedish-based battery manufacturing company operating in Gothenburg. The company is in the process of building a Gigafactory with the potential capacity of producing up to 50 GWh per year, which will be able to supply batteries for half a million electric cars each year.

At NOVO Energy, the current production strategy includes performing the entire battery manufacturing process in-house, including slurry mixing, electrode preparation, assembly, formation, and aging. While this approach provides greater control over quality and process integration, it has proven to be resource-intensive, costly, and operationally demanding (Liu et al., 2023). NOVO Energy's ability to grow and adjust to changing market needs is held back by the high fixed costs related to the specialized equipment needed for battery manufacturing. On top of that, managing the different stages of production all under one roof adds a layer of complexity that makes scaling more difficult.

NOVO Energy is considering the possibility of outsourcing certain key production steps, like slurry mixing, coating, calendaring, and slitting, as a strategy to deal with ongoing operational challenges. By partnering with specialized suppliers for these processes, the company could free up valuable internal resources to focus on higher-value tasks, for example, assembly. This shift has the potential to make the production process easier, reduce operational costs, and ultimately enhance overall production efficiency. Outsourcing, in this case, could represent not just a cost-saving measure but a strategic move toward streamlining operations and improving long-term in performance and competitiveness. (Gambal et al., 2022).

Although outsourcing can be helpful, it causes several practical concerns that could affect the company's operations. For example, there is a probability that integrating the outsourced products will not go as smoothly as the system requires. There is always the risk of disruptions, which could cause inefficiencies or delays. Another issue is maintaining consistent quality. Ensuring that the suppliers meet the high standards NOVO Energy needs can be difficult to control from a distance, and any slip-ups could damage the company's reputation (K. Chen and Xiao, 2015).

1.1.1 Problem Formulation

Since the battery industry is rapidly expanding to meet the growing demand for batteries, manufacturers are under pressure to scale efficiently while maintaining high quality and cost-effectiveness. Therefore, NOVO Energy wants to explore its alternatives and better understand what technical and economic factors that affect the outsourcing of slurry mixing, electrode coating, calendering, and slitting. Therefore, the main problem for this thesis is to investigate the benefits and drawbacks of outsourcing based on the technical and economic factors affecting it.

1.2 Aim

The aim of this thesis is to study the key technical and economic factors that influence the decision to outsource or keep the production stages in-house of slurry mixing, electrode coating, calendering, and slitting in LIB manufacturing. The study intends to examine the benefits and downsides of these factors and recommend an outsourcing strategy for NOVO Energy.

1.3 Research Questions

To achieve the purpose of the thesis, the following research questions have been stated:

RQ1: What are the key technical and economic factors influencing the decision to outsource/keep in-house the slurry mixing, electrode coating, calendering, and slitting?

RQ2: What are the economic and technical benefits/drawbacks of keeping the slurry mixture, coating, and calendering in-house or outsourcing?

The first question aims to identify and present the different economic and technical factors that can impact the decision to outsource or keep the production in-house. In addition, the focus lies on revealing the possibilities and challenges around the decision of outsourcing/keeping in-house. Moreover, the second question focuses on exploring possible scenarios by evaluating the results of the literature study and data collection from the interviews. This question focuses on highlighting the most beneficial option for NOVO Energy.

1.4 Delimitations

In the following thesis, only the prismatic LIB is studied because this is what NOVO Energy will be producing. Since different types of batteries and formats all have their unique challenges and benefits, it was decided to only focus on prismatic due to time limitations, but also to obtain a deeper analysis within one area. Therefore, only the prismatic cell batteries' processes and techniques were explored.

The study's limitations include the fact that NOVO Energy's current production is not yet complete, which may lead to a lack of empirical data since their production approach is currently not in practice. Furthermore, this may lead to increased uncertainty regarding the factors impacting the economic and technical factors in the case of NOVO Energy.

Confidential information and data belonging to NOVO Energy will not be included in this report. However, the confidential information obtained was used to gain a deeper grasp of the topic as a whole, even if not included. The study will be limited to the economic and technical factors of outsourcing, and other factors will not be taken into account. Moreover, the study is limited by time, and therefore, work after 20 weeks will not be included in this report.

Lastly, due to the scope of the report, it only covers the technical and economic factors that affect the outsourcing of LIB. More specifically, economic factors mainly relate to cost, resource availability, market dynamics, and policy implications. These often include external variables like global trade conditions, government regulations, and regional cost differences. Outsourcing related to supply chain and logistics will not be the main focus of this report. However, it is brought up in terms of affecting the technical and economic factors that were identified. Moreover, the objective is to assess the economic feasibility of outsourcing, and therefore, revenue is not taken into account.

Technical factors, on the other hand, are defined as the engineering and manufacturing challenges that affect battery performance, efficiency, and scalability. For technical factors, battery innovation is not covered as a technical factor taken into account in the analysis.

2

Literature Review

In this chapter, an extensive literature review will be presented. The chapter aims to capture the topics of LIBs and outsourcing. Beginning with insight into the state-of-the-art LIB production stages and the key economic and technical factors to consider when producing batteries. Further, the text aims to provide theory and decision-making frameworks regarding outsourcing, as well as what technical and economic factors to consider in such a decision.

2.1 Lithium-ion Battery

The production of batteries occurs at massive-scale facilities, often known as gigafactories. Here, individual cells are made and united into battery modules. They can also be assembled as packs depending on the usage. In 2021, around 150 gigafactories were in production compared to the 3 factories in 2015. The car sector is primarily responsible for this rapid evolution. Furthermore, eleven European countries intend to phase out internal combustion engines between 2030 and 2035, making battery production a crucial aspect of the transition to electric vehicles (Bridge and Faigen, 2022).

In today's society, the LIB is dominating the battery market and is one of the main energy storage solutions (Liu et al., 2023). Since the battery was initially presented to the market in 1991, the industry has used new research and materials to develop it further (Ariyoshi and Ohzuku, 2009). Moreover, the application of LIBs ranges from small portable electronic devices to EVs, giving their use a broad range. While lead acid batteries are still the largest market share, LIBs are growing fast and research focuses on their development (Ariyoshi and Ohzuku, 2009). Since lithium is the lightest material used in battery production, it gives the battery lighter weight properties compared to, for example, nickel. In addition, the size of the lithium particle enables it to travel between electrodes and through electrolytes.

LIBs consist of anode, cathode, separator, electrolyte, and housing with battery terminals (Kwade et al., 2018). Depending on, for example, the composition and package design, the complexity of the batteries can increase or decrease. During charge and discharge, the active material in the electrodes is released and absorbed (Gulbinska, 2014). The anode stores lithium during charging, while the cathode releases lithium ions. The lithium ions return to the cathode during discharge, releasing energy. Then, the conductive dilute assists the electron conducting inside the electrode by enhancing the electronic conductivity of the active materials. Further assisting the transportation of active material particles towards the current collecting foil. The current-collecting foil transfers the electricity while the binders ensure adhesion to current collectors and cohesion within the electrode. Lastly, electrolyte solution and porous separators are added. LIBs can be connected either in parallel or in series, then they are assembled into battery packs with thermal, electrical, and mechanical components (Aydin et al., 2023).

Today, there are several different ways of producing LIB cells. Some of the most common types used in EVs are cylindrical, prismatic, and pouch. The cylindrical cell has a simple cell assembly and is easy to make in different sizes. The prismatic cell, on the other hand, is simple to pack with great efficiency but requires advanced cell manufacture. The pouch has a high energy density and is lightweight, however, it may be more difficult to integrate because of the thin casing. Inside the battery cell, the sheets can be stacked differently, resulting in a variety of characteristics. The different options are z-stacking, single-sheet stacking, and winding. Both z-stacking and single-sheet stacking have good packing efficiency, and winding has a low risk of particle contamination. Single-sheet stacking and z-stacking are both slow processes and single-sheet stacking has a higher risk of particle contamination during cutting. The winding, on the other hand, has lower packing efficiency due to its structure (Halimah et al., 2019).

In the case of NOVO Energy, they are focusing on the prismatic cell. Prismatic cells consist of positive and negative electrons that are packed in a spiral structure and are usually placed in a rectangular chassis. The prismatic structure is a good way of optimizing the space and increasing the package efficiency. However, the prismatic cell is prone to deformation and has poorer thermal stability in comparison with, for example, the cylindrical cell. The main benefit of using the prismatic cell is its high energy capacity (Chengjoseph, 2022).

Batteries are particularly sensitive to moisture, so the environment in which they are manufactured is critical (Lechner and Mothwurf, 2023). Therefore, several production stages are performed in a dry room. Furthermore, in a dry room, the air is controlled to have optimal humidity levels, and these levels can even vary depending on the production stage. The reason for producing in this type of environment is that some materials, such as nickel and electrolyte materials, have moisture sensitivity. The cell assembly stage is, for example, performed in a dry room to prevent the electrostatic discharge of the battery (Korthauer, 2018). Additionally, the so-called "clean room" or "clean environment" helps to prevent cross-contamination and dust from damaging the batteries. For example, double-door systems are utilized to reduce the risk; however, eliminating it completely is difficult due to cutting and packaging operations.

Some of the key characteristics when designing LIBs include low cost at a high energy and power density, but battery lifetime is also considered a major factor (Kwade et al., 2018). For instance, optimizing the energy density in the automotive sector improves the range of the car, while the improvement of power density results in the possibility of charging faster (Bridge and Faigen, 2022). Currently, the production of LIBs is shaped by four strategic drivers. The drivers are energy storage, power delivery, weight/cost sensitivity, and power sensitivity. Moreover, all the drivers are heavily influenced by the automotive industry, which has shaped the technological path of the LIBs more than any other sector.

In 2020, the leading country in producing LIBs was China, which accounted for 76% of the production. Furthermore, the US and Europe have similar market shares of around 8% and 7% respectively. At the same time, South Korea has 5% and Japan 4%, making Asia the leading LIBs producer, which suggests that LIB production involves highly complex processes that are challenging to master, which in turn contributes to the uneven global distribution of manufacturing capabilities and explains why certain countries dominate the market (Bridge and Faigen, 2022).

2.2 Lithium-ion Battery Production

The manufacturing processes of LIBs vary depending on the manufacturer and the specific type of battery being produced. According to Liu et al. (2023), the current state-of-the-art production process for LIBs consists of the key steps of slurry preparation, coating and drying, calendering and slitting, cell assembly, electrolyte filling and sealing, formation, and aging. All the process steps can be defined into three distinct stages in the production of LIBs (Aydin et al., 2023). The defined three stages are electrode manufacturing, followed by cell assembly, and lastly, in the final phase, the cell is finished (formed). In Figure 2.1, the steps are shown, and stations marked with the red box are considered to be outsourced at NOVO Energy and will therefore receive a more detailed description. All the process steps will be introduced in more depth in the following section.

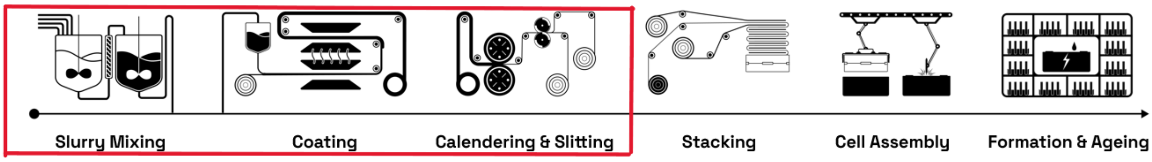


Figure 2.1: State-of-the-art Production of LIBs

2.2.1 Electrode Manufacturing

LIB electrode manufacturing involves several key steps that impact performance and durability. It starts with slurry mixing, followed by coating, drying, calendaring, and slitting, each requiring precise control to ensure quality and efficiency. These processes influence electrode structure, conductivity, and long-term stability, making them crucial for large-scale production (Li et al., 2010). In this section, all these steps and the factors affecting them will be covered.

2.2.1.1 Slurry Mixing

The first step in battery manufacturing is slurry mixing, where active materials, conductive additives, and binders are combined in a solvent to form a uniform mixture. The cathode slurry typically uses N-methyl-2-pyrrolidone (NMP) as a solvent, while the anode slurry employs water-based binders (Li et al., 2021). In this step, the mixing conditions will affect the electrochemical performance if not performed correctly. For example, the mixing conditions can significantly impact electrode microstructure and electrochemical properties, making it a crucial process for ensuring battery efficiency. The mixture is thoroughly blended to ensure a homogeneous distribution of materials, which is critical for battery performance (Liu et al., 2023). In addition, the mixing order affects the mixing uniformity, which in turn will affect the electrode properties and the performance of the electrode. Besides the sequence, slurry quality also depends on factors such as mixing technique, equipment, intensity, and duration. (Li et al., 2010).

Common mixing methods include hydrodynamic shear, ball-mill, and ultrasonic mixing, though ultrasonication faces challenges in large-scale applications despite its efficiency (Kraytsberg and Ein-Eli, 2016). In industry, Cowles Sawtooth impellers and planetary mixers are normally used, where mixing typically lasts 2–6 hours, plus an additional 1–2 hours for degassing (Kvasha et al., 2016). During slurry preparation, it is important to keep dust away to control solvent quantities and protect the material from cross-contamination (Korthauer, 2018).

2.2.1.2 Coating and Drying

After mixing, the electrode slurry is coated onto a current collector, typically aluminum foil for cathodes and copper foil for anodes, using a slot-die or similar coating technique. The coated sheets then go through a drying process in a controlled environment to remove solvents, ensuring strong adhesion of the active materials to the foil. This drying stage is particularly energy-intensive for cathode production, as it requires solvent recovery systems to capture and recycle NMP, reducing both costs and environmental impact (Liu et al., 2023).

The slot-die coating method is the industry standard in LIB manufacturing because of its precision and ability to maintain tight tolerances. In this process, the slurry is dispensed through a slot-die head onto the moving base, with coating thickness regulated by the balance between pump rate and line speed. A horizontal head position is often preferred for its superior control over coating uniformity and cleanliness. Achieving a consistent coating requires careful optimization of slurry stability, processing parameters, and the capillary number. Since large slurry batches are mixed in one shift and coated in another, stability over extended periods (8+ hours) is crucial. However, gradual property changes over time can cause variability in the final electrode, affecting overall performance (Li et al., 2011).

After coating, the wet electrode enters a drying phase lasting approximately 1–2 minutes to remove residual solvents. Anode drying is generally more efficient and consumes less energy than cathode drying. Improper drying, however, can lead to defects such as mud cracking, which compromises electrode integrity. As production speeds increase, the drying stage has become one of the most critical and time-consuming steps in LIB manufacturing, directly influencing electrode morphology, structural integrity, and material properties (Wood et al., 2017).

2.2.1.3 Calendering

Once dried, the electrodes undergo calendaring, a process in which they are compressed between rollers to achieve the desired thickness, density, and porosity. This step is important for enhancing the electrode's mechanical integrity and electrical conductivity by optimizing particle contact. Proper control of the compression level is essential, as excessive compaction can hinder electrolyte penetration, negatively impacting ion transport and overall electrode stability. Additionally, calendaring influences electrode wettability, which plays a key role in both safety and long-term performance (Liu et al., 2023).

Calendaring not only reduces pore volume but also enhances energy density, electron transport, and ion mobility within the electrolyte-filled pores. The process improves contact between electrode components, thereby increasing electronic conductivity. To make the material distribution smoother and minimize residual stress, calendaring is typically performed at high temperatures, above the binder's glass-transition temperature, allowing for better structural uniformity and mechanical durability (Li et al., 2021).

2.2.1.4 Slitting

After calendaring, the electrode sheets remain in large rolls and must be precisely cut to match the manufacturer's specific cell format. This slitting process ensures proper electrode alignment for cell assembly while also playing a critical role in battery performance and safety. The quality of these cuts is particularly important because the electrode edges influence the concentration of electric field strength. Rough edges or residual filaments from the current collector can increase the risk of short circuits or promote dendrite growth over time, which may compromise battery reliability (Liu et al., 2023).

Anodes are intentionally designed with a slightly larger cross-sectional area than cathodes to mitigate these risks. This additional overlap helps counteract edge-related electric field effects, ensures accurate alignment during assembly, and improves the cell's resistance to mechanical stress. Before proceeding to cell assembly, the electrodes go through vacuum drying to remove any residual moisture. Even a small amount of water can trigger unwanted chemical reactions within the battery, potentially degrading both performance and safety (Lee et al., 2012).

2.2.2 Cell Assembly

Once the electrodes are manufactured, they are moved to the cell assembly stage, where they are rolled into jumbo rolls and placed into casings in preparation for the final process. This stage consists of three key steps, which will be outlined in detail in this section. Depending on the cell design and process, there could be additional steps for the cell assembly as well as a different order in the steps.

2.2.2.1 Stacking and Winding

The prepared electrodes are assembled into cells through either stacking (for pouch and prismatic cells) or winding (for cylindrical cells) (Liu et al., 2023). In academic papers, the term "jelly roll" is commonly used for cylindrical cells in which the separator, cathode, and anode are wound in a spiral form. In prismatic batteries, however, it refers to the stacked layers of these components before placing them into their case (Baazouzi et al., 2023). "Pancake" and "jumbo roll", on the other hand, are rarely used in academic papers, but in industry, they are well known. The term "jumbo roll" describes the enormous rolls of electrodes used in manufacturing before cell assembly, and after jumbo rolls are slitted in half, the smaller rolls are called "pancakes". According to Pettinger et al. (2018), battery cell stacking can be categorized into two methods: single-sheet stacking and Z-folding. In the single-sheet stacking approach, separator sheets are layered alternately with cathode and anode sheets, forming a structured stack of individual components. In contrast, Z-folding involves inserting the anode and cathode sheets sideways into a continuous separator sheet that follows a Z-shaped pattern to form a jelly roll. This technique allows for efficient and compact assembly. On the other hand, in cylindrical battery designs, the cathode and anode sheets are wound around the separator. To prevent the risk of short circuits, the separator extends beyond the edges of both electrodes, ensuring proper coverage throughout the winding process (Pettinger et al., 2018).

2.2.2.2 Welding

After stacking, the aluminum and copper tabs are welded onto the cathode and anode current collectors, using techniques such as ultrasonic welding and resistance spot welding, depending on the cell design and packaging method (Liu et al., 2021). Ultrasonic welding, commonly used for pouch cells and sometimes for cylindrical and prismatic cells, offers low energy consumption and compatibility with dissimilar materials but is limited by joint thickness and potential heat generation (Zwicker et al., 2020). Resistance welding, in contrast, is a cost-effective alternative and has low thermal input but struggles with highly conductive and dissimilar materials (Das et al., 2018). Brand et al. (2015) conducted research to compare laser, ultrasonic, and resistance welding and found that laser welding had the lowest contact resistance and highest tensile strength, though its use is restricted by challenges in joining reflective and dissimilar materials.

2.2.2.3 Packaging

During the packaging stage, the jelly roll is placed inside a sturdy metal casing and wrapped in an insulating foil. This foil serves as a protective layer, preventing damage to the jelly roll as it is inserted into the metal can. In prismatic cells, the edges of the jelly roll are usually compressed and secured before being welded to establish contact with the battery's terminal connections on the lid. In the end, the housing is sealed, typically through a welding process, to ensure durability and stability (Liu et al., 2021).

2.2.3 Cell Finishing

Cell finishing is the last step of producing the batteries. In the different steps, the battery is completely assembled and electrochemically activated before being transported to its use.

2.2.3.1 Electrolyte Filling

The electrolyte, a liquid or gel containing lithium salts in a solvent, is injected into the sealed battery cell under vacuum conditions. This step ensures thorough wetting of the electrode and separator, optimizing ion conduction (Plumeyer et al., 2023).

2.2.3.2 Soaking

After filling, the cells are temporarily sealed to pass further for soaking (Liu et al., 2023). During the soaking process, the cells are placed on trays and further placed in the high-temperature room (Plumeyer et al., 2023).

2.2.3.3 Pre-charge

After the battery is sealed, it is left for a time period to let the electrolyte infiltrate the electrodes and separator. Then to improve wetting, the pre-charging process uses small currents prior to formation. It is also made to resist copper foil corrosion and the step is designed to improve quality by reducing the number of gas bubbles between the electrodes. As the voltage increases, the additives begin to reduce (Xiaoyan et al., 2021).

2.2.3.4 Aging Step 1

The aging steps can be divided into two steps, where the first step is high-temperature aging. During high-temperature aging, the cells are then stored in controlled conditions for aging, allowing the electrolyte to permeate and stabilize within the cell fully (Liu et al., 2023). The process is performed in a high-temperature environment to reduce viscosity and ensure homogeneous cell distribution. The process time depends not only on the cell size but also on the format (Plumeyer et al., 2023).

2.2.3.5 Formation

The formation is the step where the battery is electrochemically activated. The battery undergoes an initial charge-discharge cycle at a low rate to form a stable solid-electrolyte interphase (SEI) on the anode (Liu et al., 2023). The formation stage is made to form boundary layers on the electrodes, more specifically the surface of the electrodes (Plumeyer et al., 2023). This layer prevents further electrolyte decomposition and ensures long-term battery stability.

2.2.3.6 Degassing and Sealing

After the formation process is completed, the electrolyte can be reduced, causing gases to accumulate inside the battery. As a result, the degassing phase is utilized to remove the accumulated gases, improving both quality and safety. In the prismatic cell, the gas can be removed through an open port on the top of the house. (Plumeyer et al., 2023).

2.2.3.7 Second Electrolyte Filling and Final Sealing

The second filling is done to compensate for a possible reduction of electrolytes during the formation step. This step is necessary since a reduction of electrolytes occurs during the charge and discharge process because of the electrochemical activation. The electrolyte solution is injected into the evacuated cell housing with the help of a dosing lance. The second filling mostly affects larger cells since they have greater loss fractions after the formation (Plumeyer et al., 2023).

2.2.3.8 Aging Step 2

This step, which can take up to several weeks, is critical for ensuring consistent performance and longevity. In this step, quality assurance tests are also made to measure the open circuit voltage (OCV). The end-of-line (EOL) test varies depending on the cell and the purpose of it. Depending on the results from the test, the batteries are placed in different quality classes. Some of the steps of the test are, for instance, OCV, in which the measurement is done in intervals to get the self-discharge rate. In addition, alternating current internal resistances (ACIR) and direct current internal resistances (DCIR) are made as a final step before packaging (Plumeyer et al., 2023).

2.2.3.9 Packaging

In the last step, the finished batteries are packed. The package units are then placed on pallets where they are transported to a temporary storage location before being transported to where they will be used (Plumeyer et al., 2023).

2.2.4 Economic and Technical Factors Affecting Lithium-ion Batteries Production

In our analysis, we have distinguished economic and technical factors based on their core influences on LIB manufacturing. Economic factors are those mainly concerned with cost, resource availability, market dynamics, and policy implications. Economic factors often revolve around external variables such as global trade, government policies, and regional cost variations. On the other hand, technical factors refer to the fundamental engineering and manufacturing challenges that impact battery quality, efficiency, and scalability. Technical challenges are mostly inherent to the manufacturing process and focus on maintaining consistent performance, minimizing defects, and improving throughput while meeting industry standards. In this section, a structured perspective is provided on the key drivers influencing LIB production from both operational and financial standpoints.

2.2.4.1 Economic Factors

In the industry's economic framework, Capital Expenditures (CapEx) and Operational Expenditures (OpEx) serve as the two pillars forming the foundation of its economics. In LIBs manufacturing, CapEx refers to the significant upfront investments needed to build manufacturing capabilities. These costs include constructing the production facility, purchasing specialized equipment for key processes like mixing, coating, cell assembly, and formation, and establishing critical infrastructure such as cleanrooms and dry rooms to provide the strict environmental conditions essential for battery quality. CapEx can vary widely based on factors like the specific battery chemistry being produced and the overall size of the production line. For example, research has shown that the location of a manufacturing facility can influence battery cell production costs by as much as \$47 per kWh (Orangi and Strømman, 2022).

In contrast, OpEx cover the ongoing costs related to running LIB manufacturing facilities. These include expenses for energy, labor, maintenance, and raw materials. Among these, the cost of materials represents the largest share of the total cost of a battery cell. Energy consumption is also a major component, especially in energy-intensive steps like cathode active material synthesis and cell manufacturing, which together account for a significant part of total energy use in battery production (Gutsch and Leker, 2023).

The economic factors that influence the manufacturing of LIBs the most can be divided into two parts: the material cost and the process cost (Qi et al., 2023). Material is an important factor to consider since it represents 70% of the total cost of the production of LIBs (Aydin et al., 2023). Breaking down the cost for the cell production, which can be seen in Figure 2.2, it is evident that the cathode stands for the major cost. The average cost for a cell is estimated to be around \$101/kWh in 2021 (Qi et al., 2023). Further, the cathode is also the most important component, since it determines the performance and range of the battery. Moreover, the material cost for the cathode material sums up to 51% of the total cost, making it an important factor to consider. Materials such as lithium, nickel, and cobalt are refined to achieve the desired purity levels, with the majority of this occurring in Asia. As a result, countries outside the region must rely on imports to produce batteries. Even though the production is seen to be geographically dispersed, the processes are generally organizationally integrated. Therefore, to make it work, suppliers need to be coordinated (Bridge and Faigen, 2022).

One of the reasons why raw materials have this much power over the final cell's price is the unstable international environment, resulting in fluctuating prices (Qi et al., 2023). In addition, the cost-benefit for countries to import cheaper material from reserve-dominated regions results in fewer extraction initiatives in the European Union (EU), for example (Bridge and Faigen, 2022). At the same time, previous studies have shown that upstream integration is an important factor in raw material extraction and material synthesis in order to secure the supply (Ferstl et al., 2020). This can be challenging for European manufacturers due to the low amount of contractors nearby and governments putting regulations on minerals to have ownership of the manufacturing of both cells and battery materials when it comes to buying from other countries.

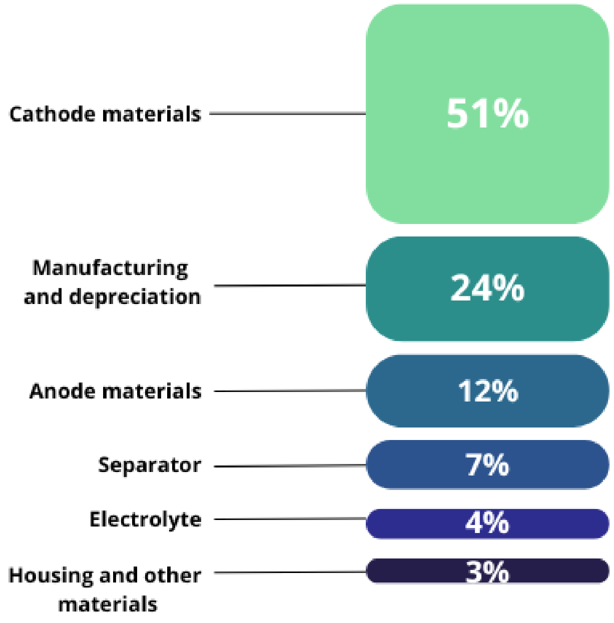


Figure 2.2: Cost Distribution of The Cell, Inspiration From Qi et al. (2023)

As shown in Figure 2.3, Asia currently dominates the global production of LIB components, manufacturing 96% of cathodes and 95% of anodes (McKinsey, 2024). However, recent policy shifts in Europe and North America, such as subsidies under the U.S. Inflation Reduction Act (IRA) and the European Union's Green Deal Industrial Plan (GDIP), reflect a growing effort to localize battery production. One of the primary motivations behind this shift is energy consumption; cathode production alone accounts for almost half of the total energy used in LIB manufacturing as mentioned before (Degen et al., 2023). As Europe aims to meet its 2030 target of reducing greenhouse gas emissions by 55%, decreasing the carbon footprint of cathode production is a critical step toward sustainability. This goal is further complicated by China's reliance on coal-powered energy for LIB production, which undermines global decarbonization efforts (Yang et al., 2022). Consequently, European and North American governments are prioritizing domestic battery manufacturing not only to reduce emissions but also to have greater control over the production process and safeguard Intellectual Property (IP)(McKinsey, 2024).

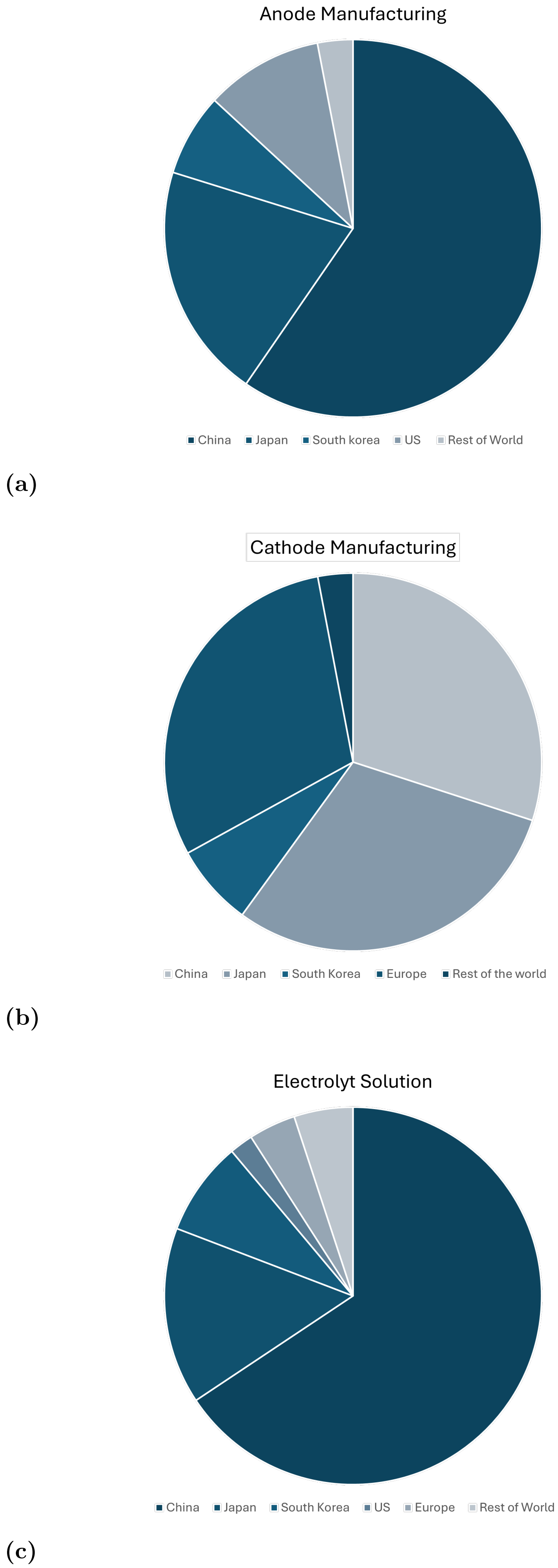


Figure 2.3: Data Gathered From Bridge and Faigen (2022)

Even though the manufacturing cost of LIBs stands at 25%, the battery manufacturing development has been lagging behind. This is mainly because of the many steps required to produce the batteries. Looking at the manufacturing cost of slurry preparation, coating and drying, calendering, and slitting, it sums up to be around 35.21%. The production stage that is the most costly is the formation and aging, landing at 32.61%. Furthermore, throughput is one aspect that influences production costs, and improved efficiency can reduce them because it affects labor costs and venue rent. Since slurry mixing takes a while to generate, one way to increase throughput is to change the mixing method. Coating and drying have the highest energy consumption out of all the production stages, with an energy consumption of 46.8%. To lower energy consumption and time consumption, which have an economic impact, one way is to avoid organic solvents. Moreover, studies show that increasing the solid content from 55% to 75% can increase the drying speed by 80% (Liu et al., 2023).

Therefore, the production of automotive lithium-ion batteries (ALIBs) is highly energy-sensitive and mainly correlated to the power consumption of the different processes (Qi et al., 2023). This factor affects the cost and environment in the end. As it was mentioned above, the most energy-consuming process of all the stations is the drying/solvent recovery, and improving production efficiency at this step is important (Liu et al., 2023). The high cost of materials and processes, together with the energy-intensive production, is one of the barriers to wider adoption when it comes to producing batteries (Lechner and Mothwurf, 2023). In addition, the energy consumption of the drying room stands for 30% to 50% of the total energy for producing batteries, which has an impact on the operational cost. Therefore, depending on where the production is allocated, the energy prices can have a significant impact on the final price for the battery.

Tariffs and trade regulations, especially in Europe, will also have increasing effects on the future of battery manufacturing. An example is the regionalizing of battery production in the EU. Before, up to 70% of the value of the car could be outsourced outside the EU while in 2024, they decreased the value to 50%, and since the battery itself stands for around 40% of the car, automakers have been pressured to source within the EU borders more than before (UK Parliament, 2023).

Moreover, the additional cost of transportation due to safety considerations, such as flammability, pushes gigafactories to place themselves near the automakers. However, depending on the placement of the factory, challenges in raw material supply may also occur (Fleischmann et al., 2023).

Furthermore, new regulations regarding the recycling of materials and scrap to close the material loop are encouraged (Bridge and Faigen, 2022). The result of embracing recycling is that countries can lower their dependencies on other countries providing the material, where Asia is the greatest (Fleischmann et al., 2023). In addition, by recycling raw materials that are primarily found in one location (such as cobalt), countries can reduce their dependency on other contractors. Further, the scrap rate is closely linked to cost due to the high material prices, and increasing the quality is one way to minimize it (Aydin et al., 2023).

Transporting LIBs, as mentioned before, is a critical economic factor in their production, influencing both cost and logistical complexity. Due to their classification as hazardous materials, LIBs require specialized packaging, compliance with international regulations such as those set by the International Air Transport Association (IATA) and the United Nations (UN), and careful handling to prevent thermal runaway risks (Reddy, 2010). These requirements increase transportation costs, especially for long-distance shipments, making logistics a key consideration in the overall supply chain (Gaines, 2018). Additionally, as demand for LIBs grows with the rise of electric vehicles and renewable energy storage, optimizing transportation methods, such as combined kinds of shipments or using more sustainable transport options, becomes essential for reducing expenses and minimizing the carbon footprint of production (Harper et al., 2019). Efficient transportation strategies not only lower costs but also enhance supply chain resilience, ensuring a steady flow of materials and finished products to global markets.

The cost of labor also has a big impact on overall production costs and competitiveness in the LIB manufacturing process. The complexity of LIB manufacturing, which involves electrode preparation, cell assembly, electrolyte filling, and formation cycling, requires skilled labor, raising the batteries' price. Globally, labor costs differ; while production in North America and Europe is more costly because of greater labor costs and stricter regulations, countries such as China enjoy lower salaries (Dai et al., 2019). Although automation and process optimization are increasingly used to reduce labor costs, human supervision is still essential for process efficiency and quality control (Zeng et al., 2019). Labor cost dynamics are also being impacted by the need for local LIB production in areas seeking energy security and lower supply chain risks (Guerra et al., 2019).

In addition to labor costs, maintenance costs are important in the total production expenses of LIB electrode manufacturing, too. This is because the production process relies on several complex machines, particularly in the coating, drying, and calendering stages, that need regular maintenance to operate effectively (Nikpour et al., 2021). Without proper care, these machines are prone to breakdowns, delays, and reduced product quality. For example, drying ovens and calendering rollers have to stay in top condition to ensure uniform electrode layers. A study by Wood et al. (2014) points out that the formation and aging stages alone can account for over 30% of the total production cost, much of which is tied to energy use and equipment upkeep.

Overhead costs in LIB production are the expenses that keep the factory running but are not directly related to making the batteries themselves. These costs include costs like the rent for the building, electricity bills, salaries for administrative staff, and the depreciation of the machinery and facilities. Though these costs might not stand out at first, they can add up fast and play a big role in driving up the total cost of manufacturing. Additionally, factors like factory floor space and the wear-and-tear on expensive equipment play a big role in overall expenses. Even though they do not directly touch the electrodes, these overhead elements quietly shape the economics of the entire production line. Keeping these costs in check, through efficient layout, smart energy use, or shared facilities, can make LIB manufacturing more competitive in the long run (Nelson et al., 2011).

In LIB manufacturing, machine depreciation makes up a significant portion of production costs and plays a critical role in overall economic assessments (Wood et al., 2014). The manufacturing process relies heavily on specialized, capital-intensive equipment, such as coating machines, calendering systems, and automated assembly lines, that undergo wear and technological obsolescence over time (Gailani et al., 2020). Depreciation is the gradual loss of value of these machines over their useful life, which directly impacts the cost model of LIB production facilities. As mentioned by Wood et al. (2014), equipment-related expenses, including depreciation, can account for over 20% of total cell manufacturing costs, depending on production scale and technology selection.

In order to sum up the key cost factors that have the greatest impact on LIB production discussed previously in the text, a chart of the production cost distribution can be seen in figure 2.4 at different regions. The location is an important parameter that affects the total cost. In the chart, it is also possible to see which factors vary the most depending on the location. From the figure, it is possible to verify that material stands for the greatest cost, followed by labor and machinery/installation.

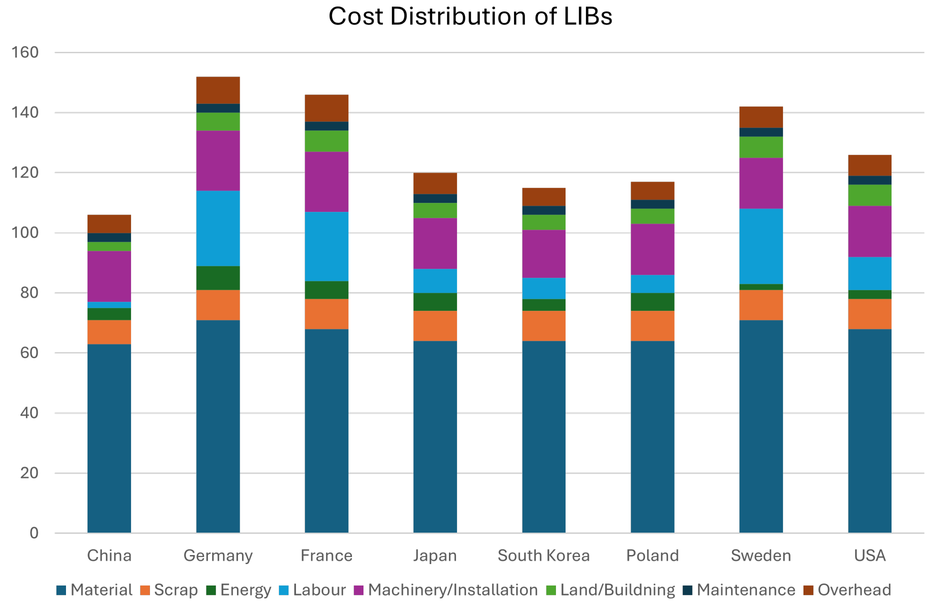


Figure 2.4: Chart for Outsourcing Inspired by Orangi and Strømman (2022)

2.2.4.2 Technical Factors

Being able to ensure reliable quality at scale will be one of the most challenging things to overcome when ramping up the production capacity during the upcoming years. Battery quality is related to factors such as lifetime, failure, reliability, and the battery's overall performance. In addition, the quality of a battery is closely related to the defect rate (Attia et al., 2025).

Electrode manufacturing for LIBs begins with the slurry mixing process, a critical stage where any impurities can lead to contamination and subsequent defects in the final product. One of the most common contaminants in cathode mixing is copper, which can significantly impact battery performance and safety (W. Chen et al., 2024). Furthermore, variations in mixing speed, mixing duration, or chemical composition can result in an uneven slurry, particle agglomeration, and unstable physical and chemical properties, all of which can compromise the quality of the electrode (Hawley and Li, 2019).

After slurry preparation, the coating process is another crucial step that determines electrode quality. Mohanty et al. (2016) classifies coating defects into four primary categories: agglomerates or blisters, pinholes, line defects, and metal particle contamination, the last one being the most severe. Agglomeration of materials often results from inadequate mixing, leading to large, non-uniform regions within the electrode. This inconsistency reduces electrical conduction and ion transport, ultimately causing localized impedance increases and capacity loss. Additionally, pinholes may form due to air bubbles trapped within the slurry during the coating process. These pinholes expose the current collector to the electrolyte, posing significant safety risks and making them highly undesirable in LIB manufacturing. Additionally, line defects occur when blockages in the slot-die coater disrupt the uniform application of the slurry, leaving exposed regions on the electrode surface. The size of these exposed areas depends on the extent of the blockage, potentially compromising battery performance and longevity (David et al., 2018).

Once the coating is complete, the electrodes undergo calendaring and slitting. During the calendaring process, defects can be broadly classified into geometrical, structural, and mechanical categories (Günther et al., 2019). Geometrical defects involve changes in the electrode's shape, often appearing as periodic fluctuations in both coated and uncoated areas (Günther et al., 2019). One example of this kind of defect is electrode corrugation, which appears as waves running along the calendaring direction due to excessive line pressures and density inconsistencies (Schmitt et al., 2012). Another common defect is foil embossing, where lateral pressure causes distortions in the uncoated foil, leading to porosity variations (Schmitt et al., 2015). Additionally, the saber effect results in the elongation and curvature of the electrode, particularly in non-symmetrical coating designs, while wrinkles at the coating edges emerge due to strain during calendaring, causing irregularities at the interface of coated and uncoated regions (Günther et al., 2019).

Structural defects, on the other hand, impact the electrode's thickness, density, and overall integrity, influencing electrical and electrochemical performance. Local thickness and density fluctuations arise from variations in mass loading and improper alignment of the calendar rollers, leading to inhomogeneous compaction. Another significant defect is coating detachment, where the coating separates from the substrate foil due to inadequate adhesion. This issue can occur both at the coating edges and within the coated area, potentially disrupting the following processing steps. Inconsistencies like these in structural properties can hinder electrode performance and affect the efficiency of downstream manufacturing stages (Günther et al., 2019).

Günther et al. (2019) claim that mechanical defects primarily result from excessive pressure and material brittleness, leading to physical damage in the electrode. Crack formation within the electrode layer can occur due to cold pressing, sometimes making the fractures nearly invisible. Foil tears, another mechanical issue, root in excessive line pressures, often intensified by localized thickness deviations caused by agglomerates. Additionally, electrode embitterment occurs when high compaction pressures make the coating brittle, leading to stiffness and poor flexibility during handling. These mechanical failures not only compromise electrode durability but also contribute to inefficiencies in the manufacturing process.

After the calendaring process, the next crucial step in battery manufacturing involves using laser cutting machines to precisely slit the calendered, coated foils to the required dimensions for battery packs. However, this stage introduces mechanical stress that can lead to defects such as warping or burr edges (Jansen et al., 2019). These imperfections may generate unwanted particles or cutting debris, which pose a risk of puncturing the separator and compromising battery safety (Yang et al., 2022).

The battery manufacturing process involves several critical steps that, if not executed properly, can lead to defects affecting performance and safety. During the stacking stage that comes after slitting, improper assembly of electrode sheets and separators may result in misalignment or wrinkles, compromising battery integrity (Keppeler et al., 2021). The electric contacting process, which involves welding electrode tabs to the connection piece, is prone to defects due to misalignment, design flaws, or incorrect welding parameters, potentially leading to tab tearing (Zwicker et al., 2020). Zhao et al. (2023) found that while positive tab tearing only reduces battery capacity, negative tab tearing is far more severe, causing excessive lithium release and significant capacity degradation. This failure is primarily driven by lithium loss and copper dissolution at the negative tab's edge, with high-rate charging exacerbating lithium release.

Right after the cell assembly, the electrolyte filling process ensures complete electrode saturation by carefully controlling injection volume, pressure, and soaking duration (W. Chen et al., 2024). Jeon (2019) revealed that trapped air between electrolyte and electrode particles can cause incomplete soaking. Furthermore, pore size distribution and porosity significantly affect the soaking process (Shodiev et al., 2021). After filling, the pre-charging and formation process enables the first charge-discharge cycle to develop a SEI film. Precise control of current, temperature, and voltage is crucial, as improper conditions can weaken SEI structure and performance (An et al., 2016). On the other hand, excess water content is also a major concern, reacting with the electrolyte to form hydrofluoric acid, which degrades the SEI film and compromises battery safety (Kitz et al., 2020).

When considering outsourcing electrode production, it is vital to evaluate the potential transport routes that may have an influence. Looking at the data in Figure 2.3 most of the components for the electrode production are based in Asia, resulting in long transport. For example, possible corrosion of electronic components during transport can affect the overall performance. Factors such as humidity, salt particles during sea transport, and different temperatures all have their impact. During transport, ensuring the use of proper lifting equipment, avoiding bumping, and avoiding contact with moisture is important. When electrodes later arrive at their location, standardized quality inspections are needed, such as looking for surface cracks, porosity, and erosion. To prevent further contamination, it is recommended to avoid placing them on the ground and instead, place them on stable racks. (Günther et al., 2019).

In LIB production, like many startups, there is a phenomenon called the Valley of Death, which refers to the difficult stage between the lab-scale stage and full commercial manufacturing, as it is shown in Figure 2.5. This is often where promising technologies hit major roadblocks; scaling up from research to real-world application is not just expensive, it is also technically complex (Islam, 2017). These technical challenges to overcome include the up-scaling problems that are related to gigafactories, where the companies are expected to excel in high throughput, high tolerances, and purity specifications, meeting tolerances on a few microns. Recent examples of a gigafactory's downfall are Northvolt and Britishvolt, where meeting quality standards and ramping up production at the same time were not possible. Common issues that contributed to the downfall were expanding too fast and having too high operational costs without sufficient financing ("The rise and fall of gigafactories | Voastra", 2024).

Attia et al. (2025) point out that even small inconsistencies in the manufacturing process can seriously impact battery quality, showing how sensitive production can be. On top of that, the U.S. Department of Energy notes that many startups struggle to attract the funding they need to move from Research and Development (R&D) to actual market deployment. As a result, many projects stall or fail altogether. Overcoming these obstacles requires stronger collaboration among researchers, industry leaders, and policymakers to help turn innovations into viable commercial products in the LIB field (US Department of Energy, 2023).

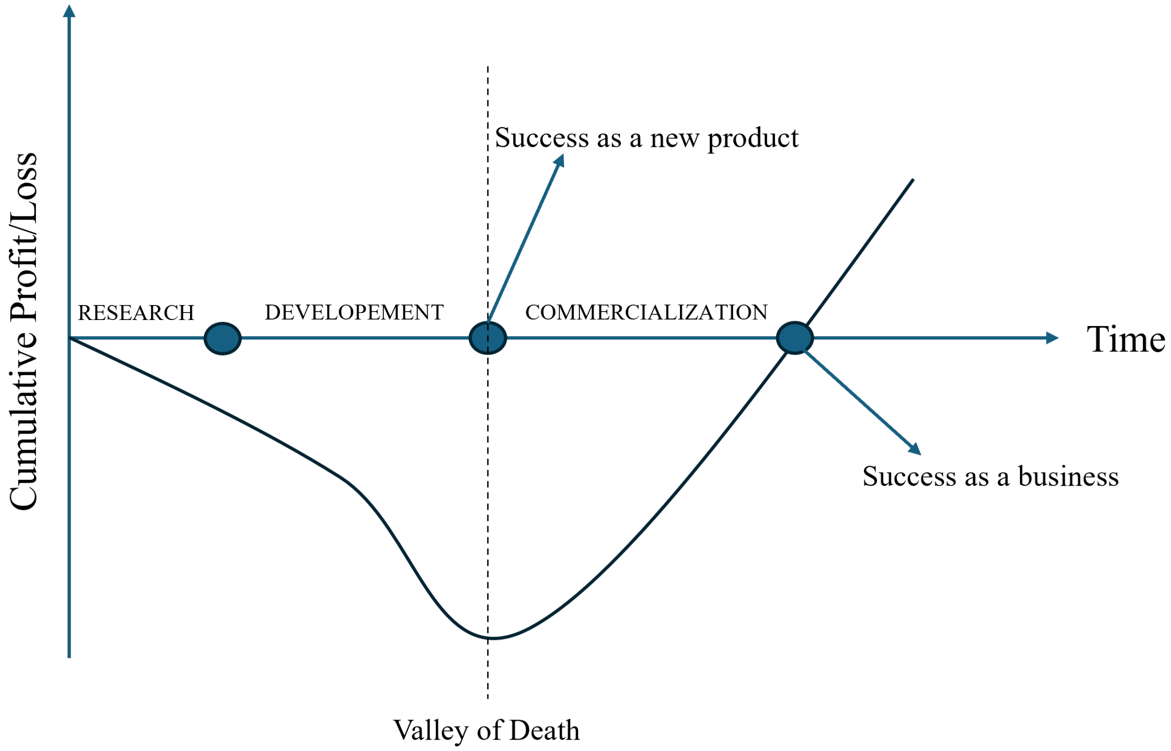


Figure 2.5: Valley of Death, Inspired by Lenzer (2019)

In the table 2.1, a summary of the main technical factors identified in the literature is presented. Moreover, the technical factors identified are categorized by the definition presented at the beginning of the chapter.

Table 2.1: Summary of Technical Factors Affecting LIB Production

Summary of Technical Factors
Quality
Scaling up
Packaging During Transport
Defect rate

In the next section that will be presented the technical and economic factors will be further examined based on the topic of outsourcing and how outsourcing can affect it based on known theory and frameworks.

2.3 Outsourcing

The definition of outsourcing originally comes from the American term "outside resourcing" (Troacă and Bodislav, 2012). Outsourcing has been a practical strategic tool for a long time, but it was not officially defined until 1997 (Deavers, 1997). Broadly, outsourcing refers to obtaining activities that an organization is capable of performing internally from external sources (Harland et al., 2005). Recently, Ishizaka et al. (2019) conducted a thorough review of literature from 1994 to 2019, defining outsourcing as a business agreement, domestic or international, aimed at gaining a competitive advantage. This is achieved by contracting out non-value-added or value-added functions, including core competencies, to capable suppliers for efficient and effective production of goods or services. In addition, outsourcing also includes the transfer of responsibility and knowledge to another contractor (Rolstadås et al., 2012).

Ishizaka et al. (2019) highlighted several key elements of outsourcing. First, it is fundamentally a business agreement where the organization and supplier agree, either verbally or in writing, to collaborate. Second, outsourcing is a strategic decision that allows companies to delegate not just secondary tasks but even core competencies to third parties, potentially improving market standing. Third, it is not limited to products or services; entire business processes can be outsourced to enhance quality and efficiency (Ishizaka et al., 2019).

Outsourcing is an important part of the production and operation management subject since it is closely linked to connecting the operations to the external environment and the overall strategy. Further, it includes improving the in-house operations while managing activities performed by suppliers. Outsourcing decisions impact the organization in several ways. The first one is that they must make a decision that fits the company's overall strategy and considers market conditions. Second, they affect the company's size, structure, and location. Lastly, depending on the extent of the task given to suppliers, management needs to ensure quality and efficiency (Tsay et al., 2018).

The enablers of outsourcing in today's society depend on several factors. One of these factors is the advancement of information and communication technologies (ICT) (Drahokoupil, 2015). The ability to coordinate and control operations from different geographical areas has created new opportunities for companies. Additionally, businesses should think about the outsourcing benefits when it comes to globalization and competitiveness (Troacă and Bodislav, 2012). The result of global advantages is that companies can obtain higher specialization and access international expertise that may be missing locally.

2.4 Types of Outsourcing

There are three strategic choices when it comes to outsourcing, which are transactional, resource-seeking, and transformational, where the choice depends on the purpose and motive of the company and the process or activity that is decided to be outsourced (Hätönen, 2008). The definitions and related motives can be seen in Table 2.2.

Table 2.2: Types of Outsourcing, Inspiration Taken From Hätönen (2008)

Type of Outsourcing	Definition	Motives
Transactional Outsourcing	Outsourcing made to directly cut cost	- Reduce cost - Cost control - Lower operational cost
Resource Seeking Outsourcing	Outsourcing capabilities/resources that currently is insufficient/inadequate	- Achieve best practice - Improve service quality - Access to skill/technology - Access to flexible workforce
Transformational Outsourcing	Outsourcing aimed at transforming the organization. For example more dynamic, more efficient etc	- Focus on core competencies - Flexibility - Accelerate project - Access to internal resources

2.5 Risks and Motives of Outsourcing

The risks and motives for outsourcing depend on the company's situation. The external environment, which a company has less control over, can influence triggers that lead to motives (Dabhilkar et al., 2009). As an example, increased market competition can force companies to lower their prices, which in turn can become a motive to outsource. In Table 2.3, a summary of the main motives that drive outsourcing is presented together with common risks connected to it. A hypothesis made by Dabhilkar et al. (2009) is that performance improvements correspond to the specific outsourcing motive.

Looking at production outsourcing, the study conducted by Quélin and Duhamel (2003) mentioned that cost savings were considered the main reason, together with access to external competencies. Production outsourcing can have several benefits, one of which is its flexibility with fast purchases and the development of new technologies. Further, the risks that come with outsourcing can be divided into operational risks, strategic risks, and composite risks (Mahmoodzadeh et al., 2009). Operational risks are due to, for example, a decrease in quality, cost, or process execution, while strategic risks are due to intellectual assets and privacy. The composite risk is mainly caused by a lack of knowledge of the business process, and these types of risk come in a long-term collaboration.

Outsourcing can further improve the focus put on internal core competencies and financial flexibility, and give access to knowledge not obtained in-house. Moreover, if the company is looking to scale up but lacks the capability to do so with its own resources, outsourcing can provide new abilities (Mahmoodzadeh et al., 2009).

Table 2.3: Motives and Risk of Outsourcing, Inspiration From Quélin and Duhamel (2003)

Motives of Outsourcing	Risks of Outsourcing
- Reducing operational cost - Focusing on core activities - Reduce capital investment - Improving quality - Access to external competences -Increase responsiveness	- Dependency on external supplier - Hidden cost - Loss of know-how - Service providers lack of necessary capabilities

Investing in better manufacturing helps achieve better performance, but investing in outsourcing affects it both positively and negatively. If a company decides to outsource without investing in its own manufacturing, the performance will decrease. However, if the outsourcing decision is made together with improving the current manufacturing, the performance can increase instead. Therefore, outsourcing is more beneficial when the resources freed up in the process are reinvested to improve the rest of the manufacturing facility (Dabhilkar et al., 2009).

When considering a make-or-buy decision, it is necessary to reflect on the degree of standardization, complexity, and importance of the part/product being analyzed. Outsourcing high-volume standardized parts with less asset specificity can result in cheaper costs and is simple to implement. High complexity, on the other hand, is often a result of technological uncertainty. In addition, a higher complexion can result in a larger information gap when collaborating, which can lower the cost benefits. When having high complexity, it can be wiser to produce in-house since companies may want to capture valuable skills (Dabhilkar et al., 2009).

2.6 Outsourcing Decision

While outsourcing offers numerous advantages, it is crucial to carefully evaluate key factors before deciding to outsource and determining the appropriate level of engagement. Inspired by the research by Kremic et al. (2006), which led to the framework below 2.6, outsourcing in manufacturing is primarily driven by three motivations: cost, strategy, and politics. While cost- and strategy-driven outsourcing are more common in private organizations, politically driven outsourcing is predominantly observed in public organizations (Kremic et al., 2006).

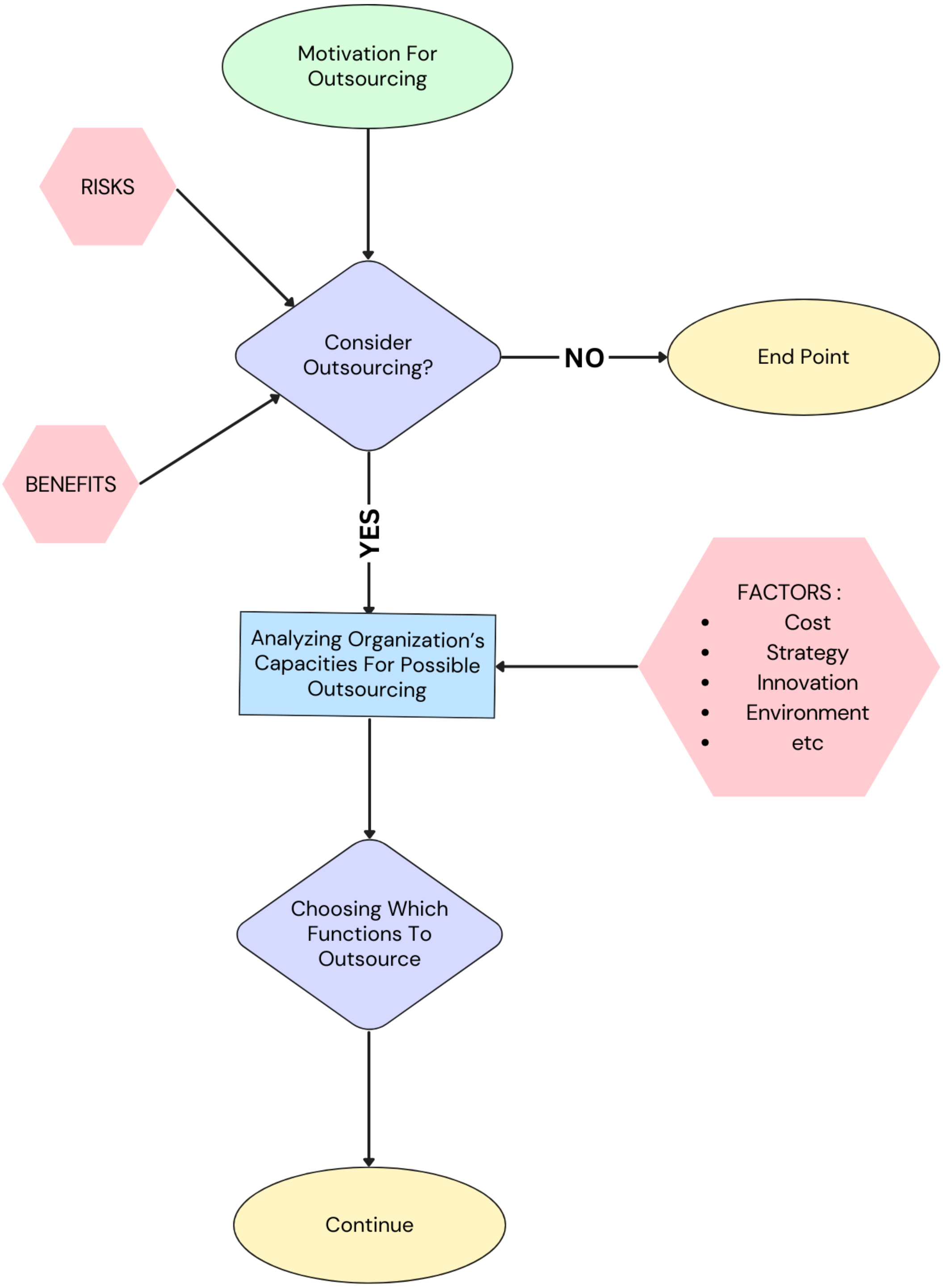


Figure 2.6: Framework for Outsourcing, Inspired by Kremic et al. (2006)

Outsourcing is often driven by cost reduction, leveraging supplier efficiencies, economies of scale, and specialization (Shrestha, 2020). However, cost savings are not always realized, with some cases resulting in higher expenses due to hidden costs like contract management and transition expenses (Bryce and Useem, 1998). Social costs, including low morale and declining skill levels, further complicate outsourcing decisions (Lahiri, 2015).

Beyond cost, outsourcing serves strategic goals, helping organizations focus on core competencies and enhance flexibility (Shrestha, 2020). It allows firms to reallocate resources, adopt new technologies, and respond quickly to market changes. However, risks include the loss of critical knowledge, reduced internal synergies, and long-term dependency on external providers (Lahiri, 2015).

One theory to consider when making an outsourcing decision is the Transactional Cost Economy (TCE). TCE can be used to explain the relationship that is between outsourcing and cost (Meixell et al., 2014). In addition, the properties of a certain transaction can be used to determine if an activity should be outsourced or kept in-house. The aspect that is considered during TCE is the comparison of the cost trade between the internal cost of producing a product and the cost of sourcing the same one. For instance, the theory states that if the cost of a sourced product becomes too high, it is better to rely on in-house production. The TCE is based on two key behavioral assumptions, where the first is bounded rationality and the other is opportunism (Aubert et al., 2003). Further, bounded rationality refers to the individual incapacity to make a rational decision while opportunism is that both parties in outsourcing have a self-interest-seeking tendency. The combination of bounded rationality and opportunism when two parties have different information will lead to a withholding of information from each other. For instance, one part may hide the negative characteristics of their product while the other part will test the product before buying to protect themselves from false allegations from the sourcing company. All of which together will generate higher transactional costs in the end.

The original idea behind coordinating the transaction between the buyer and the seller is to understand the mechanisms in the transactional cost before and after the transaction, named ex-ante and ex-post costs. Example of activities that generates costs around these events are searching and selecting the partner, negotiations on, for example, the level of engagement and prices, and writing contracts, which are all things that add up to the total cost. Further, while contracts can outline what is and is not allowed during the agreement, there is always a chance that someone involved will break the contract. This can further result in the company needing to take legal action to solve the problem, which can be both costly and time-consuming. This possible legal process, which happens after the issue occurs, involves ex-post transaction costs (Tsay et al., 2018).

There are three dimensions of the transaction cost that are in focus. These are asset specificity, uncertainty, and frequency.

Asset specificity is the most important factor to consider. This dimension refers to the uniqueness of a certain resource that the business demands (Neal et al., 2016). For instance, if the company acquires a product that several other companies use, it is unnecessarily costly to make it in-house and better to source from an outside vendor. In contrast, if the product is highly specific for the organization, it is better suited for in-house production. Asset specificity can take numerous forms, some of which are characterized as: (1) Human assets refer to transactional-specific knowledge, skills, and human capital that is obtained by learning by doing (Everaert et al., 2008); (2) Site-specificity is the strategic placement where close proximity is aimed (Williamson, 1996). By placing things close, it is easier to streamline operations; (3) Physical assets are referred to as relationship-specific equipment or machinery; (4) dedicated assets are the investments in general facilities that are tailored for a customer.

Uncertainty plays a crucial role in outsourcing decision-making, particularly because predicting the future with 100% accuracy is nearly impossible (Lu et al., 2021). In the context of business, this uncertainty arises from various factors, including market fluctuations, regulatory changes, emerging competitors, technological advancements, and the unpredictable behavior of outsourcing partners. Quélin (1998) categorizes these uncertainties into two main types: internal and external. Internal uncertainty stems from the challenges of integrating outsourced teams into an existing organization. Employees affected by outsourcing may feel undervalued, leading to decreased motivation, productivity, and commitment. Meanwhile, external uncertainty arises from the lack of control over the outsourcing provider's performance, which can impact both productivity and quality. Understanding and managing these uncertainties is essential for businesses to navigate the complexities of outsourcing effectively.

Frequency is the transactional frequency, which is the frequency at which a transaction occurs (Everaert et al., 2008). Frequent transactions can give benefits regarding economies of scale, which can recover setup costs. In other words, how often is the key resource is needed by the organization (Neal et al., 2016). If the transaction occurs frequently, the aim should be to set up a system that can save time and money when looking for a partner, while if it happens rarely, the cost should only be kept low (Ivanaj and Franzil, 2006).

2.6.1 Levels of Outsourcing

Outsourcing can also be done in total and partial ways depending on the which extent that will be outsourced (Troacă and Bodislav, 2012). Partial outsourcing is done when production is an onsite event, while full outsourcing occurs when the company has no onsite activity but is fully outsourcing the production (Drahokoupil, 2015). In one study made by Drahokoupil (2015), he concluded that out of all the Swedish companies that made an outsourcing decision, around 20% of them decided to fully outsource their production, while the rest of the companies did partial outsourcing.

Sanders et al. (2007) propose a framework for outsourcing decision-making that categorizes outsourcing engagements into four distinct levels: out-tasking, co-managed services, managed services, and full outsourcing, as shown in Figure 2.7.

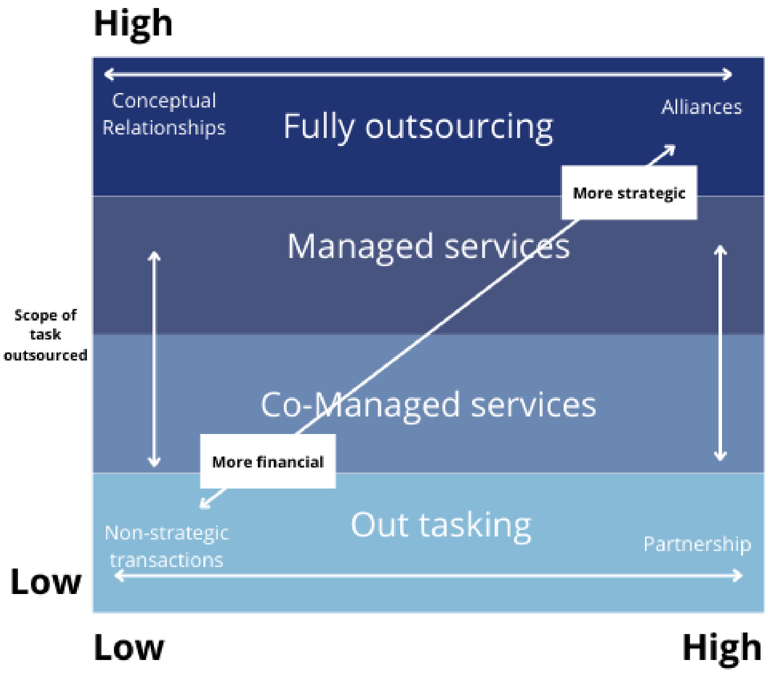


Figure 2.7: Framework Inspired By Sanders et al. (2007)

At the most basic level seen in Figure 2.7, out-tasking involves delegating a specific task to an external provider while retaining overall control within the organization. Co-managed services extend this by assigning a more substantial responsibility to an external supplier, though the client remains actively involved in overseeing the process. Managed services, on the other hand, represent a more comprehensive arrangement, where the supplier assumes full responsibility for designing, implementing, and managing a particular function, relieving the client of direct involvement. Finally, full outsourcing entails the supplier taking complete control over the design, implementation, management, and strategic direction of an entire function, operation, or process (Sanders et al., 2007).

According to Sanders et al. (2007), out-tasking and co-managed services fall under tactical outsourcing, while managed services and full outsourcing are considered strategic engagements. In addition, the selection of an appropriate outsourcing level depends on various factors, including financial, technical, and environmental considerations, among others (Sanders et al., 2007).

At the tactical level, outsourcing involves delegating specific tasks or functions that are not strategic to the client organization, minimizing associated risks (Gunasekaran et al., 2014). Out-tasking and co-managed services fall into this category, often driven by financial considerations such as cost reduction, capital constraints, or access to specialized non-core capabilities (Sanders et al., 2007). Additionally, tactical outsourcing can support geographic expansion, lower operational costs, and improve time-to-market. While its primary focus shifts over time from financial objectives to resource optimization, it remains centered on efficiency and cost-effectiveness.

In contrast, strategic outsourcing, including managed services and full outsourcing, prioritizes long-term competitive advantage over immediate financial gains (Gunasekaran et al., 2014). These engagements often require significant initial investments with profitability expected at a later stage. Unlike operational-level decisions, which focus on resource management and process execution, strategic outsourcing aligns with broader business goals (Johnson and Whittington, 2019).

2.7 Outsourcing Decision Process

Making the outsourcing decision consists of addressing the motives and performance goals of the process (Hätönen, 2008). To make the outsourcing decision, the questions of what, why, where and how need to be considered.

- What is going to be outsourced?
- Why are we outsourcing it, and the underlying motives?
- Where should we outsource?
- How should you do it?

For the first question, "What?", the focus lies on deciding the scope, scale, and complexity of the outsourcing activity. For example, the more critical it is, the more important it can be to build a strong relationship with the vendor. Questions such as "Is it strategic outsourcing or non-strategic outsourcing?" are to be considered to understand the importance. Further, the purpose is to clarify the knowledge-intensiveness and the nature of the activity in relation to other tasks, and whether the activity concerns the firm's success. For the second question, "Why?", the company wants to define the motives of the outsourcing activity. In this step, they also look at whether the outsourcing is transactional, resource-seeking, or transformational to understand why the activity is considered to be outsourced. The motives for why companies decide to outsource a process or activity will later affect the outsourcing process. The question of "Where?" to outsource is to understand the variables that affect the specific location. For example, is the activity placed offshore or nearshore, and if there are local advantages/disadvantages. Moreover, factors such as low labor costs, government policies, and infrastructure. For the last question, "How?" governance is considered a question regarding task division, and to what extent is the activity transferred to the vendor (Hätönen, 2008).

In Figure 2.8, a flow of the process when making an outsourcing decision can be seen, and also the different phases that are included from the beginning to the implementation.

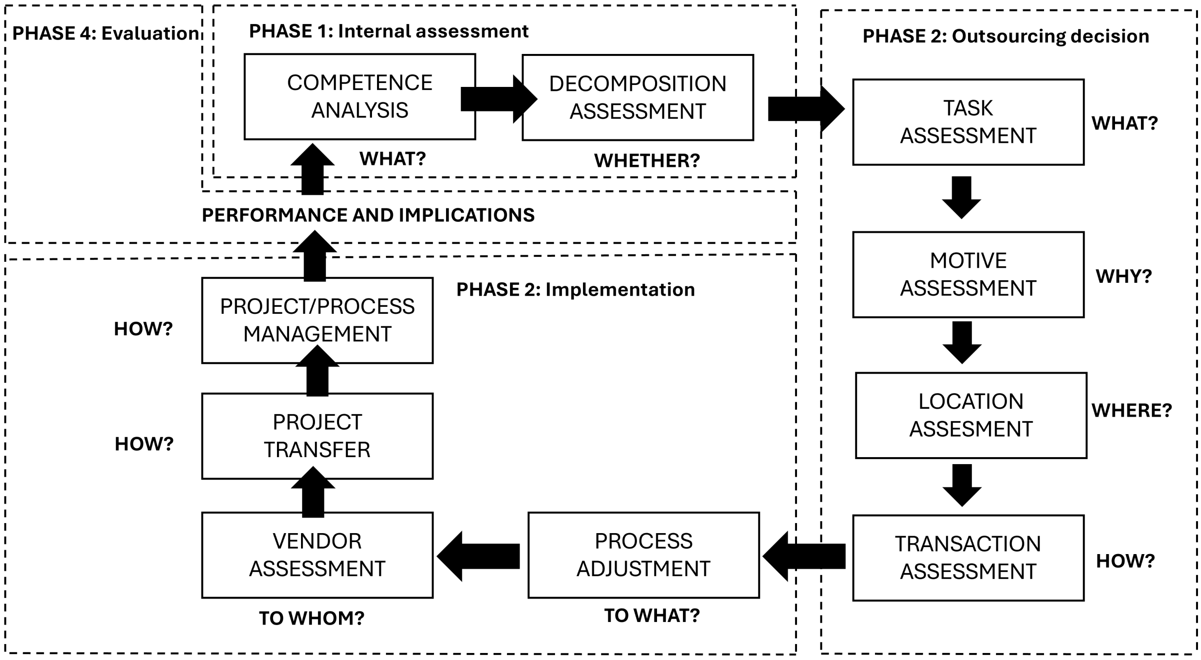


Figure 2.8: Outsourcing Process Inspired By Hätönen (2008)

2.8 Technical and Economic Motives for Outsourcing

Outsourcing can be evaluated from various angles, making it a difficult process. In this section, we will focus on the findings of the literature regarding the technical and economic aspects of outsourcing.

2.8.1 Technical Factors

Outsourcing provides companies with access to the specialized expertise of suppliers, offering significant operational benefits (Hoetker, 2004). However, when determining which aspects of manufacturing to outsource, firms often prioritize cost reduction over strategic considerations that could enhance their overall capabilities and market position (McIvor, 2009). According to McIvor (2009), the resource-based theory (RBT) provides a valuable framework for making informed outsourcing decisions, particularly in identifying which technical functions should be retained in-house and which can be delegated to external partners.

RBT conceptualizes organizations as unique combinations of assets and resources, which, when leveraged effectively, can create sustainable competitive advantages (Barney, 1991). Given this perspective, outsourcing decisions should be made strategically to ensure that firms maintain their competitive standing. To facilitate this decision-making process, McIvor (2009) introduced the construct of “contribution to competitive advantage” in the context of outsourcing. This framework categorizes business activities into two groups: those that are critical to competitive advantage and those that are not.

Activities considered “critical to competitive advantage” are those that either significantly reduce costs or create a substantial differentiation in the market relative to competitors. On the other hand, activities that do not meaningfully impact a firm’s competitive positioning fall into the “not critical to competitive advantage” category. RBT suggests that organizations should retain and internally manage activities that are “valuable, rare, and difficult to imitate”, as these elements are essential for sustaining a competitive edge. Firms can optimize their operational efficiency while maintaining strategic differentiation by focusing internal resources on high-value functions and outsourcing non-core activities. The competitive advantage gained through outsourcing can be attributed to factors such as cost reduction, superior quality, or enhanced service levels (McIvor, 2009).

Another critical technical challenge associated with outsourcing is maintaining quality control. Compared to in-house production, outsourcing increases the risk of quality issues due to the difficulties in overseeing manufacturing processes and ensuring consistent product standards (Gray et al., 2011). Several high-profile cases illustrate these risks, such as the discovery of lead in outsourced toys and melamine in pet food sourced from China (Roth, 2008), as well as the salmonella contamination in peanut butter produced by the Peanut Corporation of America, a contract manufacturer for King Nut (Gould et al., 2009). These instances highlight the difficulty of ensuring that outsourced products meet the company’s quality expectations. Additionally, identifying the root cause of quality failures can be complex, as outsourced production involves a shared responsibility between the contracting company and the manufacturer (Amaral et al., 2006). This shared ownership structure further complicates accountability and risk mitigation, making quality control a significant concern in outsourcing decisions.

Quality control in outsourcing can be even more challenging when companies prioritize rapid time-to-market over product perfection. Kaya and Özer (2009) explain this issue with the example of a hard drive manufacturer that outsourced production for a new model. The company mentioned its specific requirements in a contract with the contract manufacturer (CM). However, due to an assembly flaw, the hard drives made a minor sound during operation, despite functioning correctly. Because this issue was unforeseen and not specified in the contract, the original equipment manufacturer (OEM) had no legal grounds to hold the CM accountable. The OEM accepted the flawed products rather than delaying market entry to address the defect. While this decision enabled a faster product launch, it ultimately led to customer dissatisfaction, particularly among those sensitive to noise, resulting in a loss of market share. This outcome could have been avoided with greater attention to manufacturing processes and quality control from the CM’s side.

One of the most pressing challenges in manufacturing outsourcing is the risk of IP theft. Companies face the possibility of IP leakage not only internally but also through their suppliers, who may misuse proprietary knowledge during the outsourcing process (Kim et al., 2009). While internal measures to prevent IP breaches are well-established, a growing concern is the theft of IP in countries with weak enforcement of IP rights. The fundamental issue lies in the lack of control over how suppliers safeguard proprietary information (Sterlicchi, 2008).

Although patents provide legal recourse against IP theft, their effectiveness is limited, particularly for products with short life cycles, such as smartphones (Kim et al., 2009). In such cases, legal proceedings may extend beyond the product's market relevance, rendering patents an insufficient protective measure (Adams et al., 2006).

A particularly concerning form of IP theft in outsourcing is known as "poaching," where suppliers appropriate the contracting company's technology and expertise for their own gain (Aron et al., 2005). To mitigate this risk, companies employ two primary strategies when outsourcing in regions with weaker IP protections: vertical integration (Williamson, 1991) and legal safeguards (Teece, 1986). Despite these measures, poaching remains one of the hidden costs of outsourcing that firms may inevitably face (Skowronski and Benton, 2017).

The temptation for suppliers to engage in poaching arises from two key factors. First, suppliers often operate within the same industry and possess similar technical expertise as the company, making them potential competitors. Second, in the process of training suppliers to manufacture specific products, companies inadvertently equip them with the knowledge necessary to replicate their technology. This dual dynamic underscores the inherent risks of outsourcing and the critical need for companies to implement robust IP protection strategies when engaging with international suppliers (Aron et al., 2005).

Dependability is also a crucial technical aspect of outsourcing, as it directly impacts production continuity, quality, and overall business performance. When companies entrust external providers with parts of their production process, they must ensure that these partners are reliable in terms of meeting deadlines, maintaining consistent quality, and adhering to agreed-upon standards (Willcocks et al., 2017). Dependability also includes the ability of the outsourcing partner to handle unexpected disruptions, such as supply chain delays or technical failures, without compromising the final product (Dibbern et al., 2004). Without a dependable outsourcing partner, companies risk delays, increased costs, and damage to their reputation, making it essential to thoroughly evaluate a provider's track record before entering an agreement (Willcocks et al., 2017).

2.8.2 Economic Factors

Outsourcing has the potential to significantly impact manufacturing costs, but it does not always result in straightforward cost reductions (Mauler et al., 2021). Instead, it tends to shift expenses among categories, such as labor, materials, and overhead. Empirical evidence shows that outsourcing often decreases labor costs by eliminating in-house production activities but increases material costs due to the purchase of preprocessed components or sub-assemblies from suppliers (Meixell et al., 2014). These shifts in cost distribution highlight the importance of carefully analyzing the financial implications of outsourcing, as it may not consistently reduce the overall cost of goods sold (COGS).

One of the complications that can occur is overhead expenses. While outsourcing reduces direct labor costs, it also introduces new overhead expenses related to procurement and contract management. Companies must account for supplier negotiations, logistics, and administrative oversight, which can offset expected savings. Although some overhead costs, such as floor supervision, may decrease, others arise from managing supplier relationships and ensuring quality and delivery standards compliance. As a result, the net effect on overhead costs remains uncertain and varies across industries (Meixell et al., 2014).

Hidden costs further complicate the financial outcomes of outsourcing. Firms often underestimate expenses related to international logistics, currency fluctuations, and regulatory compliance, which can erode anticipated savings (Rasheed and Gilley, 2005). Additionally, cultural and communication barriers can increase coordination efforts, leading to inefficiencies and unexpected costs (Liao et al., 2011). These factors suggest that the financial benefits of outsourcing are not always as straightforward as they may seem.

Due to these challenges, some firms are reconsidering their outsourcing strategies and shifting production back to domestic facilities. This trend reflects a broader recognition that outsourcing decisions should be based on a comprehensive evaluation of all associated costs rather than just labor savings. A well-informed approach to outsourcing requires careful assessment of both direct expenses and potential hidden costs to ensure long-term financial and operational benefits (Meixell et al., 2014).

2.9 Research Gap

Previous research on outsourcing in battery manufacturing is quite limited, and few previous papers exist. One similar study on the topic conducted by Arora et al. (2025) on partial outsourcing at the beginning of the production was made. The study used simulated annealing to investigate the effects of partial outsourcing and rework in a battery production system. However, the elements that were outsourced were not specified. Some of the study's findings included the use of partial outsourcing as a tactic for dealing with back orders and increasing efficiency, particularly during periods of high market demand. Furthermore, the report reveals that some of the benefits of adopting outsourcing include lowering the overall cost of the system, a greater emphasis on corporate growth, faster delivery, and increased flexibility. Furthermore, the study suggests that if partial outsourcing is done, the manager should focus on assuring quality in the outsourced areas in order to keep the production system's reputation intact (Arora et al., 2025).

The topic of outsourcing and battery manufacturing processes has been separately studied. While these two topics are widely researched, there are limited studies within the combination of the fields and specifically on the outsourcing of electrode production, resulting in a gap in understanding. Therefore, this study will explore how the outsourcing of electrode production will affect the technical and economic factors.

3

Method

This section outlines every phase of the research project as well as the elements included when composing the final report. The study uses a qualitative exploratory design, using a multi-method approach that combines literature review and semi-structured interviews. To provide an extensive overview of the outsourcing opportunities and limitations, a scenario analysis is also included. The aim of the chapter is to get a comprehensive understanding of the steps used to conduct the thesis.

3.1 Research Strategy

The research strategy for the project was to study the case of NOVO Energy, where the case study follows a qualitative research approach. In case study research, the experience of the actors as well as contemporary events was studied. The method was used for NOVO Energy since obtaining a holistic view of the outsourcing topic was the aim. Case studies are especially useful in contexts where an event cannot be studied outside but needs to be understood from the experience of others. A case study is defined as *an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and the context are not clearly evident* (Woodside, 2010). Connecting this to the case of this thesis, NOVO Energy was chosen as a case to explore and understand the different options for the electrode production. Although NOVO Energy is not currently deciding to outsource, they want to better understand the technical and economic factors involved in this decision for the future. The case study approach made it possible to analyze these complex relationships in a structured and detailed way. Since a case study is a research method used to investigate, for example, a specific phenomenon, it allows the researcher to gain in-depth knowledge about the topic and is ideal when a holistic and in-depth investigation is needed (Tellis, 1997). In this case, the phenomenon involves investigating the outsourcing of electrode production. The characteristic of a case study is that it is a multi-perspective analysis where different perspectives of actors are taken into account. This aspect, in particular, was considered to be useful for studying NOVO Energy since multiple perspectives from different departments, such as the Electrode Manufacturing team, Cell Assembly team, and Finance department, were to be taken into account.

The thesis followed an abductive research approach since it is an iterative process between the literature study and empirical data. The literature study and empirical data complement each other as a continuous, ongoing process throughout the study, where both elements are considered to be cornerstones of the thesis. This was determined as an appropriate strategy for the thesis because an abductive method is used with the help of a combination of induction and deduction, which is the ongoing interaction between theoretical and empirical results (Dubois and Gadde, 2002). In addition, this approach was considered to be useful to get in-depth knowledge of the technical and economic factors, both from theory and experience. As noted by Romeijn (2008), the abductive approach usually also aims to describe abductive reasoning as a process of looking for an explanation for a phenomenon and generating a new theory. This part of the approach was not applied within this thesis. However, in this work, the focus was rather on the reasoning and modifying the literature study based on the empirical result, instead of theory generation.

3.2 Research Design

Since the research questions and the aim follow an exploratory approach, the literature review and interviews were conducted as an iterative process. The purpose of having an iterative process was to continuously refine the knowledge regarding the technical and economic factors that can affect the outsourcing decision. After the result was obtained, scenario analysis was conducted with the purpose of investigating the possibilities and limitations of the different outsourcing options. The result of the scenario analysis was confirmed together with a focus group. In Figure 3.2, a description of the different phases that were done in order to conduct the study is shown, as well as information about the steps taken in each phase.

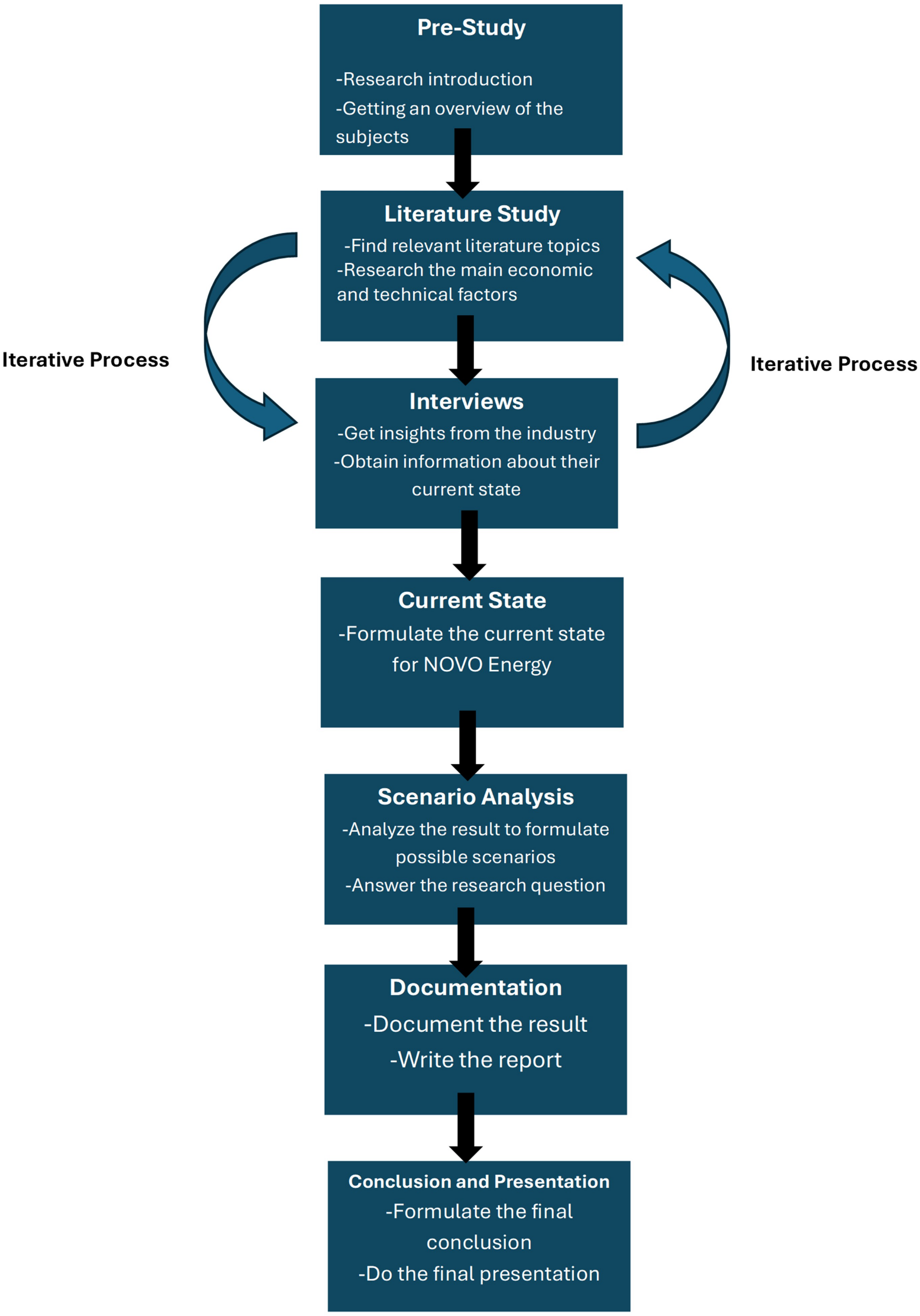


Figure 3.1: Research Design Procedure

3.3 Literature Study

In the first step of the study, a literature review was performed. The purpose of the literature review was to obtain in-depth knowledge of existing research and studies on the technological and economic factors affected by outsourcing decisions, specifically in the case of battery manufacturing. Moreover, the study focused on building a foundation within the key topics and concepts surrounding battery manufacturing and outsourcing. This information was later used as a baseline for conducting the interviews. The literature study was included since conducting a well-planned literature study as a research method leads to advanced knowledge within a certain area (Snyder, 2019). In addition, it can be used to synthesize previous research findings and build new concepts later in the study. The literature study was conducted by searching peer-reviewed papers on databases such as Google Scholar, Web of Science, Research Gate, Science Direct, and Scopus. Some of the keywords that were used during the literature study consist of using, for example, the Boolean logic: ((Outsourcing) AND ("Lithium-ion battery manufacturing")), (("Outsourcing decision") OR ("outsourcing strategy")), ("Outsourcing strategy"), and ("Battery manufacturing") in order to find relevant information.

To collect more company-specific information in the case of NOVO Energy, industrial reports and documents from NOVO Energy were used to gather insights on what their current production strategy looks like in order to understand the current state. Furthermore, the material provided at NOVO Energy was utilized to learn about the advantages and disadvantages of outsourcing electrode production, as well as to gain a basic understanding of the company and what matters to them.

3.4 Interviews

During the literature review, several limitations in the technical and economic aspects of the manufacturing of LIBs were identified. These gaps highlighted the need for an in-depth qualitative study to understand the technical and economic factors involved in producing LIBs. The expertise of professionals with direct experience in battery production was crucial to gaining valuable insights. Therefore, interviews were conducted with specialists from NOVO Energy, specifically those working in manufacturing and finance. Their perspectives played a key role in assessing whether outsourcing electrode production would be a viable option.

3.4.1 Field Access

The interviewees were selected from NOVO Energy's Electrode Manufacturing, Cell Assembly, and Finance departments to provide additional insight into the technical and financial aspects of LIB manufacturing. Wutich et al. (2024) suggests that in empirical research, meaning saturation is typically achieved with a maximum of 24 interviews. Based on this, we selected 17 participants from the mentioned teams to ensure a comprehensive and diverse set of perspectives in our study. For them to better prepare for the interview, all interviewees were given information about the ethical statement as well as the themes of the questions that would be asked.

Table 3.1: Selected Interviewees From The Electrode Department

Interviewee	Current Role	Duration of Interview
A	Senior Process Engineer - Slurry Mixing	1h
B	Process Engineer - Coating	1h
C	Process Engineer - Coating	1h
D	Acting Manager - Calendering and Slitting	45min
E	Senior Process Engineer - Calendering and Slitting	1h
F	Manager Process Engineer - Slurry Mixing	1h
G	Senior Process Engineer - Calendering	1h
H	Senior Process Engineer - Calendering	1h
I	Lead Process Engineer - Coating	1h
J	Senior Manager - Electrode Manufacturing	1h

Table 3.2: Selected Interviewees From The Assembly Department

Interviewee	Current Role	Duration of Interview
K	Senior Process Engineer - Stacking	1h
L	Process Engineer - Stacking	45min
M	Senior Manager - Cell Assembly	1h
N	Manager Engineer - Stacking	1h

Table 3.3: Selected Interviewees From The Finance Department

Interviewee	Current Role	Duration of Interview
O	Junior Business Controller	45min
P	Manager Business Controller	1h

Table 3.4: Selected Interviewee From Engineering Team

Interviewee	Current Role	Duration of Interview
Q	Vice President of Engineering	1h

3.4.2 Interview Method

The interviews were constructed in a semi-structured way where predefined questions in combination with open-ended exploratory questions were asked. By using semi-structured interviews, it was possible to address complex topics and come across previously unknown issues that a structured interview would not be possible to do (Wilson, 2013). The process of conducting this part involved determining the goals and focus of the study as a first step. Then, an interview guide with general questions was outlined as a baseline for each interview. Here, questions such as the background and description of the position of the person at NOVO Energy were defined. After that, depending on the person and their occupation, different exploratory questions and interview guides were used to capture meaningful insights. All of the interviews were recorded on Teams in order to save the results and use them for transcription.

Moreover, two more specific interview guides were developed. One of which was the technical interview guide aimed at the people working at the engineering department, where the focus was on understanding the complexity of producing electrodes and batteries in general. Moreover, the technical aspect focused on manufacturing processes, efficiency, scalability, and IP protection. A similar economic interview guide was developed for the Finance department to cover the economic aspect, including capital investment, operational costs, supply chain risks, and cost per kilowatt-hour. Both of the guides aimed to capture the factors affecting an outsourcing decision.

3.4.3 Interview Analysis

After conducting the interviews, as shown in Figure 3.2, we transcribed the responses to facilitate a structured analysis using the recordings for Teams. The transcription was made using its built-in transcription tool. After familiarizing with the data, an initial coding process was made together with the early development of the themes. The transcriptions were then summarized into key themes that could be identified. This process allowed us to systematically compare and discuss key insights by organizing the answers into relevant categories.

Moreover, it was possible to pinpoint critical factors that had not been addressed in the existing literature by identifying recurring challenges and common themes in the responses. These additional considerations played a key role in our final evaluation of whether outsourcing electrode production would be a viable option.

The analysis was made using a qualitative analysis method. More specifically, thematic analysis was used to identify the common core themes and patterns from the results (Figgou and Pavlopoulos, 2015). Clustering qualitative data into common themes allows for the identification of the most significant factors within a subject, as well as the discovery of correlations and the integration of different concepts. After identifying all the themes, they were reviewed once again to see if some of the sub-themes could be merged into one or if there were themes not contributing to the result of the thesis.

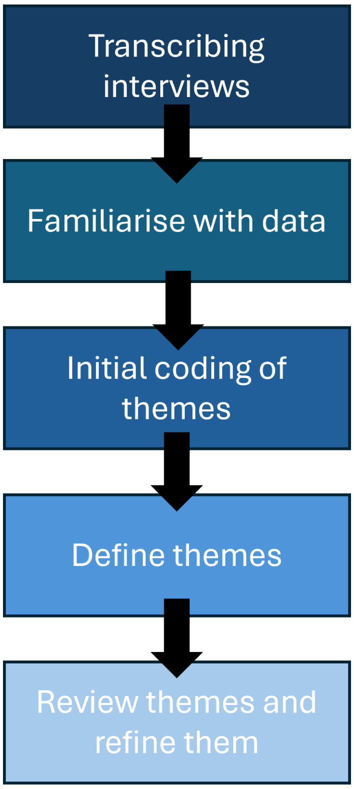


Figure 3.2: Analysis of The Interviews

3.4.4 Ethical Statement

Before participating in the interview, all participants were fully informed about the study's purpose, allowing them to make an informed decision whether they wanted to be interviewed or not (Bell et al., 2022). This transparency helped us ensure that they understood the research context and the significance of their contributions. Additionally, participants were made aware of how their responses would be used in the study and recorded, with assurances that their identities would remain confidential. While their professional roles were mentioned in the study, their names were deleted to maintain anonymity. In addition, the participant would gain access to their transcribed answers in order to review them for confidential information and once again confirm that the given information could be included. This is since there was always a possibility that the questions asked may lead the participant to answer with information that can be confidential during the interview session.

3.5 Scenario Analysis

The scenario analysis was conducted with the aim of understanding the different options and alternatives NOVO Energy has for outsourcing the electrode production. After gathering the results from the interviews and the literature review, four possible scenarios were identified, which included retaining manufacturing in-house, entirely outsourcing the electrode production, and two distinct hybrid outsourcing solutions. Scenario analysis is widely used to analyze the impact of possible future events by taking several different alternatives into account (Balaman, 2018). The general aim behind constructing a scenario is to generate orientation to a possible future event, together with certain key factors (Kosow and Gaßner, 2008). It is important to remember that a scenario does not represent the future, but instead it is a future-oriented construction. Every scenario is also based on a set of assumptions about how the future could possibly look, therefore, scenarios do not provide "true" knowledge and are a hypothetical construction. As pointed out in the quote *"Scenarios are perhaps most effective when seen as a powerful tool to broaden perspectives, raise questions and challenge conventional thinking."* (Kosow and Gaßner, 2008).

Constructing the scenarios for the analysis is done in a method of five distinct phases. The first phase includes scenario field identification, where it was decided what type of scenarios were to be constructed and what information was aimed to be obtained (Kosow and Gaßner, 2008). Here, a focus was on understanding if some possible future scenario was more preferable when it came to outsourcing or not, and understanding the effect a certain scenario had on the electrode production. In phases two and three, key factors for the scenario should be identified and analyzed, usually collected during empirical and theoretical analysis, which in the case of this thesis was the interviews and literature study to get a holistic view of the outsourcing possibilities. The key factors identified were, as pointed out previously defined at technical and economic factors that affect the scenarios. Lastly, the two remaining steps are scenario generation and scenario transfer, where the scenarios themselves are being created. In Figure 3.5, a picture of the different steps that were taken can be seen.

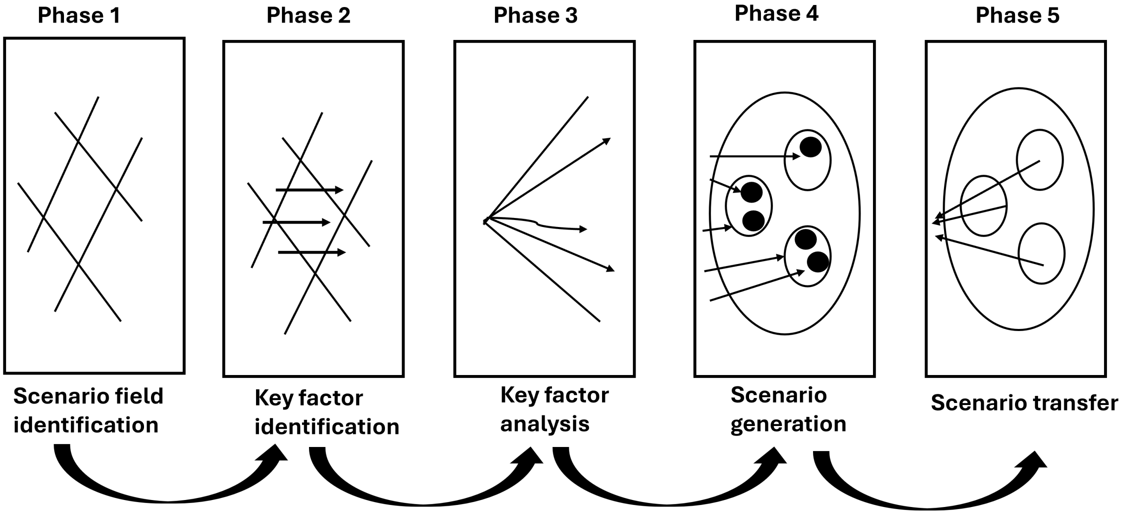


Figure 3.3: Workflow of Scenario Analysis, Inspired By Kosow and Gaßner (2008)

The four scenarios that were created follow an explorative approach where, regardless of their desirability, the consequences of different decisions are looked into (Kosow and Gaßner, 2008). In our case, the technical and economic factors were looked into and based on the scenario, the prediction of its consequences where explored; more specifically, the benefits and drawbacks of a certain factor for a certain scenario. During an explorative approach, questions such as "what do we know and what do we not know?" are asked. The scenario analysis consisted of two different analyses, an economic scenario analysis and a technical scenario analysis, described further below. Four scenarios were chosen, even though more scenarios can be made since recommendations say that around four to five scenarios are usually the most meaningful(Kosow and Gaßner, 2008). To summarize, it is preferred to have enough scenarios so that the most important perspectives are covered, but not too many so that the process of understanding them becomes too confusing.

3.5.1 Economic Scenario Analysis

The economic analysis was conducted to evaluate the four proposed scenarios, each representing a potential solution. The analysis focused on comparing key economic factors that influence whether a given scenario is economically possible. These factors included the costs of machinery, material, labor, energy, transportation, scraps, customs, and hidden costs. The data supporting this evaluation were drawn from a combination of the comprehensive literature review and qualitative insights gathered through interviews with industry experts.

In scenarios where outsourcing was considered a part of the solution, the analysis included the economic differences of outsourcing operations to different regions, specifically China, Europe, and the United States. This regional comparison was made to identify the most cost-effective and strategically advantageous locations.

To keep the evaluation realistic and relevant, the data for each scenario was chosen to reflect its specific context. For the in-house scenario, cost estimates were provided by NOVO Energy's finance team and supported by observations from internal seminars at NOVO Energy. In the case of the Outsourcing scenario, the focus shifted to published sources, particularly cost structures outlined by Orangi and Strømman (2022).

The scenarios, Gradual Vertical Integration and Parallel Make-and-Buy, were made by the recurring themes that were raised during interviews with professionals at NOVO Energy. Many of these experts had hands-on experience with hybrid production models. While these strategies are not widely covered in the literature, the input from experts helped fill those gaps, making the evaluations more realistic and grounded in day-to-day industry practice.

Each scenario was assessed using a mix of qualitative and quantitative inputs. This meant not just running the numbers but also interpreting what they meant with the help of expert opinions gathered from the interviews. The method follows the approach suggested by Symstad et al. (2017), who highlight the value of combining empirical data with expert insights in scenario planning. For every economic factor, the analysis considered whether its influence would likely strengthen or weaken the financial case for that scenario. Including expert insights in the analysis, as noted by Kośny and Piotrowska (2019), helped the evaluation go beyond just the numbers, capturing more subtle trade-offs that purely quantitative methods might miss. By combining these different layers of insight, the assessment became more balanced, more grounded in real-world thinking, and ultimately more reliable.

3.5.2 Technical Scenario Analysis

The technical analysis was constructed using the four different scenarios together with the identified technical factors that affect an outsourcing decision. For every technical factor presented, the corresponding drawbacks and benefits are presented for each scenario. The aim of doing the technical analysis using scenarios was to obtain a holistic view of the options and whether any options are noticeably better than the other. Moreover, the different technical factors are considered of equal importance in this case, where no weighing of importance was done.

The evaluation of whether a technical factor was considered to be affected in a positive or a negative way was based on all the results from the literature study and the results. Moreover, the interaction between one factor being positive in one scenario and the same factor being negative in another comes from understanding the relationship between them. The understanding of the relationships between the factors was also obtained by the literature study and results.

Moreover, the evaluation of the factors that had been identified where further discussed in order to validate them together with the focus group. This is since the focus group can give in-depth data on the topic and valuable opinions for the analysis (Then et al., 2014). This allowed us to confirm or challenge the assumptions and conclusions drawn from the literature and interviews. In addition, a deeper understanding of the scenarios and factors was presented.

3.5.3 Focus Group

After analyzing the results of the interviews, a focus group was held to check and improve the analysis of the interview responses to ensure that the results truly reflect the views of important people in the organization. A focus group is a collection of people who gather to discuss a certain topic (Conrad, 2001). The members can have experience within the topic or be new to it. In this situation, the members had varying levels of familiarity with the topic, with some having outsourcing experience and others having finance experience, with the goal of gathering people with diverse knowledge who could complement one another in the analysis.

A focus group normally consists of a number of participants ranging somewhere between 4-31 people (Al-Ababneh, 2018). However, there is no strict rule for how many participants a focus group should have. Smaller groups, where the number of participants ranges from four to six participants may be more productive since all the members need to be actively involved in the discussion, compared to a larger group where equal contribution can be hard to achieve. Therefore, four participants were chosen to have a more intensive discussion and to focus more on confirming the scenarios.

The meeting included the Head of Engineering, Head of Electrode Manufacturing, Head of Cell Assembly, and Head of Finance, each representing a key department. This method follows common practices in qualitative research, where focus groups help confirm and strengthen the results (Krueger and Casey, 2014). Focus groups are useful for gathering multiple points of view on a certain issue (Conrad, 2001). Compared to the interviews collected, the focus groups allowed the participants to share ideas and change of ideas.

During the focus group session, the participants were shown five tables, made during the scenario analysis, one focusing on economic factors and the others on technical aspects. The group discussed the tables, offering feedback, pointing out any missing information, and sharing ideas that may not have come up in individual interviews. In addition, the focus group members were sent the tables and scenarios beforehand to be able to come to the meeting prepared and be ready to discuss directly. Moreover, the focus group shed new light on aspects that resulted in a deeper understanding. This group discussion helped confirm the analysis and provided a better understanding of how economic and technical factors work together in this study (Hall, 2020). Further, a focus group usually has a duration of 30 to 2.5 hours (Al-Ababneh, 2018). During the focus group, an agreement among the participants where fulfilled after 30 minutes, where all key highlights had been discussed.

The focus group session was recorded on Teams and later transcribed into a document. Thematic analysis was utilized to analyze the session, just as it was for the interviews. However, the group session outcomes were not given in themes, but rather as a recommendation, along with a literature review and results.

3.5.4 Reliability and Validation

A case study is known to be a triangulated research strategy (Tellis, 1997). Therefore, to validate the result, the triangulation method was used. The triangulation method is especially useful for validating the result of a case study since you confirm your result based on multiple sources of data (Bans-Akutey and Tiimub, 2021). Triangulation can be done with different types of sources, such as theory, interviews, and observations.

Achieving validity in the result is important to make sure that the findings made during the study can correctly be used and interpreted by the stakeholders, which in this case is NOVO Energy (Bans-Akutey and Tiimub, 2021). Further, the use of a variety of methods supports the work by confirming it in different ways and that it is accurate. In addition, triangulation gives more insights to better explain the results obtained and reduces the possibility of biases in the sampling or researcher biases.

Therefore, the method further increases the credibility of the study. Despite the positive outcomes of using triangulation, it is important to highlight the fact that the validity of every research cannot reach 100% because the data can be constantly questioned.

In this thesis, triangulation was done together with the literature study, interviews, observations, and internal documents provided by NOVO Energy. In the Figure 3.4, a descriptive picture can be seen of the triangulation method used.

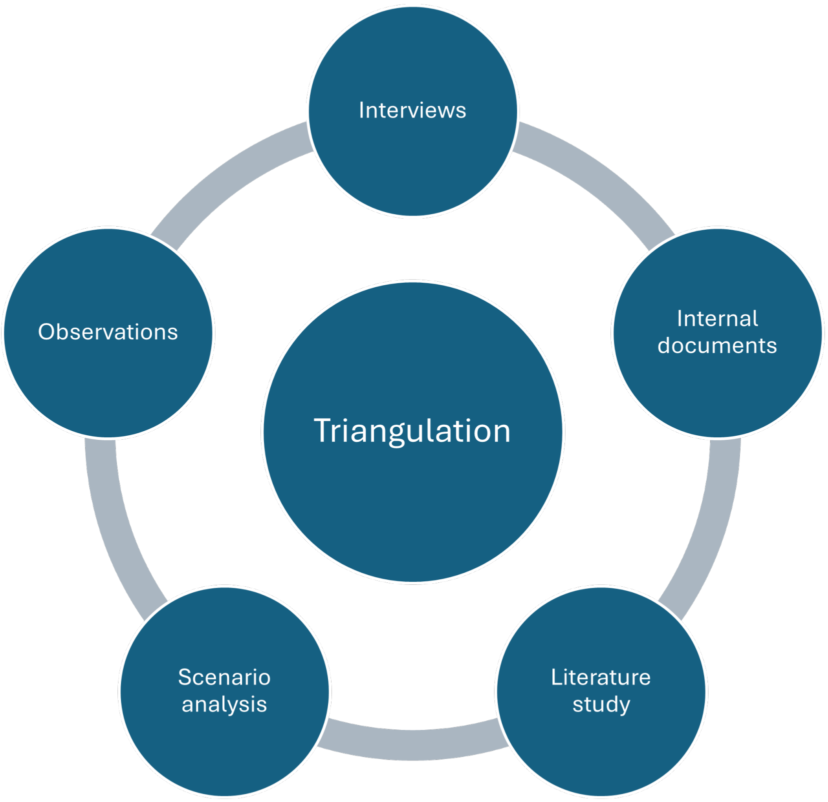


Figure 3.4: Triangulation Method

4

Results

The following chapter contains the thesis's findings collected from the interviews. The first section describes the current situation of NOVO Energy as an organization and where they are standing right now. Lastly, the second stage of the results is given in the themes identified during the interviews, emphasizing the most critical topics of outsourcing and battery production.

4.1 Current state

NOVO Energy, a joint venture between Northvolt and Volvo Cars was founded in 2022 with the mission to produce batteries specifically tailored for Volvo Cars. Construction of NOVO Energy's first gigafactory began in 2023, with plans to reach a capacity of up to 50 gigawatt hours (GWh). A contract with Northvolt is still running where Volvo Cars aim to become independent owners over NOVO Energy since Northvolt Sweden filed for bankruptcy. As one of the participants pointed out, *"Having a joint venture where half of it is bankrupted is not so common,"* which gives a situation where you are trying to leave the old joint venture and at the same time, trying to find a new partner. Another interviewee expressed it as, *"Until Volvo Cars does not acquire the full ownership of the company, we will continue to be in such a status."*

Since NOVO Energy is currently in startup mode, they have no current sales or production running at the moment, *"Currently, we have a target for our site on around 35,000,000 cells per year."* The intended aim was to be running by 2026, but due to Northvolt's bankruptcy, NOVO Energy is a little behind schedule. From an economic standpoint, several things are currently on pause as well. *"NOVO is dependent on equity contributions to be able to move forward and continue to invest since no cash is generated due to the production not being finished."* Therefore NOVO Energy has implemented cost-saving measures in response to shifting market dynamics and a revised business strategy. While awaiting a new possible business partner, things will be running, as one participant stated, *"When everything is settled, we are prepared to run in the same pace as before."* NOVO Energy is therefore equipped, both technically and economically, to commence the company's next stage when everything is ready.

4.2 Drivers and Hinders for Outsourcing vs In-House

In this section of the result, the common themes identified during the interviews will be presented. The benefits and challenges of producing the electrodes in-house or outsourced will be highlighted.

4.2.1 Quality

The electrode is often described as the heart of a lithium-ion battery. If issues arise during electrode production, the overall functionality of the battery can be compromised, even if the later manufacturing steps are executed perfectly. As one interviewee emphasized, *"If the quality of the electrode is good, we can do the slitting. We can do proper calendaring, but we do not know in the beginning how it is coming. If not, there is a lot of waste (30-40 percent)."* This highlights the importance of understanding the critical parameters that influence electrode quality.

The manufacturing process begins with the preparation of a slurry by mixing raw materials. While many parameters must be controlled at this stage, dosing accuracy was consistently identified as the most critical. If the ratio between the active material and the binder is incorrect, it can cause delamination during calendaring, where the coated layer separates from the foil. As one participant explained, *"When it comes to the slurry mixing, what I will say is maintaining your active material ratio to binder ratio is the most important. So, you need to have proper dosing and have your quality checks with the percentage of dosing accuracy. For slurry mixing, maintaining your dosing accuracy is technically the first or the main challenge."*

Another important factor during both the slurry mixing and coating stages is viscosity. Proper viscosity is essential to ensure that the slurry can be coated smoothly and consistently onto the foil. As noted by one interviewee, *"Viscosity is the most important quality-related parameter since it will affect the whole battery."* Solid content also plays a significant role; if the solid content is higher than expected, unmixed particles may lead to defects during coating. One informant pointed out, *"If you have more solid contents than usual, you will encounter a lot of particles that are unmixed and that would give you defects in the coating process."*

Finally, several participants emphasized the importance of raw material quality at the very beginning of the process. As one explained, *"One quality-related problem I can see is the material at the beginning of the process. Depending on the refined level of material, it heavily affects the quality of the slurry and electrodes."*

The next major step in the process is coating, which many consider to be one of the most difficult stages. As one participant put it, *"They say the coating is the toughest in electrode manufacturing because there are a lot of parameters that you have to get right to meet this sweet spot in the production."* Among all the variables involved, loading was highlighted as especially important. One interviewee emphasized, *"Loading is very important when it comes to coating. They have to give the proper loading and also distribute evenly. If there is an imbalance between the coating edges and at the center, it will create some issues for the next step."*

Once the coating is complete, the process moves on to calendaring, where getting the thickness right is critical. If not properly controlled, this stage can introduce a range of defects. As one participant explained, *"So you need to maintain uniform thickness and uniform loading. The more agglomerations you have in it, the more you have pin holes. You will have strikes, straps in your electrode, and governor damage. Also you can have foil breaks if you measure wrong."*

After calendaring, the final step in electrode manufacturing is slitting. This process is critical, as it ensures that the electrodes meet the exact dimensions required for the final cell assembly. One participant explained it well, *"So until that before slitting, it was only your quality (the thickness and loading) that you were looking at. But when it comes to the slitting, it should meet the cell's dimensions."* During slitting, the knife must be sharp and properly positioned to avoid issues later on. As another participant pointed out, *"For slitting, you should put the knife in the middle of it exactly and also we don't want waviness or burrs."* Surface defects like burrs are a particular concern, not just for aesthetic reasons but for safety. As one person emphasized, *"We don't want burrs in the slitting because they have the tendency to penetrate the separator and also cause a short circuit or a thermal runway in the cell."* In short, slitting is not just about cutting to size; it is a critical quality control step that helps ensure the performance and safety of the final battery.

Finally, creating a reliable and high-performing electrode involves getting a lot of parameters just right. Since the electrode directly impacts the battery's overall quality and capacity, any misstep in its production can have significant consequences. Two key elements play a major role in achieving this: the parameters of the equipment used and the people operating it. As one expert put it, *"To get the right quality, both as a basis or scaling up, needs a lot of design of experience (DOE) to reach the desired level of performance."* In other words, reaching the desired outcome is not just about having the right tools; it requires a lot of experimentation and fine-tuning.

On the human side of the production, experience and skill are just as crucial. *"Trained and skilled people also affect quality. You need skilled people who can see the quality issues and that comes with experience. And quality and scrap go hand in hand also, which makes sense, since the more quality issues you have, the more scrap you will have. But even with skilled people, there are always things that surprise you."* This explains the importance of having knowledgeable operators who can spot problems early, reduce waste, and maintain consistency. Still, even with the best training, unexpected challenges are always part of the process. It all reflects just how complex and sensitive electrode production can be.

4.2.2 IP Protection

In the battery industry, slurry formulations are considered highly confidential intellectual property and no one is willing to share them. As one interviewee explained, *"Others can do benchmarking on everything else except the slurry. So, this is where all our intellectual properties usually are."* Considering this, the idea of outsourcing electrode manufacturing raised significant concerns among participants, particularly regarding the risk of IP theft. One informant mentioned the danger of poaching, *"If we outsource electrodes, they might make our recipes as a reference to improve their own model or their product specification."*

Even with monitoring measures in place, the risk remains. When we asked our informants whether regular oversight could mitigate these concerns, one interviewee offered an interesting perspective: *"Even if you go there frequently to check their systems, if I am an engineer on that side and I know the recipe by heart and I leave, I go work somewhere else with all your knowledge in my head."* This response shows the challenges of safeguarding proprietary knowledge once it is shared outside the company.

After hearing about these concerns about IP theft, we proposed an alternative solution to minimize the risk of knowledge leakage. Specifically, we asked our interviewees whether their concerns would be resolved if the new partner were responsible for producing the electrodes on our behalf. This approach appeared to ease some of the participants' worries. As one respondent stated, *"Once we are sure that our partner does it well, then of course it is better because no more for this handing over the recipe to start mixing!"*

4.2.3 Scalability

Scaling up and reaching capacity for battery manufacturers is a remaining challenge, especially during ramp-up. The main reason is the complex process, and together with that, enough experience is required to meet the right quality. As one of the interviewees put it, *"Achieving an overall equipment efficiency (OEE) above 80% is crucial but difficult due to the complexity of lithium-ion battery production, which combines chemical, thin-film, automation, and warehousing processes."* Another expressed it as *"This ramp-up phase is the toughest because that needs a lot of competence in battery and all."* A different factor that was emphasized, which makes scaling up challenging, is the fact that NOVO Energy is producing prismatic cells in comparison to cylindrical cells. The interviewee pointed out that *"Comparing the cylindrical cell and the prismatic cell, it is much harder to produce prismatic cells in bigger quantities. You can only produce around 20% of the prismatic cells as you would get out of the cylindrical cells."*

Commonly, several of the participants agreed that scaling up in the initial stage is a highly time-consuming process where several things can occur, *"In the initial stage where all the machines are in place, you need to do a lot of DOE to set the* *final parameters. Company X failed since they did not have enough skilled people, and they wanted to scale up too fast.”* and *“Where companies do wrong is when they want to scale too fast during the ramp-up time and have too ambitious timelines. And I think this is mainly due to companies wanting to be quick to market and the automotive companies want to have the best products before their competitors.”* All things considered, it strikes a balance between scaling up being a time-consuming procedure and moving too quickly, which can result in additional issues.

Scalability challenges can also vary depending on where in the production you are located, *“Electrode production can be scaled by increasing speed, adjusting temperature, or tweaking parameters, but it will take time.”* Producing also significantly depends on the product itself and how fast you can produce it. *“Assembly scaling is difficult and may require new machines and expanded facilities.”* This is because you cannot stack as fast as you want.

Historically, most of the problems during scaling up repeat themselves, but due to companies wanting to acquire a strong market position, this type of information is kept as a company secret *“Countries like Japan, Korea, and China faced similar difficulties in scaling up production. A key challenge is the high raw material cost, which constitutes 60-70% of the product cost, meaning waste directly impacts profitability,”* resulting in start-ups making the same mistakes over and over again.

As for now, the factory at NOVO Energy is set at a certain limit, *“The factory has been optimized for a certain number of batteries. We have a purchase order and upper and lower limits for production because the level of production is never a flat line, and we have fluctuations with which we have to deal.”* Passing over the production limit of the factory is not possible and would require new machines to be able to do so, which there is no space for. Therefore, the factory has the capacity to handle some fluctuations in demand but only to a certain limit. This is where an eventual block two would be needed. The participants expressed that going over this limit is not so likely at the moment, *“We have our own vehicle manufacturing, so they know the demand and the fluctuations”* and *“The plan for NOVO is to produce more than what Volvo has actually “ordered” so we have some room for “unplanned” orders which makes us pretty flexible for a volatile market.”* On the other hand, some participants were less sure. For instance, NOVO Energy is in a position that is directly affected by the demand of Volvo Cars. *“Like Volvo in the case of NOVO, any changes in the customer’s strategy directly impact production, making flexibility and high productivity difficult to balance.”* Although Volvo has a purchasing order and a future demand plan, it is challenging to forecast every scenario when NOVO Energy relies on a single actor to determine the order quantity. Moreover, other dimensions, such as *“Additionally, the fluctuating automotive market, influenced by political and social factors, adds uncertainty. For instance, U.S. tariffs and elections have caused market shifts, making scalability even harder,”* resulting in it being even harder to predict the future demand and if additional scaling is needed.

At the same time, there were fewer critics when it came to scaling up another factory at NOVO Energy after the first one. One participant explained it as *"Because you have experience with one plant and you know some lessons learned from that phase,"* so they were less afraid that the same mistakes would happen again if an additional factory were built.

4.2.4 Integration

When considering the option of outsourcing electrode production as part of the manufacturing strategy, one key factor that emerged from the interviews was the challenge of integration with the in-house production processes. A major concern raised was related to quality issues, particularly the risk of defects in outsourced components. These concerns naturally led to deeper discussions around quality control. One interviewee expressed skepticism about the consistency of external suppliers' quality standards, stating, *"I need to doubt on the materials that they are using in the level of quality checks they do on the process. Because in the end, you cannot judge between a good electrode and a bad electrode until you have a cell built with that. You can specify the requirement in the contract and the outcome you want but it doesn't mean it will work in the end."* Although some participants noted that NOVO Energy has robust in-line quality control systems that could potentially detect defects early, concerns remained about ensuring similar standards at the supplier level. This led to the suggestion of placing NOVO Energy personnel at the supplier's site to conduct quality checks or implementing an additional layer of inspection before the outsourced electrodes are introduced into the cell assembly process. However, as one interviewee pointed out, this might not be a realistic option, *"If we can have people there to do quality check for us, it would be good, but I don't think it is possible. They will not allow that, because nobody likes it when other people come into your plant and check your processes."*

Traceability also surfaced as a critical issue during the interviews. NOVO Energy currently operates with a system capable of tracing each electrode back to the specific slurry batch used in its production. This level of traceability becomes difficult to maintain if electrode manufacturing is outsourced. One participant explained this complexity, noting, *"It would be a mess to integrate the bought jellyrolls because you have no ID on the roll to connect to a certain batch. So, what you have to do is put an imaginary number on the roll when it arrives. Therefore, it will be hard to track it back to the specific batch, in other words, it is hard to match the outsource catalog and jellyroll."* Another interviewee emphasized the long-term implications, particularly in cases requiring recalls or investigations years after production, *"If the electrode manufacturing is internal, it's very easy to set up the traceability standards. If it's external, they may have working with a different system, so at a certain point, if I need to track back on what was used on the specific cell, even if it can happen after five years to need a recall for something, it will become way more challenging because then you need to rely on your supplier database."*

A final concern related to integration was the impact on inventory management. Outsourcing would necessitate larger inventories to buffer against supply disruptions, which introduces new warehousing challenges. As one participant put it, *"Some other challenges can be how you would have stored onsite to keep your production up and running if something goes wrong with one shipment, those kinds of challenges. So, inventory challenges are there, also how are you going to store those materials? Because you need to have a protected environment. Again, it's more of an inventory and warehousing challenge that you're going to have."*

4.2.5 Economic

When it comes to the economic aspects of making an outsourcing decision, the participants showed different insights into how it can be affected, where both pros and cons could be seen. One interviewee expressed their initial concern, *"You lose control over efficiency, pricing, and quality. Suppliers can set higher prices, particularly for critical components like electrodes,"* and another pointed out *"If the production of electrodes is outsourced to a specific country, market shifts, tariffs, and regulations can affect costs. For example, outsourcing to China or Korea may seem cost-effective now, but policy changes, trade restrictions, or supply chain disruptions could impact long-term viability. If an investment is made in a particular country's production capacity, shifting operations later becomes costly,"* which both highlighted the complexity that comes when shifting the responsibility to another contractor. Outsourcing, particularly in regard to policy changes, has been mentioned due to the multiple hidden costs that can occur and are impossible to predict and account for ahead of time.

Moreover, an interesting point of view was brought up during one of the interviews, *"Outsourcing does not reduce costs but rather spreads them over time and may result in paying twice if later transitioning to in-house production."* When we then asked about outsourcing the electrode production, the following was stated *"A significant upfront investment is required for in-house electrode production. However, when outsourcing, the key question is how much of this investment is product-specific vs. general-purpose. If 80% of the equipment is product-specific, outsourcing may not be cost-effective. If only 5% is specific, outsourcing becomes a viable short-term solution. The depreciation of machinery should be factored into cost comparisons."* When further elaborating on the economic benefits of keeping the electrode in-house, the following topic was underlined *"But when we look to the future, managing your own slurry or waste is clearly beneficial. It eliminates the need to rely on the market, where you'd have to sell it at a margin, reducing overall costs and increasing efficiency,"* which clearly shows that having control over your own production is a more optimal option among the participants. It was confirmed by another interviewee from another viewpoint, *"If suppliers increase prices or experience disruptions, the company may face unexpected cost spikes and delays."* These are factors important to the battery industry in general since it is a cost-sensitive market when supplying to the automotive industry.

When discussing further with the participants about whether outsourcing could be a viable option in the ramp-up stage, one stated *"Pushing the investment of the electrode production to a later stage when we have reached a positive cash flow, could be a good idea since you do not need so much money up-front. Of course, you still need to pay for the outsourcing part, but the investment in-house is not needed in the same way."*.

Some of the highlighted main cost drivers for electrode production are labor, material, energy, scrap, tariffs, equipment depreciation, raw material, and transportation, as mentioned by the participants. As explained by an interviewee, *"The most costs go to raw material (around 70%, mostly cathode)"* and *"Differences in material costs between regions may not be significant, except where subsidies apply."* One of the cost drivers for the in-house production of batteries in general is brought up as *"Early production stages have high scrap rates where the first 2-3 batches are wasted. An estimation of what it can cost in a general battery manufacturer is an initial scrap cost per batch: ~$350,000– $400,000. The scrap rate improves over 6–12 months when the production has reached stable quality levels."*

The importance of recycling as a way of controlling cost during in-house is, therefore, something mentioned by several of the participants, where one stated it as *"General things to consider are recycling scrap materials (e.g., cutaway foil) to reduce waste and recover value. Recycling a part like scrap that we have from the process, when it comes to, like cutaway foil for example, is an easy way of not only spending money, but also to get some money back."* Even though recycling is mentioned as a key way of returning some of the money spent on raw materials, a participant expressed, *"During ramp-up, scrap costs can escalate rapidly, reaching several tons per day. This results in excessive material waste during the initial production stages. As the process progresses, learning curves come into play, gradually improving efficiency and reducing scrap rates."* It emphasizes the difficulties of ramping up battery production and the fact that it will continue to be a significant cost for all battery manufacturers.

4.2.6 Tariffs

Tariffs on imported goods are a significant economic factor influencing outsourcing decisions. As one expert mentioned, *"Tariffs are always very challenging because normally you can have tariffs on a finished product, this is typically how they work, but on semi-products then it's always very borderline and it can change pretty quickly. So that always has to be checked from time to time, and regulation can change your entire planning depending on how the market is evolving."* Given the unpredictable nature of tariff policies, businesses must continuously monitor trade regulations, as sudden changes can impact cost structures and overall strategic planning.

4.2.7 Security of Supply

One of the key concerns regarding the outsourcing of electrode manufacturing is the potential loss of control over both the production process and product quality. Relying on external suppliers introduces risks such as missed deadlines or quality inconsistencies, which could significantly disrupt the entire supply chain. As one participant highlighted, *"Electrode manufacturing is one of the most important processes in making electrodes because that decides how your product will be. So, about the quality of the electrodes, that's going to be a challenge because we have a certain set of standards, but we don't know what they're following and how they're producing that then. We will lose control of our most important process. We cannot adjust anything because we're going to leave it up to them. And if we have certain things we have to do a certain way, we don't have control over that."*

Beyond operational concerns, outsourcing can also impact the company's financial structure. A lack of transparency in supplier costs and financial arrangements may cause additional challenges, as mentioned in one of the interviews, *"When you're outsourcing something, you become dependent on someone else. And there is maybe not as much of, you could say, open book accounting where you see all the figures you need."*

Another major dependability-related drawback of outsourcing is the potential loss of in-house expertise and technical competence. If production is entirely dependent on external suppliers, the company risks eroding its own knowledge base and workforce skills. As one interviewee pointed out, *"They (the workforce) won't know how to produce electrodes because they're depending on the supplier to do so. People here won't really grow and won't have the know-how of how to make an electrode. So, in the future, you cannot be completely dependent on an external supply to do it for you."*

4.2.8 Transportation

Transportation is another aspect affecting the decision to outsource or to keep it in-house. The participants emphasized that the transportation of sensitive electrodes can be challenging when it comes to avoiding quality problems, but also regarding the cost of it and the fixture to hold it in place, a lot of things can happen during transportation. The packaging of electrodes is crucial for maintaining the right quality. Depending on the format of the electrodes, it can be easier or more difficult, *"The jumbo rolls are easier to handle and is usually how you ship it"* and *"If you get the outsourced electrodes as pancakes, it means twice the packaging and shipping costs so you need to do it as unpressed jumbo rolls,"* due to the complexity of fixtures when shipping the pancakes being one of the main reasons. To underline the complexity of integrating new suppliers, especially for the electrodes, *"You also need to be a bit cautious with your supplier. What if something happens with the supplier, or all of a sudden, they need to increase prices? Therefore, a lot of time will probably go to writing a contract between us and them. For example, whose fault is it if the electrodes arrive badly? That needs to be clarified,"* an interviewee argued.

One of the participants highlighted the following issue, *"Most of the electrodes are shipped by sea instead of flight since this is cheaper. Shipping through the sea, though, gives a risk of being exposed to humidity, which can destroy the electrodes,"* which is an additional quality problem besides the one that is occurring in the production itself. Moreover, another participant highlighted *"Relying on external suppliers for electrodes introduces risks such as fluctuating material prices, potential supply chain disruptions, and complications in quality assurance,"* which is important to take into consideration when looking at the ongoing political situation. As highlighted *"More and more the geopolitical factors are becoming even more important nowadays. So one can argue that the so-called security of supply is becoming one of the most important drivers for all industries, not only the battery industry."* In general, several of the participants expressed that increasing lead times when outsourcing the electrodes will be a challenge, and predicting if it will be on time or not.

In addition, as the participants expressed, additional quality steps are required before entering the downstream production to handle the possible humidity and quality problems that can occur during transportation. One of the participants highlighted the importance of a possible redrying station as *"The reason a redrying station may be needed before stacking is the moisture the electrode is in contact with during transport."* Moreover, warehousing of the electrodes is mentioned as something on top of everything that needs to be considered, and an interviewee expressed it as *"Again, it's more inventory, logistics, warehousing challenges that you're going to have and you need to have a protected environment."*. At the same time, another participant stresses,*"Transportation costs differ significantly when shipping finished jumbo rolls versus raw materials. Tariffs on semi-finished products can be unpredictable and require regular monitoring as regulations change."*

4.2.9 Previous Outsourcing Experience

Some of the participants had outsourcing experience from previous battery manufacturing companies, not only in general working with outsourcing, but also highly specific regarding outsourcing of electrodes, which gave valuable insights. The participants expressed that they had seen it themselves where things usually go wrong, but could also see the benefits of why other companies have done it. A common nominator among all the participants with outsourcing experience was that they outsource to a sub-company within the company.

An interviewee stated from past experience that *"I have outsourcing experience from working with Company X. Where they had outsourced the pancakes. They started with outsourcing the pancakes in order to optimize the production downstream from the slitting. They stabilized the processes to see that they were working as they should and when they had everything under control they started to build the electrode part of the production and integrate it. It was a success since they had time to put on the other processes first to ensure the right quality, but still were able to deliver products."*. Further asking the participant if any downsides were experienced working this way the following argument was stated *"From my past experience the cost for all the scrap and quality controlling was pretty high, so in my opinion it is not always worth the money you save by outsourcing since there are other costs you have to pay. They kind of lost some of the money they saved."*. Another participant explained that they worked in a similar way, *"I worked for Company Y in Singapore for cylindrical batteries but the R&D and the electrode manufacturing was in Japan and we would outsource them from the mother company in Japan."*.

Further, one interviewee summarizes their thoughts with *"From past experience, I have a lot of issues with the jumbo rolls when it comes to quality, because of the quality problems and capacity issues we faced at Company X. Quality checks on the jumbo rolls were usually made only on the first 3 meters of the roll, and then it proceeded in the process proceeded. Since there was no previous quality control, it can be hard to predict the problems."*.

Towards the end, one of the participants with previous outsourcing experience that were interviewed summarized their thoughts on outsourcing with a key emphasis on whether it is a long-term solution or short-term as *"The decision to keep a process in-house depends on the duration and criticality of the operation. For short-term phases, such as commissioning and ramp-up, in-house execution ensures better fine-tuning of the assembly line with long-term materials, making the transition to full production smoother despite initial difficulties. In the long term, keeping production in-house is crucial for the security of supply, cost control, and intellectual property protection, especially when dealing with key components like electrodes, which constitute a major cost driver. Relying on a third party for a significant portion of production introduces supply risks and potential IP challenges, necessitating careful evaluation before outsourcing."*

5

Scenario Analysis

To assess the alternatives for the electrode production, a total of four scenarios will be created throughout the scenario analysis based on the literature review and qualitative results, which will be presented below. The scenarios will then be evaluated with a technical evaluation and an economic evaluation. All four scenarios were constructed using the same set of key technical and economic factors identified during the research. These factors were derived from both academic theory and industry-specific expertise gathered during the interviews and were consistently applied across all scenarios to ensure comparability.

5.1 Technical Evaluation

In the technical evaluation, the four scenarios will be compared against each other based on the main technical factors affecting the manufacturing of LIBs, specifically the electrodes, where benefits and drawbacks can be seen for each factor and scenario. As mentioned before, the technical factors are defined as the fundamental engineering and manufacturing challenges that impact battery quality, efficiency, and scalability. Technical challenges are mostly inherent to the manufacturing process and focus on maintaining consistent performance, minimizing defects, and improving throughput while meeting industry standards. Therefore, the defined factors from the literature study and empirical studies are brought up in each scenario's table together in order to show how each factor is affected by the specific scenario. In the tables, a + stands for the positive effects of a certain factor, while a - stands for the downside of the factor.

5.1.1 Scenario One (In-house)

The first scenario that will be presented in Table 5.1 is the in-house alternative, which is NOVO Energy's initial plan as well as their strategy for the current state. In this scenario, it is assumed that all of the steps of the process are made by NOVO Energy only, and all steps remain in-house. Furthermore, it is anticipated that no third-party suppliers are involved in the electrode production process, as NOVO Energy controls everything from manufacturing processes to quality control. This scenario was constructed as the baseline scenario, since it is the strategy that is taken right now by them.

Table 5.1: Technical Evaluation For Scenario One

Technical Factors	**Scenario 1**
Quality Control	+Have full control over the quality control -Require well educated staff to recognize quality issues and a reliable quality system +Faster feedback loops for corrections
General Quality	-Prone to quality issues before being stabilized +Can confirm required quality to customers
Intellectual Property	+Low risk of IP theft +Protects proprietary know-how
Flexibility	+Flexibility in terms of real time changes -Lower flexibility for volume changes
Traceability	+Full traceability among processes and material
Speed of Ramping Up	-Longer ramp time due to DOE and setting parameters -The need to stabilize the whole process, both up-stream and down-stream +Slower but lessons learned transfer to next block
Customization	-Can customize to customer needs -Required R&D to customize product/processes +Tailored control of solid content, viscosity, thickness
Process Control	+Full control over processes
Material	-High visibility and control over material origin and quality.
Scrap	-Great amount of scrap initially +Possibility to recycle scrap
Integration	+Easy to integrate

5.1.2 Scenario Two (Full Outsourcing)

In the second scenario that is proposed, NOVO Energy will fully outsource the whole electrode production. Here, it is assumed that no production exists in-house when it comes to the electrode manufacturing. Moreover, this scenario includes no equipment, process, or technology relating to the electrodes that are used or invested in. It is also assumed that the supply comes from a single supplier. Further, this leaves NOVO Energy fully dependent on its supplier for its production to run, where it is further assumed that a long-term contract is in place, where no disturbance is occurring to the contract itself regarding being able to supply or not. This scenario's analysis is presented in Table 5.2.

Table 5.2: Technical Evaluation For Scenario Two

Technical Factors	**Scenario 2**
Quality Control	-Lack of control -Require quality control of incoming electrodes -May require on site quality control at supplier -Slow feedback loop if problem occurs after delivery -Hard to track where the quality issue on electrodes occurred
General Quality	-Risk of inconsistency among batches +Supplier can provide high quality electrodes from beginning -Hard to predict quality on incoming electrodes -May be difficult communicating quality issues to supplier -Hard to say who is responsible for the quality problems between supplier and buyer -Quality issues happening during transport
Intellectual Property	-Risk of IP theft -Risk of losing competitive advantage with formulations
Flexibility	-Change requests in design/process require renegotiation with supplier +Supplier can easily change volume -Low flexibility in minimum order quantity since this is negotiated from start
Traceability	-Lack traceability -Supplier may not provide all information for clear traceability
Speed of Ramping Up	+Faster ramp up since supplier already have stable lines -Risk of delays in electrodes when ramping up
Customization	-Harder to get those precise, tailored process tweaks when customizing
Process Control	-Loss of process control -Not able to tweak/optimize machines at supplier
Material	-Not knowing if the material used reached requirements -Possibility of supplier changing material without communicating it
Scrap	+Less scrap initially due to not having to stabilize electrode production -Scrap from quality issues during transport, for example extensive humidity -Not able to recycle scrap in-house
Integration	-Can be harder to integrate due to possible unknown quality issues

5.1.3 Scenario Three (Gradual Vertical Integration)

In this scenario, NOVO Energy would start by initially outsourcing the electrode production during the early stages when ramping up production. The reason behind this scenario is to stabilize the downstream part of the production, which is from stacking down to the finished product, first. Once a steady cash flow is established, NOVO Energy could then invest in building its own electrode manufacturing line. By doing it this way, it is only needed to stabilize half of the processes at a time. In this scenario, it is assumed that the supplier is delivering high-quality electrodes with no major problems occurring besides common quality issues. Further, it is assumed that NOVO Energy will reach a positive cash flow after ramp-up has been made, where over time, NOVO Energy could phase out the outsourced electrodes and gradually shift to fully in-house produced electrodes. This scenario also assumes a flexible supplier that is willing to gradually lower its supply when NOVO Energy wants to shift to in-house production. In addition, it is considered to be technically feasible to shift from outsourced electrodes to in-house production. This scenario was constructed with the help of the results of the interviews since this was what a few of the participants had experienced previously from other companies within the battery industry, and was therefore considered to be a reasonable possibility for NOVO Energy as well. Some of the technical aspects affecting NOVO Energy during this scenario are shown in Table 5.3.

Table 5.3: Technical Evaluation For Scenario Three

Technical Factors	**Scenario 3**
Quality Control	-Lack of full control at first -Lack of know-how over the quality at the beginning +Outsourced suppliers likely have established quality controls and experience.
General Quality	+Faster access to consistent-quality electrodes early on. -Limited control over quality improvement. -Risk of variability between outsourced and future in-house electrodes.
Intellectual Property	-Risk of IP theft -Switching to in-house production later, may require new formulations for competitive advantage, as the first have been shared.
Flexibility	+Quicker market entry +Outsourcing allows rapid adjustments without fixed assets +Freeing up internal resources for downstream focus early on -Delayed in-house development reduces long-term agility -Slower respond to changes in electrode technologies
Traceability	-Difficulty in traceability for outsourced electrodes
Speed of Ramping Up	+Higher than pure in-house
Customization	+In-house development later allows tailored design -Customization is constrained by supplier capabilities and contracts
Process Control	+Simplifies early operations by relying on experienced suppliers -Limited control over the process initially -Slower feedback loop for process improvements
Material	+Less need to manage raw material logistics early on -Limited visibility and control over material origin and quality. -Transitioning to in-house later requires building sourcing channels from scratch.
Scrap	+Early outsourcing likely results in lower scrap rates due to supplier expertise. +Scrap management is primarily the supplier's responsibility at first. -Transition to in-house production may lead to increased scrap at first. -Less opportunity to optimize scrap reduction early on.
Integration	+Easier downstream integration early on, as outsourced electrodes have high quality from the beginning +Allows downstream teams to stabilize processes -Shifting to in-house electrodes may disrupt established downstream workflows.

5.1.4 Scenario Four (Parallel Make-and-Buy)

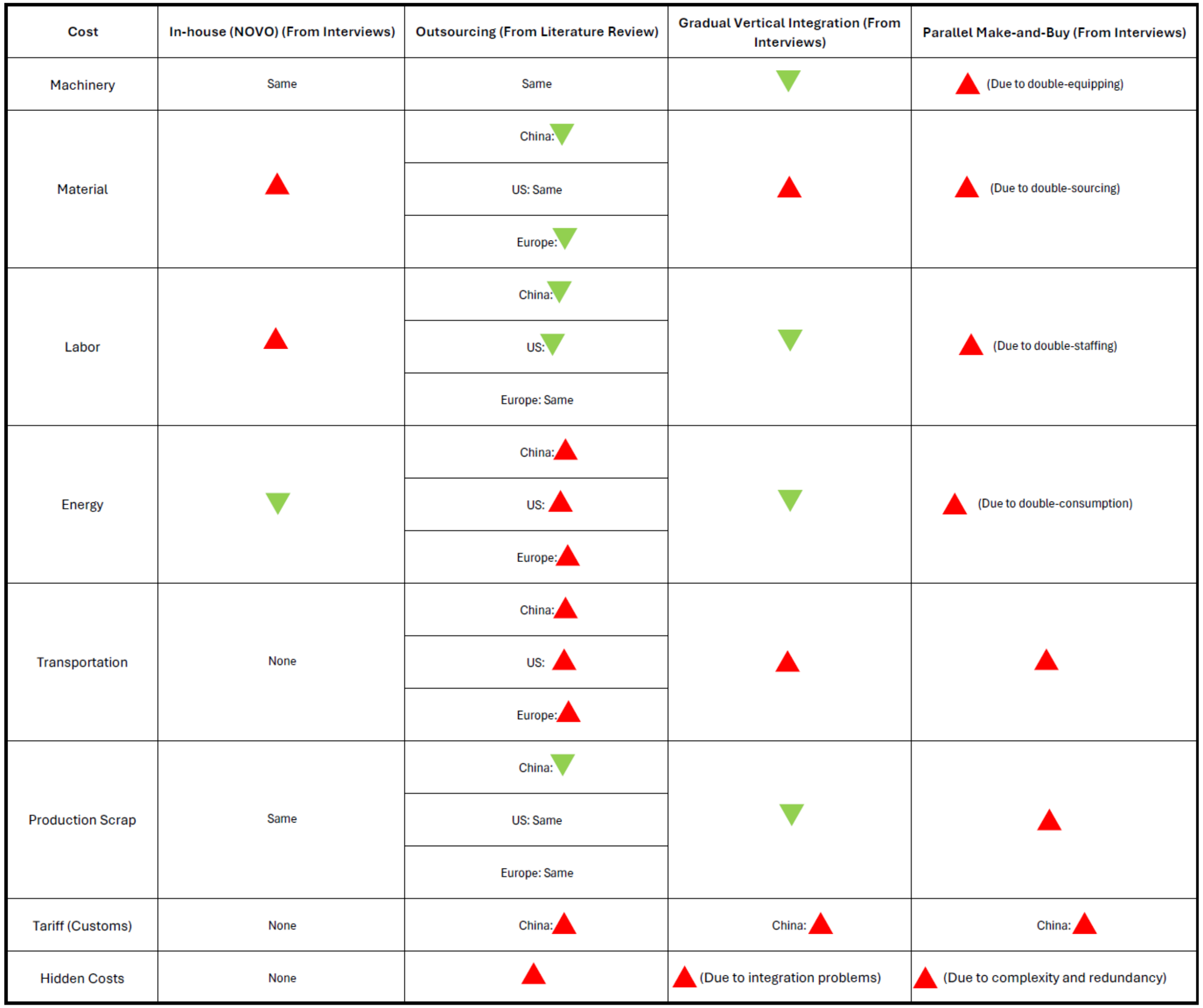
The fourth scenario, as it is seen in Table 5.4, takes things a step further by developing in-house electrode manufacturing at the same time as using outsourced electrodes. The idea behind this scenario is that together with the outsourced electrodes, stabilize the downstream process, from stacking down to the finished product. At the same time in-house line starts working in parallel to stabilize the upstream, but these electrodes are not used in the downstream until the right quality requirements have been reached. Ultimately, both upstream and downstream are being stabilized at the same time. All assumptions made for Scenario Three are also valid for Scenario Four. In addition, it is assumed that NOVO Energy has both the resources and enough space to work with two different types of electrodes simultaneously. The electrodes produced in the upstream are also assumed to be used for educational purposes and learning about quality issues.

Table 5.4: Technical Evaluation For Scenario Four

Technical Factors	**Scenario 4**
Quality Control	+Building expertise in electrode quality even during outsourcing phase -Lack of control over the outsourced electrodes
General Quality	+Direct oversight enables faster resolution of quality issues. -Initial in-house output may be less consistent due to ramp-up challenges. -Balancing two sources could lead to quality inconsistency between batches.
Intellectual Property	-Risk of IP theft
Flexibility	+Builds flexibility through dual sourcing from day one. +In-house line allows quicker adaptation to changes in materials or design. +Reduces dependence on any one supplier +Supports smoother long-term production with options to adjust the balance between outsourced and in-house electrodes. -Higher operational complexity reduces day-to-day flexibility. -Requires early commitment to in-house processes
Traceability	-Difficulty in traceability for outsourced electrodes
Speed of Ramping Up	+Higher than other scenarios, but not higher than full outsourcing
Customization	+In-house line from the start enables early design tweaks +Dual approach allows benchmarking outsourced vs. custom designs -Customization efforts may be slowed by split focus between two systems
Process Control	+Greater control over production parameters early on +Enables quicker experimentation and optimization on the in-house line -Managing two parallel systems complicates process standardization
Material	+Early in-house development allows direct control over material sourcing. +Dual paths offer flexibility if supplier issues or shortages arise. -More complex sourcing management (managing both internal and supplier).
Scrap	+In-house line allows early learning and optimization to reduce scrap over time. +Opportunity to benchmark scrap rates between in-house and supplier processes. -Initial in-house setup will produce higher scrap due to process tuning.
Integration	+Parallel streams let NOVO Energy test and stabilize upstream and downstream processes in real time. -Introducing two electrode sources may complicate downstream calibration and consistency.

5.2 Economic Evaluation

The four scenarios were also evaluated from an economic perspective to understand the most suitable solution for NOVO Energy's current situation. Economic factors are those mainly concerned with cost, resource availability, market dynamics, and policy implications. Economic factors often revolve around external variables such as global trade, government policies, and regional cost variations. In Figure 5.1, each triangle represents a key economic indicator: green triangles indicate favorable outcomes, while red triangles indicate unfavorable ones. Triangles pointing upward show higher values, while those pointing downward represent lower values.



Cost	In-house (NOVO) (From Interviews)	Outsourcing (From Literature Review)	Gradual Vertical Integration (From Interviews)	Parallel Make-and-Buy (From Interviews)
Machinery	Same	Same	▼	▲ (Due to double-equipping)
Material	▲	China: ▼ US: Same Europe: ▼	▲	▲ (Due to double-sourcing)
Labor	▲	China: ▼ US: ▼ Europe: Same	▼	▲ (Due to double-staffing)
Energy	▼	China: ▲ US: ▲ Europe: ▲	▼	▲ (Due to double-consumption)
Transportation	None	China: ▲ US: ▲ Europe: ▲	▲	▲
Production Scrap	Same	China: ▼ US: Same Europe: Same	▼	▲
Tariff (Customs)	None	China: ▲	China: ▲	China: ▲
Hidden Costs	None	▲	▲ (Due to integration problems)	▲ (Due to complexity and redundancy)

Figure 5.1: Scenarios' Economic Analysis

6

Recommendation

Based on the insights gathered during the focus group session, a phased combination of Scenario Three and Scenario Four emerges as the most balanced and pragmatic approach for the electrode manufacturing strategy. Rather than fully committing to one predefined scenario, participants emphasized the advantages of starting with Scenario Three for the initial production line, followed by a gradual transition toward Scenario Four for the lines after that.

In Scenario Three, the idea is to start by buying the electrodes from an outside supplier rather than jumping straight into producing them in-house at NOVO Energy. This gives NOVO Energy time to reach a more stable position financially before taking on the cost and complexity of electrode manufacturing. It is a practical move, especially for the first line that is going to start producing at NOVO Energy, where things are most uncertain, both technically and financially. One participant summed it up well, *"The biggest problem is Line One, I would say,"* mentioning the higher risks involved when everything is still new and untested.

When the first in-house electrode line is running smoothly and producing high-quality electrodes, the company can begin working on the other lines. This is where Scenario Four comes into play. It suggests keeping external suppliers in the mix a bit longer, even as in-house capacity ramps up. That way, new downstream processes have time to settle, and the team can focus on fine-tuning without the pressure of everything needing to work perfectly all at once. As one person explained, *"We start with the supplier first and then when Line One is ready, you switch over to Line Two,"* as it is shown in Figure 6.1. It is a smart, step-by-step approach, spread out the investment, lower the risk, and learn as they go.

Taking a hybrid approach between the two scenarios brings a range of practical and financial advantages. It keeps upfront expenses lower, provides better control over how quickly production ramps up, and gives teams space and time to adapt based on suppliers' performance and internal development. It is also important since it can help avoid common early-stage pitfalls like unexpected downtime or waste from trial-and-error. As one team member put it, *"Even if electrodes are not ready, assembly does not have to stop,"* highlighting how valuable it is to avoid relying too heavily on processes that are still being refined.

In the end, the most effective path forward is to begin with Scenario Three for sourcing the electrodes and then gradually move towards Scenario Four. This step-by-step transition supports both cost efficiency and technical stability for NOVO Energy, which are key priorities when launching a new product in a production environment.

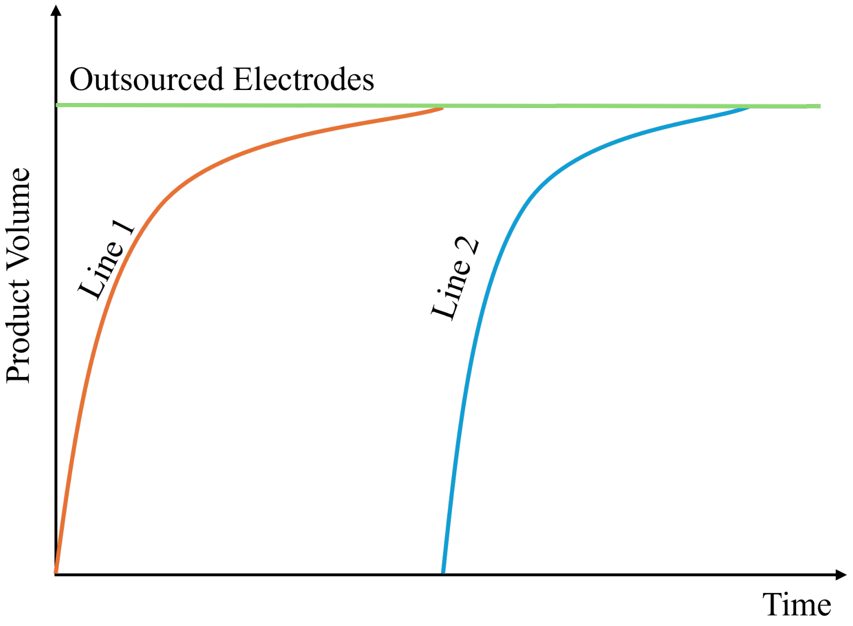


Figure 6.1: Recommended Strategy Generated During Focus Group

7

Discussion

The following thesis started by addressing the strategic question central to NOVO Energy's electrode production on whether to continue manufacturing the electrodes in-house or if outsourcing is a possible option. Moreover, we conducted an extensive review of the literature on battery production and outsourcing theory to build a solid foundation for the thesis. This information allowed us to identify the key technical and economic factors that could influence outsourcing decisions and LIB manufacturing. However, when researching we found significant gaps in the academic literature, particularly when it came to the practical examples from other companies and considerations of outsourcing LIB manufacturing.

In order to try and bridge these gaps found in the literature that were previously found, we conducted interviews with industry experts at NOVO Energy. Their insights provided a deeper understanding of the company's current state and more factors that need to be taken into account that the literature study did not cover. At first, the analysis was framed as a comparison between two distinct options: maintaining full In-house production or fully outsourcing the electrode production. However, based on the expert input, we came up with two additional, more middle-ground alternatives: Gradual Vertical Integration and Parallel Make-and-Buy.

Towards the end of the thesis, all four scenarios that were created were evaluated from both an economic and a technical perspective. The results of these analyses were reviewed and discussed with relevant stakeholders at NOVO Energy in a focus group to ensure accuracy and applicability for NOVO Energy. The whole process resulted in a well supported recommendation regarding whether NOVO Energy should maintain its current in-house strategy or consider one of the alternative scenarios that were suggested in the thesis. This information could possibly be applied to a new plant or future lines that could be established.

7.1 Answering Research Questions

RQ1: What are the key technical and economic factors influencing the decision to outsource/keep in-house the slurry mixing, electrode coating, and calendering and slitting?

The first research question covered in this thesis focuses on the technical and economic factors that influence whether the electrode manufacturing processes, including slurry mixing, coating, calendaring, and slitting, should be outsourced or be kept in-house. By using a combination of the academic research in the form of the literature study and insights from industry experts at NOVO Energy, several key technical factors have been identified. These factors include quality, IP protection, process flexibility, traceability, quality control, customization potential, ease of integration, scrap rate, raw material handling, and process control. Looking at the economic factors identified, the main drivers affecting this decision are the costs associated with machinery, materials, labor, customs, transportation, energy usage, scrap, and the hidden expenses.

RQ2: What are the economic and technical benefits/drawbacks of keeping the slurry mixture, coating, and calendering in-house or outsourcing?

When deciding whether to have slurry mixing, coating, and calendering in-house or to outsource them, there are several key factors that need to be considered. This needs to be done from both the technical and economic perspectives. Looking at the technical side, managing these processes in-house gives NOVO Energy greater control. This includes control over the important factors such as quality of the product, processes, and the protection of IP. In addition, by keeping everything in-house companies like NOVO Energy can more effectively adjust things like slurry dispersion, coating thickness, and slurry loading to ensure better consistency but also quicker feedback loops. Moreover, in-house production helps reduce risks that are commonly associated with outsourcing, such as variability in equipment tuning, lack of process transparency, and traceability of batches. It also helps avoid the potential leakage of proprietary information.

When it comes to the economic aspect, manufacturing electrodes in-house can have major long-term financial advantages. Although outsourcing could sometimes seem like a more economic beneficial in the short run, controlling manufacturing in-house gives NOVO Energy better control over costs. This includes labor, materials, energy, and transportation. In addition, it is also important to mention that outsourcing will probably increase the cost of materials because companies like NOVO Energy will be buying semi-complete products instead of raw materials. On the other hand, outsourcing may provide a faster ramp-up of production initially. However, it can also lead to possible problems where some of these problems include supply chain interruptions, increased long-term expenses, and difficulties if manufacturing must eventually be brought back in-house.

Moreover, having the production in-house improves the integration of components and reduces the complexities that can occur when transporting. Companies like NOVO Energy can reduce the dependencies on external suppliers, mitigating the risks of geopolitical disruptions, delays, or supplier failures. All of this which are more probable when outsourcing. In-house operations also improve traceability and quality control which ensures a more reliable and efficient production process. Although outsourcing may offer short-term financial relief, including less scrap and access to specialized capabilities. Long-term benefits of in-house production, particularly in terms of quality control, cost optimization, and IP protection make it a more viable choice.

7.2 Academic Contributions

This thesis contributes to academia on strategic manufacturing decisions through scenario analysis conducted for electrode production within LIB manufacturing. In this work, by analyzing four different solutions of full In-house, full Outsourcing, Gradual Vertical Integration, and Parallel Make-and-Buy, this work moved beyond the binary decision of whether to outsource or not. Instead, this thesis introduces a more flexible and dynamic understanding of manufacturing strategy in a high-tech and capital-intensive industry such as battery manufacturing.

One of the major academic contributions of this thesis is the creation of a scenario-based framework that can support decision-making under uncertain situations. Instead of treating outsourcing as a simple yes or no decision, as was done by Deavers (1997), Ishizaka et al. (2019), and Rolstadås et al. (2012), the framework allows companies to evaluate different options according to how they can progress in the future, where hybrid versions of outsourcing are looked into. By adopting this hybrid approach and thinking, employees at NOVO Energy can develop a more grounded understanding of the risks, opportunities, and trade-offs for each factor. This can be an important advantage in the battery manufacturing industry. Specifically, since being able to rapidly scale your production and technological innovation are key driver of success in this industry.

Furthermore, this thesis addresses an important gap in existing literature by focusing specifically on electrode manufacturing. Outsourcing has been discussed a lot in broader manufacturing contexts, such as IT and telecommunications (Quélin and Duhamel, 2003), manufacturers in Sweden in defense and military equipment, automotive and heavy vehicles, steel, and forestry products (Dabhilkar et al., 2009), and electronics (Tsay et al., 2018). However, relatively little attention has been given to complex areas such as the electrode production (Arora et al., 2025). By highlighting the unique operational, technical, and strategic considerations involved in the outsourcing of electrode production, the study provides valuable insights for researchers and practitioners working in the battery manufacturing field.

Another important contribution of this thesis is how it brings practical, real-world insights into the academic discussion, unlike works like Adams et al. (2006), Kim et al. (2009), and Meixell et al. (2014), which were purely based on literature. By interviewing specialists from NOVO Energy, the research adds depth to the theoretical analysis, grounding it in the realities of industry practice. These conversations helped identify the factors that actually shape outsourcing decisions, like technical risks, cost implications, and the pressure to meet tight deadlines. With the help of expert insights, the thesis keeps its focus grounded in the realities companies face, making the findings not just theoretically sound but also practically meaningful.

The thesis also takes a fresh look at outsourcing by exploring transitional and hybrid strategies like phased ramp-ups and parallel sourcing. Rather than treating outsourcing decisions as fixed events (Barney, 1991; Kim et al., 2009; McIvor, 2009; Meixell et al., 2014), the study shows that these choices can and often do evolve over time. Companies can use this flexibility to manage uncertainty and develop their own internal capabilities at the same time. By highlighting this approach, the research adds a new dimension to the academic conversation and better reflects the fast-changing challenges of today's industrial landscape.

7.3 Practical Contributions

Different findings of this thesis offer several practical contributions to the battery manufacturing field, especially electrode production. The practical applications of this research are particularly relevant to the complex decision-making involving the outsourcing of electrode production. The findings in this thesis offer NOVO Energy a comprehensive framework to understand both the technical and economic factors affecting the electrode and battery production. In addition, the thesis provides different possible scenarios for NOVO Energy, and together with the technical and economic factors influencing the different scenarios, NOVO Energy is provided with a holistic view over several possible options. However, as explained by Dabhilkar et al. (2009), the risk and motives for outsourcing depend on the situation of the company, where new triggers can result in other motives such as changed dynamics of competition or tariffs.

More specifically, NOVO Energy can use this analysis in order to develop a robust electrode production strategy when balancing the short-term advantages of outsourcing with the long-term benefits of maintaining in-house control over the production, as highlighted in the results. By further understanding the types of outsourcing strategies, such as transactional, resource seeking, and transformational, they can better understand that the motives they have for outsourcing can help them decide which production strategy to take (Hätönen, 2008). Together with the scenarios and motives, practitioners at NOVO Energy can better understand whether to outsource or keep in-house and make a more reliable decision.

Because the framework is flexible to a variety of hypothetical scenarios. NOVO Energy can use the framework to better understand its different alternatives when building additional production lines or possibly building a second factory in the future. Moreover, practitioners within the battery field can use the theory presented in the thesis, such as the RBT, which highlights the importance of valuable, rare, and difficult-to-imitate products or services (McIvor, 2009). Looking at the scenarios through this lens can give new perspectives to the scenarios. In addition, analyzing the economic factors from a TCE perspective for the scenarios can deepen the understanding of additional costs and why they occur and can come from. For example, as presented by the theory, negotiations, selecting partners, prices, and the level of engagement are all factors that could have an effect on the cost but may be hidden at first (Tsay et al., 2018). By implementing these insights early in the process when planning for new lines or factories, NOVO Energy may proactively eliminate technical risks, optimize investment, avoid hidden costs, and keep important technical skills and intellectual property internally at NOVO Energy.

Looking at the thesis in a broader context, NOVO Energy can gain a holistic perspective since the thesis offers a well-grounded approach to strategic manufacturing decisions. These include applying the established scenarios, well-known theories, and frameworks for outsourcing in battery manufacturing.

7.4 Discussion of Methods

The literature study that was conducted served as a starting point for mapping out the main technical and economic factors affecting the LIB production and outsourcing. The literature study covered the main factors and theories needed to understand how an outsourcing decision is affected, but also about how LIB manufacturing works. By building a strong foundation of theory, this could later be used when conducting the interviews, as the topics would be better understood.

The main limitation of the theory study is that there were few previous articles on outsourcing within the battery field. One of the closest related articles connected to this thesis is Arora et al. (2025), which investigated partial outsourcing in early battery production. Where the importance of assuring quality of the outsourced parts where highlighted. This results in a gap where some insights from academia could be missed. More previous articles on outsourcing within battery manufacturing could have strengthened the literature study further, since more perspectives and a better synthesis could be obtained.

Another limitation within this study is the lack of transparency in industrial practices when it comes to battery manufacturing, especially considering the competitive market of the battery sector, resulting in a lack of detailed information on other outsourcing strategies or production processes. Therefore, a lot of the information obtained about outsourcing was generalized to the academics of outsourcing and not specific to the battery field or a certain company. The same applies to researching battery manufacturing, where specific process information of producing LIBs was not collected since most companies consider this confidential, therefore, the literature study instead provided an overview of the state of are production of LIBs.

When developing our definitions of economic and technical factors in LIB manufacturing, we aimed to create a useful distinction that would help organize our analysis. We based this on a combination of literature, industry reports, and common patterns in how these challenges are typically discussed (McIvor, 2009; McKinsey, 2024; Meixell et al., 2014; US Department of Energy, 2023). Economic factors, as we define them, are mainly influenced by external conditions, things like cost, supply chains, market demand, and policy. Technical factors, on the other hand, are more tied to the engineering side of battery production, including the need to improve quality, efficiency, and scalability. We acknowledge, however, that this distinction is not always quite obvious. A technical issue like poor material can quickly become an economic problem if it raises costs or slows production. Likewise, economic pressures, such as the need to lower costs, often drive technical innovation. In other words, the same issue might be seen as economic by one stakeholder and technical by another. Our goal was not to draw a rigid line, but to offer a framework that helps highlight the different types of factors affecting the outsourcing decisions in LIB manufacturing.

The thesis interviews provided in-depth insights into how LIB is produced and which technical and economic factors have the greatest impact on it. Several experts from the electrode, assembly, and financial departments provided vital knowledge that could not be obtained from a literature study. This resulted in the discovery of additional factors to consider and also how the factors are connected. Furthermore, the interviews provided more in-depth explanations for why particular factors are significant, based on both knowledge and previous experience. The recommended number of participants to interview was approximately 24 to reach meaning saturation (Wutich et al., 2024). The sampling of the interviews was considered enough at 17 based on the saturation obtained towards the end of the last interviews, meaning that similar information was repeated among the participants. Some of the ways that the interview sampling could have been improved further are if more people from the financial department could have participated in order to get a better saturation and more insights from them, since only two people participated in the study. In addition, other departments, such as material handling, could have been interviewed because they are in charge of controlling the material flow, and they could have revealed concerns with importing the electrodes or how the incoming electrodes should be stored.

Looking at the result that was sampled, it is also important to remember that there is a chance that the answers collected could be biased. At the same time, the interview method was semi-structured to be able to address complex topics and unknown issues (Wilson, 2013). Therefore, some different topics could be brought up by different participants, ultimately highlighting different things. A significant limitation that affected the result was the confidentiality constraints from NOVO Energy, where strategic decisions and information regarding their exact production process and design could not be included in this report. The restriction affected some areas of analysis where less in-depth information could be provided to the reader. However, even if the information was not explicitly written in the report, it was still obtained by us. The material was nevertheless valuable for us to learn more about the organization. Furthermore, the information provided offered us a better understanding of NOVO Energy and how the company operates, which influenced the final outcome of the research.

We chose scenario analysis to further analyze our results because outsourcing electrode production is a highly complex situation with many elements at play. And as outlined by Balaman (2018), scenario analysis can be used when you want to take in several different factors when analyzing hypothetical future events. Further, Kosow and Gaßner (2008) mentions that scenario analysis is an effective tool to broaden perspectives and challenge conventional thinking. Therefore, this was decided to be suitable to better understand outsourcing since many factors affect it. At the same time, there is uncertainty around outsourcing, which leads us to the conclusion that creating hypothetical scenarios based on the results and literature review was the best way to evaluate the various outsourcing alternatives that NOVO Energy has. This is to get a holistic view of the topic of outsourcing, with details about the factors affecting it. To ensure that the scenarios developed were reasonable and feasible for NOVO Energy, a focus group was formed. The conversation provided validation and new insights into the scenarios, increasing their credibility. However, this discussion could also be influenced by bias when discussing whether a certain scenario is better than the other. The recommended number of participants for a focus group can be anything between 4 to 31 participants, as Al-Ababneh (2018) explained, depending on the situation. Since it was decided to go with four participants in this study, due to limitations in time but also participants, there is a possibility that better conclusions could be drawn with more participants. However, since the focus was more on confirming our analysis and not making a new one, it was still decided to be enough.

Limitations in the scenario analysis are that the scenarios are based on hypothetical scenarios, where several assumptions have been made to construct them. Therefore, they are not the truth but rather fictional. Moreover, since assumptions had to be made, a rather complex situation is simplified. Since the focus group had a duration of 30 minutes, which was within the recommended gap by Al-Ababneh (2018), there was some unequal discussion of the scenarios, where some were discussed more than others, which could possibly lead to less verification of some of the scenarios. However, it was believed that the longer discussions that were put on some of them were due to the fact that they needed to be discussed more in depth among the participants. Pointed out by Krueger and Casey (2014) focus group can help to confirm and strengthen the result, which was the main focus of this session.

While the economic evaluation provides valuable insights, it is important to recognize a few limitations that could affect the accuracy and reliability of the results. Many of the cost estimates, especially for machinery, labor, and energy, were given as ranges rather than fixed figures. At this early stage, relying on using the ranges was unavoidable because of the limited availability of precise data (McKinsey, 2024; Orangi and Strømman, 2022). Although this allowed the analysis to move forward, it also brought in uncertainty, since the actual numbers may change as more accurate data becomes available later on.

Another major limitation is that NOVO Energy has not started full-scale production yet. The cost figures that were gathered were based on forecasts, not real operating data. These predictions are helpful for initial planning, but they do not necessarily capture all the real-world expenses that come with running a facility. Because of this, the analysis is built on assumptions rather than actual outcomes, which naturally makes the findings less certain until production gets underway.

In addition, there is the issue of data scope. The focus of this thesis is on electrode manufacturing, but most of the available literature and cost data were limited to cell-level manufacturing (Lechner and Mothwurf, 2023; Orangi and Strømman, 2022; Qi et al., 2023). Since electrode-specific cost data were scarce, it was necessary to adapt the broader cell manufacturing data to fit the analysis. Based on feedback from industry experts, it was assumed that the cost structures would not be drastically different at the electrode level, but this is still an assumption that could affect the results. This simplification means the analysis might miss some of the finer details related to the cost of making electrodes.

Although these limitations do not take away from the overall value of the study, they are important to keep in mind when looking at the results. In the future, as NOVO Energy starts production or as more specific data on electrode manufacturing becomes available, it will be possible to improve these findings and get a better understanding of how realistic each scenario is from a cost perspective.

On the other hand, although the technical evaluation was based on a triangulation of methods, where several methods are used to validate the result of a case study, as explained by Bans-Akutey and Tiimub (2021), with the information initially derived from the literature study and results, and later confirmed by the focus group, it also involved some subjective judgment when creating the scenarios from the start and evaluating the technical factors. Therefore, there is a risk of it being influenced by interpretation bias, and consequently, this could have resulted in us interpreting the result and literature study differently compared to experts. Different evaluators with varying industry backgrounds might reach slightly different conclusions. Furthermore, as noted by Bans-Akutey and Tiimub (2021), no study data can be considered 100 % accurate because it is constantly subject to doubt.

7.5 Ethical, Societal and Ecological Perspectives

From an ethical perspective, it is important to highlight that outsourcing can sometimes involve producing in a low-cost country with lower wages or other regulations. As pointed out by Dai et al. (2019), North America and Europe are more costly to produce in because of their stricter regulations than in, for example, China. In general, fair wages and safe work environments are important to consider if outsourcing to a country with less regulation or work standards is an option. It is also important to make sure the country provides workers' rights to produce the electrodes. This can be especially hard to ensure if outsourcing is done, since organizations rely on an external partner and need to make sure they are following the same standards as set up by the mother company. Therefore, supply chain and production transparency are important to have knowledge about all the steps involved.

From a societal perspective, outsourcing can both come with benefits and drawbacks. For example, outsourcing can bring new jobs to the place where the companies outsource to, but it can also lead to layoffs at the original manufacturer if they outsource a section of the company. Further, looking in particular at outsourcing the electrode production, which requires highly skilled and experienced people, the original manufacturer ultimately can lose this skill in the field if it places the production in another company. This can then later result in a supplier's ability to sustain or scale its own battery production since it will have to rely on expertise from outside its region or country. Ultimately, losing the know-how of the industry. Losing critical knowledge is highlighted as a common risk for outsourcing by Shrestha (2020) and is important to consider. Moreover, moving this experience out of the EU, where there is already a lack of experience, can even further hinder the green transition with the help of the battery industry.

Looking at the ecological perspective, outsourcing can impact the environment if the production is moved to a region with less regulation on carbon footprint or recycling, which may result in higher emissions than in a country with stronger regulations and laws based on which the original manufacturer produces. This can be especially important since new regulations on the recycling of materials are becoming more important and are encouraged (Bridge and Faigen, 2022).

Furthermore, outsourcing the electrodes can impact the environment in terms of clean energy. Since Europe produces primarily with green energy, it is more environmentally friendly than producing in other countries that may utilize less clean energy. For instance, China uses coal-powered energy for LIB production, which makes reaching decarbonization efforts harder (Yang et al., 2022). As a result, outsourcing to a country with fewer laws and regulations may result in a greater overall carbon footprint for NOVO Energy, even if the final product is employed in the green transition to electric cars.

Outsourcing typically results in longer supply chains since it moves a portion of the production that was previously near to somewhere further away. This can sometimes occur on the other side of the world. Looking at outsourcing the electrodes, they must be transported to the final stages of LIB production. This causes additional transport emissions that could have been avoided if outsourcing had not occurred. Therefore, sustainable transportation options need to be considered to increase resilience and minimize the carbon footprint (Harper et al., 2019).

7.6 Future Research on Battery Manufacturing and Outsourcing

The potential for future research within battery manufacturing is great, where a lot of topics surrounding batteries are lacking in research. Furthermore, since the battery industry grows fast, some areas, such as outsourcing in general in the battery industry, remain open for additional exploration since the research has not caught up, particularly the outsourcing of electrode versus keeping it in-house.

Outsourcing research typically focuses on the supply chain implications, as well as the strategic decision of where to place the organization. In addition, when it comes to outsourcing from an economic standpoint, most of the research is covered well; there is a lack of application in the battery industry. Moreover, research on the topic of outsourcing the electrode production is almost non-existent, and here, a greater focus needs to be put on bridging the gap between the industry and academia. The reason why future research should be put into the outsourcing of electrode production is that a lot of other battery manufacturers are using this as a strategy. But since other companies want to keep their strong proposition, little information on the process and factors to consider when outsourcing the electrodes is to be found.

Future research should aim to systematically explore the technical and economic factors and the strategic dimensions of the outsourcing of LIB manufacturing. Even though the process of battery production is well-established, such as the electrode production with slurry mixing, coating, and cell assembly, there is less emphasis put on the feasibility and risks associated with outsourcing each individual step in previous research. Existing research within this field often focuses on battery design, materials, or production efficiency, but not on the strategic decision of outsourcing it.

Since battery manufacturing outsourcing research is limited, future work could borrow insights from more mature industries like the automotive industry when it comes to outsourcing, even though they share fewer similarities otherwise. This is to be able to adopt similar lessons that other industries have already learned.

To further broaden the perspective of outsourcing the electrode, greater emphasis should also be put on recycling, the environment, and the factors affecting the supply chain and logistics, since this was not in the scope of this thesis and therefore was not covered by us.

8

Conclusion

The following thesis has explored whether NOVO Energy should continue to produce the electrodes in-house or consider outsourcing as a possible alternative strategy. Further, we looked at the technical and economic factors that are affected during the outsourcing of electrode production. Due to the demand for lithium-ion batteries continuing to increase, manufacturers face pressure to scale efficiently. This, while continuing to maintain a high technical standard within the industry. Therefore, the research aimed to address this challenge by further evaluating the technical and economic factors obtained during the study.

Later in the study, four scenarios were created and analyzed in the scenario analysis. The four scenarios created were fully In-house production, fully Outsourcing, Gradual Vertical Integration, and Parallel Make-and-Buy. All four of the scenarios were based on the insights that we gathered from both the literature study and the interviews with industry experts at NOVO Energy. This allowed a holistic view of the different outsourcing options that NOVO Energy could possibly have. Further, the different scenarios were assessed with the help of the key technological and economic factors that were identified in the literature review and the results. The findings revealed that while outsourcing can offer short-term cost advantages and a faster market entry, it also introduces significant risks related to quality control and intellectual property around formulations of the slurry. Which were highlighted as important to consider. At the same time, maintaining in-house production provides greater control and integration. This is important to maintain product consistency and long-term competitiveness. Towards the later stage of the study, the value of hybrid strategies was highlighted as a possible strategy since they can help with the control over processes and cost.

In conclusion, the final recommendation of this thesis to NOVO Energy is to take a phased approach that combines aspects of both Scenario Three and Scenario Four. Resulting in the use of a hybrid strategy between the last two scenarios. Starting by sourcing the electrodes from external suppliers for the first production line to minimize risk and upfront costs until the cash flow is positive and stable. NOVO Energy can then gradually shift to using more of the in-house electrodes while continuing to rely on outsourced electrodes for future lines when the first in-house production line is operating properly. This approach helps to have a more seamless shift to entirely in-house production, giving downstream operations time to settle without worrying about interruptions or quality problems.

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A

Appendix A

Technical Interview Guide

Introduction:

Can you please introduce yourself?

Current State Questions:

Main Question:

1. How is Novo Energy planning to carry out production in the electrode manufacturing area you are working on?

Follow-up Question:

1. Are there specific bottlenecks that slow down production or affect quality?
2. What are the most critical steps in the process that impact overall efficiency and quality?

Technical Challenges in Key Processes:

Main Question:

1. What are the key technical challenges/requirements in slurry mixing, electrode coating, and calendering/slitting?

Follow-up Question:

1. What are the main technical challenges in maintaining high-quality standards while increasing production volume?

Outsourcing vs In-House Production:

Main Question:

1. If you would think about outsourcing parts of the electrode production, what are the first challenges that come to mind?

Follow-up Question:

1. What would be the biggest risk when integrating the electrodes in the production?
2. What are the technical benefits of producing the batteries in-house versus outsourcing?
3. What factors would make in-house production a more viable long-term option?
4. If outsourcing were considered, what factors would be most important in ensuring a smooth transition?
5. Does outsourcing provide access to better technology or processes that NOVO currently lacks?
6. How important is maintaining control over proprietary formulations and processes at NOVO?

7. If outsourcing could reduce costs or increase production capacity, what factors would still make in-house production preferable?

Economic Aspect:

Main Question:

1. What are the key costs/economic factors associated with maintaining and improving in-house production?

Follow-up Question:

1. Are there any cost-saving opportunities within the current production model?
2. Are there any economic issues or inefficiencies in the current production process?

Integration & Scalability of Outsourced Components:

Main Question:

1. How easily can in-house production be scaled to meet increasing demand, and do you have the capacity to handle market fluctuation?

Follow-up Question:

1. Do you think outsourcing can provide more flexibility when it comes to battery manufacturing?
2. What challenges arise in integrating outsourced components?

Quality Control & Consistency:

Main Question:

1. How does NOVO Energy ensure quality consistency in in-house production? Do we have to change the quality control process if we outsource the electrode manufacturing?
2. What are the biggest quality control challenges in outsourcing these processes?
3. How important is maintaining control over proprietary formulations and processes at NOVO?

Follow-up Question:

1. Could outsourcing lead to inconsistencies in product quality?

Ending Questions:

1. Are there any additional factors you believe are important in this analysis when considering outsourcing or not?

B

Appendix B

Economic Interview Guide

Introduction:

Can you please introduce yourself?

Economical factors:

Main Question:

1. What would you say are the main economic factors that affect the production at NOVO?
2. When thinking about outsourcing parts of the production, what are the main challenges from an economic perspective that comes to mind?

Follow up questions:

1. What is your take on pushing the investment cost for electrode production to a later stage and instead buy them? Do you think that is a more viable option?
2. What cost cutdowns are you mainly trying to do
3. Is there other options to cut down the cost, for example do you think outsourcing can cost down cost on material etc or that the same.

Cost Analysis of In-House Production

Main Question:

1. What are the major cost drivers for in-house manufacturing (e.g., labor, raw materials, equipment, maintenance)?

Follow-up Question:

2. What is the cost of electrode manufacturing stages (slurry mixing, coating and drying, calendaring, and slitting) in terms of materials and energy (cost per kWh)?
3. What are the economic benefits of producing in-house in Gothenburg?
4. What are the hidden or unexpected economic costs associated with (outsourcing) LIB manufacturing?
5. Would you say that it would be more economically beneficial to outsource some of the production

Cost Implications of Outsourcing

Main Question:

1. What economic risks/benefits do you see with outsourcing electrode production?

Ending Questions:

Are there any additional factors you believe are important in this analysis when considering outsourcing or not?