Battery Cell Offering for Mid-Market Battery Electric Vehicles

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DIVISION OF INNOVATION ENGINEERING | DEPARTMENT OF DESIGN SCIENCES
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MASTER THESIS

Battery Cell Offering for Mid-Market Battery Electric Vehicles

Demand, alternatives, and outlook for competitiveness from the perspective of a European premium battery cell producer

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LUND
UNIVERSITY

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Abstract

The rapid transformation of the automotive industry to electric vehicles is putting immense pressure on not just vehicle manufacturers (OEMs), but the entire battery electric vehicle (BEV) supply chain. This includes lithium-ion battery cells, the current state-of-the-art technology for energy storage in BEVs. The technological development within lithium-ion battery cells, which is greatly driven by the needs of vehicle OEMs, has for the past decade included developing more energy dense battery cells to cater for longer driving ranges as well as cheaper cells to enable electrification of more low-cost segments of passenger vehicles. This thesis has studied the automotive mid-market with the purpose of understanding its needs in relation to a lithium-ion battery cell and what battery chemistries that could satisfy its demand. In addition, the thesis has investigated the outlook for a European premium battery cell producer to be competitive on mid-market cells.

From interviews with industry and academic experts, combined with a literature review of relevant research, this thesis found that automotive OEMs are expected to demand a lower-cost battery cell for the mid-market in comparison to cells currently developed for premium BEVs. With the price of the cell being the most important aspect, OEMs are willing to sacrifice energy density and fast charging capabilities to reach an acceptable price level – which is expected to be around 60-80 USD/kWh on cell level by 2030.

Regarding materials and technology in the battery cell, the most promising path was identified as reducing (or eliminating) the amount of cobalt in the cathode electrode. This in combination with high recycling ambitions and a simplified, large-scale production was found as an efficient way of reaching lower costs while maintaining adequate cell performance.

Lastly, for a European premium battery cell producer to be competitive when diversifying its offering to the structurally attractive market of battery cells to mid-market BEVs, a strategic alignment with prior offering was deemed as a critical, long-term success factor. Furthermore, the thesis found that the greatest chances of reaching this will be to target the high-growth market of upper-mid passenger vehicles.

Keywords: lithium-ion battery, BEV, mid-market, low-cost battery

Sammanfattning

Det snabba skiftet inom bilindustrin mot elektiska fordon sätter stor press på inte bara biltillverkare, utan på hela försörjningskedjan för elbilar. Detta innefattar litiumjonbattericeller som är det mest moderna sättet att lagra energi i elbilar. Den tekniska utvecklingen av litiumjonceller drivs i stor utsträckning av behoven från biltillverkare. Under det senaste årtiondet har det inneburit att både celler med hög energidensitet för att tillgodose behovet av längre räckvidd samt billigare celler för att möjliggöra elektrifiering av fordon inom lågkostnadssegment har utvecklats. Denna masteruppsats har studerat mellansegmentet av bilmarknaden i syfte att förstå mellansegmentets behov i relation till litiumjonbattericeller, samt vilka typer av celler som kan uppfylla detta behov. Masteruppsatsen har även undersökt förutsättningarna för en europeisk premiumproducent av battericeller att vara konkurrenskraftig med celler för mellansegmentet.

Genom intervjuer med experter från industri och akademi, i kombination med en litteraturstudie över relevant forskning, har denna uppsats funnit att biltillverkare förväntas kräva en cell med lägre kostnad för mellansegmentet i relation till de celler som tillverkas för dagens premium-elbilar. Priset på cellen har funnits vara den viktigaste aspekten, och biltillverkare tros vara villiga att offra energidensitet och snabbladdningsmöjligheter for att nå en acceptabel prisnivå – vilket är förväntad att vara runt 60-80 USD/kWh på cellnivå vid 2030.

Angående material och teknologi i battericellen var den mest lovande identifierade vägen framåt reduktion (eller eliminering) av mängden kobolt i katodelektroden. Detta i kombination med höga ambitioner för återvinning och en förenklad, storskalig, produktion ansågs som ett effektivt sätt att minska kostnader samtidigt som tillräcklig cell-prestanda behölls.

Slutligen bedömdes marknaden för battericeller till mellansegmentet av elbilar att vara strukturellt attraktiv. För att en europeisk premium-producent ska vara konkurrenskraftig på sagda marknad, har det bedömts att en strategisk matchning med tidigare erbjudande kommer att vara en kritisk framgångsfaktor. För att uppnå detta fann denna uppsats att företaget bör ha den snabbt växande övre delen av mellansegmentet av elektrifierade personbilar som målgrupp.

Nyckelord: litiumjonbatteri, elbil, mellansegment, lågkostnadsbatteri

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Lund, May 2022

Rebecka Markensten & Oscar Bengtsson

Table of Contents

List of Acronyms & Abbreviations 11

1 Introduction 12

- 1.1 Background 12
  - 1.1.1 Automotive Electrification 12
  - 1.1.2 Northvolt 13
  - 1.1.3 Battery Electric Vehicles & The UNSDGs 13
- 1.2 Purpose 14
  - 1.2.1 Research Questions 14
- 1.3 Delimitations & Definitions 15
- 1.4 Thesis Structure 16

2 Methodology 18

- 2.1 Research Strategy 18
  - 2.1.1 Research Approach 19
  - 2.1.2 Research Methods 20
  - 2.1.3 Analysis 24
- 2.2 Research Quality 25

3 Technological Review 27

- 3.1 Lithium-ion Battery Cells 27
  - 3.1.1 Active Materials 28
  - 3.1.2 Non-active Materials 31
  - 3.1.3 Manufacturing Process 32
  - 3.1.4 Form Factors 32
  - 3.1.5 Carbon Footprint of Cell Production 34
  - 3.1.6 Performance Indicators 35
- 3.2 Beyond Lithium-ion Battery Cells 36

4 Markets & Competitive Landscape 37
  4.1 Electric Vehicle Market 37
    4.1.1 Market Development 37
    4.1.2 Passenger Vehicle Classifications 38
    4.1.3 Vehicle Market Split 39
    4.1.4 Business Models 41
  4.2 Lithium-ion Battery Cell Market 42
    4.2.1 Competitive Landscape 42
    4.2.2 Current Cathode Active Material Offering 44
    4.2.3 Cost Structure of Lithium-ion Battery Cells 44
    4.2.4 Regulations on European Lithium-ion Batteries 50
    4.2.5 Performance Indicators & Customer Preferences 50
5 Conceptual Frameworks 51
  5.1 Thematic Frameworks 51
    5.1.1 RQ 1: Customer Preferences 51
    5.1.2 RQ 2: Battery Technology Alternatives 52
  5.2 Theoretical Frameworks 52
    5.2.1 Diversification 52
    5.2.2 Porter’s Five Forces 53
    5.2.3 Porter’s Generic Strategies 54
    5.2.4 RQ 3: Outlook on Competitiveness 55
6 Analysis 57
  6.1 RQ 1: Customer Preferences 57
    6.1.1 Price 58
    6.1.2 Range 60
    6.1.3 Fast Charging 60
    6.1.4 Sustainability 60
    6.1.5 Cyclability 61
    6.1.6 The US 61
    6.1.7 Upcoming Business Models 61

6.2 RQ 2: Battery Technology Alternatives 62
  6.2.1 Cathode Active Material 62
  6.2.2 Anode Active Material 66
  6.2.3 Future Technologies 66
  6.2.4 Other Aspects 67
6.3 RQ 3: Outlook on Competitiveness 68
  6.3.1 Porter’s Five Forces 68
  6.3.2 Porter’s Generic Strategies 72
7 Discussion 74
7.1 Customer Expectations & Technological Limitations 74
7.2 Competitive Cell Offering 76
  7.2.1 Aligning Cell Chemistry with Unique Selling Points 76
  7.2.2 Potential Competitive Strategies 77
  7.2.3 Potentials & Risks of Entering the Mid-Market 78
8 Conclusions 81
8.1 Answers to RQs 81
  8.1.1 RQ 1 81
  8.1.2 RQ 2 82
  8.1.3 RQ 3 82
8.2 Implications of Thesis on The UNSDGs 83
8.3 Limitations, Validity & Reliability 83
8.4 Future Research 84
9 References 86
Appendix A Interview Guide 94
A.1 Interview Guide 94
  A.1.1 Battery Cell Market 94
  A.1.2 Battery Technology 95
  A.1.3 Cost Structure 95
  A.1.4 Battery Cell Characteristics & Customer Demand 96
Appendix B Assumptions for Market Segmentation 97

B.1 Assumptions for Figure 4.1 & 4.2 ... 97
Appendix C Results From Rating of Performance Indicators ... 99
C.1 Table of Individual Ratings ... 99
C.2 Normalization of Values ... 101
C.3 Merged Figure ... 103

List of Acronyms & Abbreviations

AAM	anode active material
BEV	battery electric vehicle
CAM	cathode active material
EV	electric vehicle
ICE	internal combustion engine
LFP	lithium iron phosphate (cathode active material)
LMO	lithium manganese oxide (cathode active material)
LNMO	lithium nickel manganese oxide (cathode active material)
NCA	nickel cobalt aluminum (cathode active material)
NMC	nickel manganese cobalt (cathode active material)
NMX	nickel manganese x (cathode active material with no cobalt)
OEM	original equipment manufacturer (here as in car manufacturer)
UNSDGs	United Nations Sustainable Development Goals

1 Introduction

The following section aims to provide an understanding of the thesis and Northvolt as a company. Furthermore, the purpose of the thesis, research questions and delimitations will be introduced.

1.1 Background

1.1.1 Automotive Electrification

The ongoing transformation of the automotive industry from *internal combustion engines*, ICEs, to *electric vehicles*, EVs, is taking place at unprecedented speed. Due to regulatory adjustments, changes in consumer behavior and technological advancements, passenger EV adoption reached a tipping point in the second half of 2020 where sales and market penetration accelerated despite the economic effects of Covid-19 (McKinsey & Company, 2021). This development is forecasted to continue and by 2030 it is estimated that 150 million EVs will be on the road globally (Tidblad et. al., 2021).

In addition to affecting vehicle manufacturers, or *original equipment manufacturers* (OEMs), this transformation puts immense pressure on the entire supply chain and especially the production of lithium-ion battery cells, which is one of the most expensive and important components of the EVs. An industry which previously only existed in Asia is now expanding globally and, in Europe alone, announced battery cell production will increase 20-fold to 2030 compared to 2020 levels (McKinsey & Company, 2021).

90-95% of the demand for lithium-ion battery cells is expected to come from the automotive industry by 2030. Due to this dominating share, the technological development of lithium-ion battery cells over the last decade has primarily been driven the demands of automotive OEMs and EV end-users. This has entailed, among other aspects, higher energy densities to allow for longer driving ranges (Tidblad et. al., 2021).

However, automotive OEMs are not only demanding more high-performing lithium-ion battery cells, but they are also demanding cheaper battery cells to cater for all kinds of EVs (Boston Consulting Group, 2018). While the high-end premium

EVs are likely to demand the forefront of technological advancements, the question is raised regarding what kind of lithium-ion battery cell that will satisfy the demand of the mid-segment of the automotive industry. From the perspective of an existing European battery cell producer, it is crucial to fully understand the future dynamics of the automotive industry and how it relates to battery cell characteristics to enable strategic decision-making. It is this topic that this degree project is aimed at targeting.

1.1.2 Northvolt

The degree project was carried out in collaboration with the company Northvolt AB, headquartered in Stockholm. Northvolt is a Swedish producer of environmentally friendly battery cells to be supplied for use in different applications in various industries – there among, the automotive industry.

Northvolt was founded in 2016 by former Tesla employees Peter Carlsson and Paolo Cerruti. The mission of Northvolt was, and is still today, to enable the transition to a decarbonized society and industry by producing the greenest battery on earth. I.e., producing with a minimal carbon footprint and setting the highest ambitions for recycling. Besides headquarters in Stockholm, the company possesses R&D facilities in Västerås, main production facility in Skellefteå and additional assembly facility in Gdansk in Poland. Further, facilities in Borlänge and northern Germany, as well as a joint venture factory with Volvo in Gothenburg, have been announced (Northvolt, n.d.a; Northvolt, n.d.b).

More concretely, Northvolt produces lithium-ion battery cells. These battery cells are to be supplied to the automotive market, energy storage solutions, industrial and portable applications. However, a vast majority of current demand of battery cells lies in the automotive industry and it is hence a key customer segment for Northvolt. Among current automotive partners are Volkswagen, BMW, Volvo, and Scania (Northvolt Chronicles, n.d.b).

As a European producer of sustainable battery cells, Northvolt has focused on supplying the premium automotive market with state-of-art, high-performance cells. However, as the market for *battery electric vehicles* (BEVs) grows, new market opportunities are developing. One potential new market on the rise is the BEV mid-market, and to capture the full value potential of the automotive electrification, offerings suitable for the mid-market are required.

1.1.3 Battery Electric Vehicles & The UNSDGs

Besides the fact that electrification of the automotive mid-market creates new business opportunities, transportation is a crucial part of reaching the *United Nations Sustainable Development Goals*, UNSDGs. This thesis mainly relates to goals connected to carbon footprint, recycling, and sustainable production. I.e., the goals 11 – Sustainable Cities and Communities, 12 – Responsible Consumption and Production, and 13 – Climate Action (United Nations, n.d.a).

Almost 25% of the greenhouse gas emissions derived from energy usage stems from transportation (United Nations, n.d.b). Additionally, the biggest contributor within the sector is road passenger vehicles (United Nations, 2021). The United Nations (2018) states that transportation should be powered by clean and renewable energy – which is not fulfilled today. Hence, sustainable electrification of the passenger vehicles is of utmost importance.

However, there are some concerns regarding the sustainability of EV battery production. Especially, that the current lithium-ion batteries contain raw materials related to substantial environmental impact, such as nickel, copper and aluminum (Abdelbaky et. al., 2020).

Another fundamental aspect relating to green batteries and the raw materials is recycling. During 2019, total electronic and electrical waste amounted to 56.3 million tons. This correlates to approximately 7.3 kg of electronic waste per person. Furthermore, out of the 7.3 kg per person, only 1.7 kg are known to have been disposed of sustainably (United Nations, n.d.c). In 2030 and 2040, Abdelbaky et. al. (2020) forecasts that 120 thousand and 1.8 million EV batteries will become waste in EU respectively – and thereby need functioning recycling.

1.2 Purpose

The aim of the thesis is to gain a thorough understanding of the characteristics of the European BEV mid-market in the later part of this decade, and especially how this relates to demand of lithium-ion battery cells. More specifically, this entails (1) understanding of what the vehicle manufacturers value and demand from lithium-ion battery cells for mid-market battery electric vehicles, and (2) what potential battery chemistries and technologies, available and under development, that may satisfy stated demand. In addition, the thesis aims to investigate the outlook for a European premium battery producer, such as Northvolt, to be competitive on lithium-ion battery cells targeting mid-market BEVs.

1.2.1 Research Questions

The purpose can be synthesized into three main research questions (RQs), stated in Table 1.1 below.

Table. 1.1. Research Questions

RQ 1	What are the customer expectations on performance, sustainability (environmental and social), and price of battery cells for the BEV mid-market?
RQ 2	What are potential alternatives of materials and technology in a battery cell satisfying the demand of a mid-market BEV?
RQ 3	What is the outlook for a European premium battery cell producer to be competitive on the BEV mid-market?

1.3 Delimitations & Definitions

Several restrains are identified to limit the scope of the RQs. First, the automotive market in scope is mainly Europe, and secondarily the US. The timeframe is set to 2025 to 2030. Furthermore, the market in scope is solely battery electric passenger vehicles, which is defined as light-duty vehicles excluding vans, vehicles designed to carry cargo as well as two- or three-wheelers.

Throughout this thesis, the terms *mid BEV market*, *mid-market* or *mid-segment* are recurring. The terms are synonymous and are defined as the middle segment when the passenger BEV market is split into three categories – the other two being *low* and *premium*. The terms relate to the European market if not further specified. A more specific definition of what BEVs that are included in low, mid, and premium are presented in Chapter 4. However, common characteristics for the segments include:

- **Low**: Low-cost, small cars
- **Mid**: High-volume, medium sized cars
- **Premium**: Exclusive, expensive large cars

It should be noted that due to a lack of a unified standardization in the classification of passenger vehicles, it is difficult to conduct an exact segmentation and it will be subject to some assumptions and interpretations. Additionally, lacking standardization implicate that there generally exists inconsistencies in the information to be found on passenger vehicles between different sources. It has been impossible to completely avoid these inconsistencies, however, the authors have done their utmost to only include trustworthy data that is relevant and useful to fulfil the purpose of the research.

This thesis will attempt to answer the RQs from the perspective of a *European premium battery cell producer*. More specifically, this entails a firm which produces lithium-ion battery cells and has its factory based in Europe. The company is assumed to currently produce NMC-based battery cells (to be further explained) with sustainability as main differentiator. Being a sustainable European-based player, the firm highly values European-based supply chains. Further, the producer currently targets the premium-end of the BEV market.

Furthermore, throughout the thesis the term *customer* refers to the direct customer of a battery producer, i.e. OEMs, whereas *end customer* refers to consumers utilizing the BEVs.

Additionally, the authors of this thesis have experienced that the terms of *cost* and *price* regarding battery cells and packs are used somewhat interchangeably in literature and in the industry. The obvious difference between the two is that price includes a profit margin and is the value given to the customer, while cost excludes profit and is hence of more relevance to the producing company. Therefore, in this thesis regarding battery cells and packs, the term price has been used in the perspective of OEMs, and cost has been used in the perspective of a battery cell producer. However, the reader should note that since the values of cost and price brought up in this thesis often are presented as intervals rather than an exact value, the profit difference often becomes insignificant.

1.4 Thesis Structure

Chapter 2 – Methodology

The following chapter describes the chosen research methodology based on the scope and aim of the project. An overview of the process and relevant approach and methods are presented.

Chapter 3 – Technological Review

The following chapter describes the fundamental elements of a lithium-ion battery cell – both in terms of materials used, production process, and the impact of different battery shapes.

Chapter 4 – Markets and Competitive Landscape

The following chapter provides a background to the EV and BEV markets, as well as the competitive landscape of battery cell manufacturers. Lastly, market development of CAM and risks in the supply chain are described.

Chapter 5 – Conceptual Frameworks

The following chapter provides a thorough background of the frameworks used to structure the gathered information and conduct the analysis.

Chapter 6 – Analysis

The following chapter addresses the main results from the conducted interviews. Additionally, the results are related to existing literature presented in prior chapters.

The analysis follows the structure of the previously presented conceptual frameworks.

Chapter 7 – Discussion

The following section will provide a further discussion of the results and insights presented in the analysis. First, the match between customer expectations and technological alternatives are discussed, followed by importance and possibilities of strategic alignment. Lastly, risks and possibilities of entering the mid-market are examined.

Chapter 8 – Conclusions

The following chapter will present a final answer to each of the RQs, in addition to suggestions for future research and limitations on the conducted study.

Chapter 9 – References

Appendix A – Interview Guide

This appendix contains the most frequently asked questions during the semi-structured interviews, categorized into subjects.

Appendix B – Assumptions for Market Segmentation

This appendix contains an explanation of the assumptions made to create the segments low, mid, and premium used in the projections based on the data from IHS Markit.

Appendix C – Results from Rating of Performance Indicators

This appendix contains an in-depth presentation of interviewees' ratings on the various performance indicators discussed throughout the thesis. The individual responses are provided, as well as the method used to compare and normalize the values.

2 Methodology

The following chapter describes the chosen research methodology based on the scope and aim of the project. An overview of the process and relevant approach and methods are presented.

2.1 Research Strategy

To conduct research that will be able to answer the stated thesis questions, it is essential that an appropriate *research strategy* is chosen. A research strategy includes a thorough, structured plan of action of how to approach the research in order to achieve the objectives. Additionally, the strategy includes details regarding what research methods to be utilized in order to retrieve appropriate information (Denscombe, 2010). The overall process of this research project can be observed in Figure 2.1.

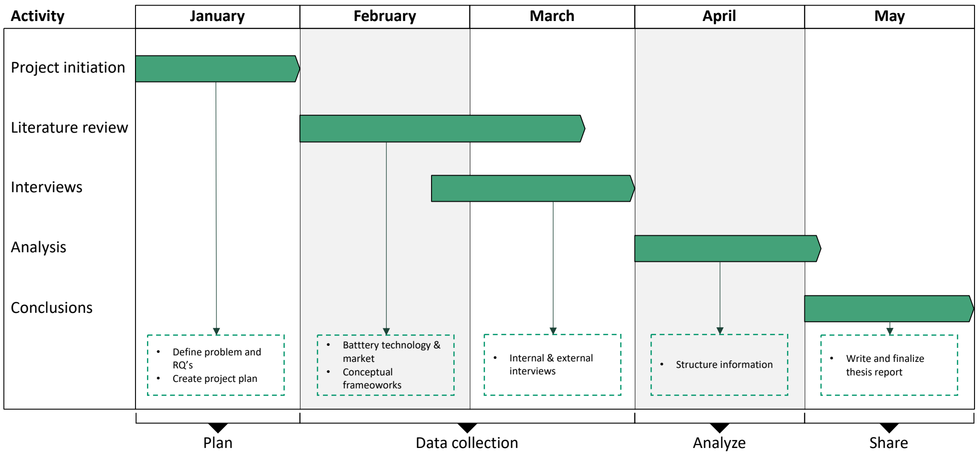


Figure 2.1. Research process for this project.

2.1.1 Research Approach

The *research approach* (also *research design* in some literature) provides the directions of how to accomplish the research. There are many different approaches available to study business problems and it is common to combine several approaches in a single research project. However, approaches should be chosen based on how efficiently it provides relevant information to the RQs, which in turn should be derived from what type of data is available (Hair, Page, Brunsveld, 2020).

Data can generally be divided into two categories: quantitative and qualitative. Quantitative data is information where numerical values are used to directly describe the characteristics of something. This provides objectivity and the direct possibility to conduct statistical analysis. Qualitative data, on the other hand, refers to information in an unstructured format, such as textual or visual contents. In contrast to the quantitative data, qualitative data require interpretation and there is a need to resolve ambiguity to retain trustworthy information (Hair, Page & Brunsveld, 2020).

As this thesis aimed to provide a better understanding of the dynamics of a future market, there was general a scarcity of quantitative data to access and the project has therefore relied heavily on qualitative data. However, there are some aspects and areas of the research which have contained a greater mixture of qualitative and quantitative data – e.g., when mapping OEM demand. The research approach for this project has been a combination between *descriptive research* and *exploratory research*.

The descriptive research approach aims to, as the name reveals, describe situations, behaviors, themes and relationships using collected data (Hair, Page & Brunsveld, 2020; Aytan, 2022). For this project, the descriptive research approach was applied when performing the initial data collection of reviewing existing literature to gain a theoretical foundation ahead of the exploratory study.

An exploratory research approach is most frequently used when there is little existing knowledge about the research objectives and is tightly linked with the use of qualitative data. Its aim is not to test a predetermined hypothesis, rather to discover new relationships, patterns, themes, or ideas. This approach is particularly useful in highly innovative industries (Hair, Page & Brunsveld, 2020) – fitting for the rapidly evolving battery industry. The exploratory research design has been the main approach used to answer the stated RQs for this project. More specifically, the approach was utilized through a literature review and interviews.

Since the RQs were answered mainly using the exploratory research approach, and the data collection combined secondary data from literature and primary, empirical data from interviews, the logical reasoning to form conclusions has followed the *abductive approach*. This approach is an alternative to the more conventional *deductive* or *inductive* approaches, and it allows for swift use of both existing theory and empirical data when investigating RQs. Specifically, it allows for turning to new literature to understand findings from empirical data (Blomkvist & Hallin, 2015).

2.1.2 Research Methods

2.1.2.1 Data Collection

Throughout the research, the data collection methods consisted of both a literature review as well as interviews with industry and technology experts. Data gathered from the literature review and interviews with experts were classified as external, whereas interviews with experts within Northvolt were categorized as internal information.

The complete process of the data collection can be viewed in Figure 2.2. As can be observed, the process was not linear, instead it followed an abductive approach of including iterations between the literature review and interviews. The reason why this was deemed necessary was two-fold. Firstly, the amount of existing research on lithium-ion batteries and EVs is simply immense. To exemplify, searches for “li-ion battery” and “battery electric vehicle” result in over 50,000 results each on LUBSearch – only including publications from 2018 and onwards. Even a more specific search as “low cost automotive li-ion battery” results in over 150 publications. The amount of research that has been done in these fields is simply overwhelming for a research project lasting 20 weeks in total. Therefore, having expert interviews highlighting specific aspects that they assess as especially critical for the RQs of this project, allows for a more targeted and manageable literature review. Secondly, the RQs of this thesis are quite broad and span across several areas – from customer preferences and competitive strategies to different battery chemistry alternatives and cost structures. This broad approach also benefits from an iterative process between expert interviews and targeted literature review.

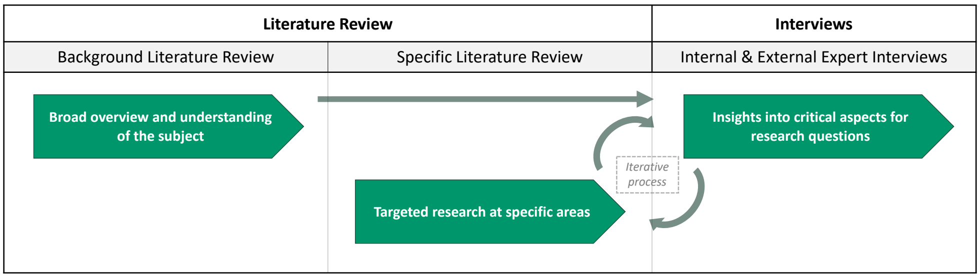


Figure 2.2: Overview of the data collection process.

2.1.2.1.1 Literature Review

To provide a foundation in the beginning of a research project, a literature review is suitable (Denscombe, 2010). The literature review method was selected to conduct the descriptive research and to complement interviews for the exploratory study. The main areas of interest when conducting the literature study were the technology of lithium-ion batteries, the market characteristics of the automotive battery market, as well as relevant conceptual frameworks. When gathering information, the primary databases used were LUBSearch and Google Scholar. For complementary information required for the RQs, the following sources were used: IHS Markit (market data), EV Database (BEV price data), Statista (market data and raw material prices) and consultancy reports (market insights).

As mentioned, and presented in Figure 2.2, the literature review was divided into two parts. The first, named “Background Literature Review”, was conducted early in the project. The aim of this phase was to acquire a broad understanding of the theory behind the RQs as well as preparing for and creating relevant and accurate interview guides. For this part, the following keywords were included: “li-ion battery cells”, “battery electric vehicles”, “automotive battery cells”. Generally, in this initial phase the authors aimed to find review articles and books which provide comprehensive and understandable overviews, such as Schmuch et. al. (2018) and Berg (2015).

The second part of the literature review is referred to in Figure 2.2 as “Specific Literature Review” and was aimed at more in-depth understanding of aspects especially important for the RQs. This phase was part of the iterative process between reviewing existing literature and interviewing experts within the industry. Getting insights from interviews and applying those to the literature review was key to ensure an efficient gathering of theory in the ocean of publications available. More specifically, when several interviewees highlighted important aspects that had not been covered by the initial data gathering, targeted search for those specific keywords were done in the databases mentioned above. To exemplify, this has included keywords such as: “sodium-ion battery cells”, “low cobalt cathode material”, “raw material cost li-ion battery cell”.

When reviewing literature related to BEVs and battery cell technology, in both phases of the literature review, the authors aimed to include as recent research as possible. This meant that preferred publications were published in 2019 or later. This was not the case for all reference literature, however, when literature was older a thorough evaluation of the accuracy of the source was done.

Furthermore, it should again be noted that due to the vast number of published articles on the subject, a complete and exhaustive literature review was impossible for the scope of this thesis. However, the authors have done their utmost in ensuring that the gathered literature is as exhaustive as possible for the purpose of this thesis.

In Table 2.1 below, the most frequently cited articles in the literature review are presented, cited three or more times. Observe that the literature review covered more publications, which can be found in the reference list, Chapter 9.

Table 2.1. List of publications most frequently cited in the literature review.

Authors (year)	***Title***
Armand et. al. (2020)	Lithium-ion batteries – Current state of the art and anticipated developments
Berg (2015)	Batteries for Electric Vehicles
BloombergNEF (2021a)	Battery Pack Prices Fall to an Average of USD132/kWh, But Rising Commodity Prices Start to Bite.
Castelvecchi (2021)	Electric cars and batteries: how will the world produce enough?
Duffner et. al. (2021)	Large-scale automotive battery cell manufacturing: Analyzing strategic and operational effects on manufacturing costs.
Huang & Qian (2021)	Consumer adoption of electric vehicles in alternative business models
Liu et. al. (2021)	Current and future lithium-ion battery manufacturing
McKinsey & Company (2021)	Why the automotive future is electric
Miao et. al. (2019)	Current Li-Ion Battery Technologies in Electric Vehicles and Opportunities for Advancements
Porter (1985)	Competitive Advantage: Creating and Sustaining Superior Performance
Schmuch et. al. (2018)	Performance and cost of materials for lithium-based rechargeable automotive batteries
Tidblad et.al. (2021)	Future Material Developments for Electric Vehicle Battery Cells Answering Growing Demands from an End-User Perspective
Tyler-Dudley et. al. (2021)	CATL: China's Battery King
Xu et. al. (2020)	Future material demand for automotive lithium-based batteries
Zhao et. al. (2022)	Cobalt-Free Cathode Materials: Families and their Prospects.

2.1.2.1.2 Interviews

To gain in-depth knowledge and insights to the defined RQs, interviews were held with industry experts, both internally at Northvolt and with external sources.

When conducting the interviews, a combination of the semi-structured and unstructured approach was utilized. This method entailed having a clear list of topics to discuss with each interviewee, while simultaneously prioritizing getting in-depth information from the expert's own ideas and associations with less defined boundaries (Denscombe, 2010).

Since the RQs of this thesis span across different areas, not all interviewees contributed to all areas. Instead, the interviewees contributed to the RQs within their area of knowledge. The methodology of semi- and unstructured interviews allowed interviews to be adapted depending on the desired outcome and specific RQs in focus. Appendix A entails a generic interview guide with the most frequently asked question within different categories.

Table 2.2 and 2.3 provide a list of internal and external experts that were interviewed throughout the project. It should be noted that to gather information related to the RQs, especially RQ 1, other approaches may appear more intuitive. For example, interviewing mainly the customers of Northvolt. As seen in the list of interviewees below, there are very few customer representatives included. This is due to a difficulty of reaching and gaining access to such people within the timeframe of this study. Hence, internal Northvolt employees with close customer relations, and other industry experts have been interviewed instead.

Table 2.2. List of interviewees internally at Northvolt.

Name	***Title***	***Areas of contribution in thesis (shaded)***		
		RQ 1	*RQ 2*	*RQ 3*
Andreas Westerberg	Director of Commercial	▨	▨	▨
Artiom LaMadrid	Key Account Manager	▨	▨	▨
Caroline Vernet	Strategy Manager	▨	▨	▨
Erika Gyllström	Director of Sustainability	▨	▨	▨
Hampus Ahlqvist	Key Account Manager	▨		▨
Hwamyung Jang	Advanced Materials Manager		▨	▨
Jan Kaiser	Key Account Manager	▨		▨
Joakim Beckvid Trachell	Cost Engineer	▨	▨	▨
Megan Wilson	Purchasing Analyst	▨	▨	▨

Mirko Stadel	Senior Cost Engineer	▨	▨	▨
Peter Olofsson	Program Manager	▨		▨
Sara Elfsson	Senior Director Sales & Business Development	▨		▨
Sebastian Roth	Strategic Project Manager Blueprint	▨		
Stephanie Schenk	Strategy Manager	▨	▨	▨

Table 2.3. List of interviewees from external organizations.

Name	*Title*	***Areas of contribution in thesis (shaded)***		
		RQ 1	*RQ 2*	*RQ 3*
Anders Nordelöf	PhD, Environmental Systems Analysis, Chalmers University of Technology	▨	▨	▨
Anders Wihlborg	Procurement Director HV Batteries, Volvo Cars	▨		▨
Daniel Brandell	Professor in Materials Chemistry, Uppsala University	▨	▨	▨
Erik Naessén	Former Volkswagen Employee, EV Educator	▨		▨
Espen Hauge	President, AVERE (European Association for Electromobility)	▨		▨

2.1.3 Analysis

When conducting qualitative data analysis, a potential method is the thematic analysis approach. The method entails the creation of several categories or themes, into which the collected data will be sorted (Blomkvist & Hallin, 2015). The thematic method was mainly used in the project, and as an alternative that Blomkvist & Hallin (2015) suggests, themes were found through the review of existing literature on the subject.

The process of analyzing the data was made through the steps explained by Höst (2006): data collection, coding, grouping and conclusions. The data gathering consisted principally of transcriptions from conducted interviews, and the coded data from these transcriptions were then grouped into the correct category.

It should be noted that the results from the interviews are presented continuously throughout the analysis.

2.1.3.1 RQ 1: Customer Preferences

For the first RQ, regarding battery performance and price, a mixture of quantitative and qualitative analysis was used. The quantitative parts consisted of interviewees with knowledge of car manufacturers rating the importance of various performance metrics, in addition to gathering data from prior studies on the forecasted cost development on batteries. Although, as the sample size for these studies were relatively small, the analysis will contain very limited statistical assessment.

However, the main approach to answering the first RQ was a qualitative thematic approach. The themes were decided based on the existing knowledge in the field acquired through the literature review. The thematic framework in question will be further presented in Chapter 5.

2.1.3.2 RQ 2: Battery Technology Alternatives

For the second RQ, relating to potential battery technologies satisfying the demand of mid-market battery cells, the analysis has been purely qualitative. In similarity with RQ 1, a simple framework of the relevant categories was created though assessing the current literature. This will also be presented in Chapter 5.

2.1.3.3 RQ 3: Outlook on Competitiveness

Lastly, for the third RQ regarding outlook on competitiveness, the thematic analysis is based on a few theoretical frameworks related to the area. On a high level, Porter's Three Tests for diversification are used to structure the analysis. This framework is accompanied by two supportive frameworks in Porter's Five Forces and Porter's Generic Strategies. Hence, the themes used for RQ 3 are derived from these theoretical frameworks. The logic and reasoning for these frameworks are presented in detail in Chapter 5.

2.2 Research Quality

For all research to obtain a certain quality, *validity* and *reliability* are crucial features. Validity refers to the truthfulness and accurateness of the findings, whereas reliability rather refers to the repeatability of the study (Brink, 1993; Brink, 1991) and ensuring correctly recorded information (Brink, 1991). According to Brink (1993), key risks of research errors related to validity and reliability exist connected to the researcher, the interviewees, the social context, and the data collection.

In this thesis, the validity was ensured through triangulation of both external experts, internal interviewees, and published literature. The importance of triangulation is expressed by both Brink (1993) and Brink (1991). The recording of accurate information, part of the reliability, was ensured through using multiple methods of gathering information simultaneously. During the interviews, the responses were both transcribed in notes and recorded as suggested by Brink (1991).

It should be noted that recording of the interviews were only conducted with the respondent's prior permission and used strictly by the authors for the purpose of transcription.

3 Technological Review

The following chapter describes the fundamental elements of a lithium-ion battery cell – both in terms of materials used, production process, and the impact of different battery shapes.

3.1 Lithium-ion Battery Cells

The current state-of-art technology for EV batteries is the lithium-ion battery (Duffner et. al., 2021). The first lithium-ion battery cell was created in the 1970s and made its commercial introduction in the 1990s – the discovery was awarded with the Nobel Prize in Chemistry in 2019 (Berg, 2015; The Royal Swedish Academy of Sciences, 2019). As with other electrochemical cells, the main components of a lithium-ion battery cell are *electrodes*, *electrolyte*, *separator,* and *current collectors*. Further, the electrodes constitute of a positive *cathode* and a negative *anode* (Berg, 2015), see Figure 3.1 below.

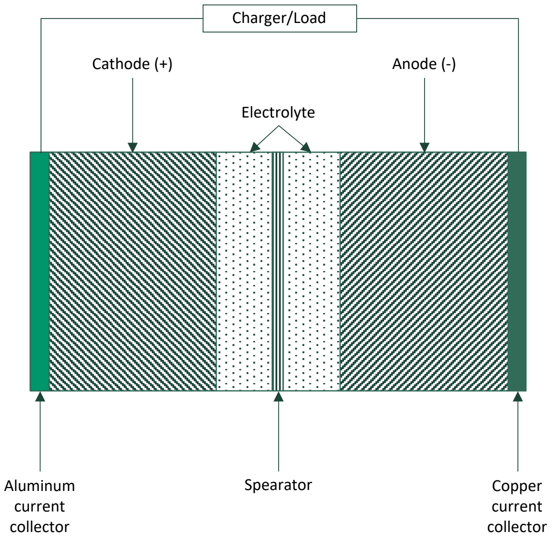


Figure 3.1. Schematic image of a lithium-ion battery components (adopted from Zhang et. al. (2018)).

As the name suggests, the lithium-ions play an essential role in the electrochemistry of the battery cell. When the cell is charged, lithium atoms are stored on the anode side of the cell. During a discharge cycle, electrons are separated from the lithium atoms and travel through an external circuit to the cathode. The newly formed lithium-ions wander through the electrolyte, through the separator, and are unified with its electrons on the cathode side to maintain the charge balance. Charging the battery cell will reverse the discharge process and transfer the lithium back to the anode (Berg, 2015; University of Washington, n.d.).

The different components and materials in the battery cell can be divided into *active material* and *non-active material*. The active materials are the materials taking part in the chemical reactions of converting electrical energy to chemical energy and vice versa. Conversely, the non-active materials are not part of the main chemical reactions (Berg, 2015).

3.1.1 Active Materials

The active materials of a battery cell are gathered in the two electrodes: the cathode and the anode. The nature of these active materials is what many of the performance characteristics of the battery cell – such as cell voltage, capacity, and energy – depend on (Berg, 2015). Especially important is the active material on the cathode side since it is the most cost driving component of the battery cell and the main bottleneck for cell performance (Duffner et. al., 2021).

3.1.1.1 Cathode Active Material

There is a large variety of *cathode active material* (CAM) that have been developed and there exists no ideal material that meets all requirements. The different CAMs can be divided into two main categories: oxides and polyanionics (Berg, 2015).

Early oxides used as CAM were LCO ($LiCoO_2$) and LNO ($LiNiO_2$). Together with *lithium manganese oxide*, LMO ($LiMnO_2/Li_2Mn_2O_4$), these oxides are similar but use different *transition metals* in cobalt, nickel and manganese (Nitta et. al., 2015). However, due to instabilities and other performance issues, these single transition metal-oxides were further improved by combining transition metals to form the active materials of *nickel cobalt aluminum*, NCA, and *nickel manganese cobalt*, NMC (also NCM), which are currently the most widely used CAM in automotive battery cells (Berg, 2015; Schmuch et. al., 2018). Both these oxides contain lithium, nickel, and cobalt, but NCA contain aluminium, and NMC contain manganese. Relatively to other CAM, NCA and NMC have high electrode potential, which mean high cell voltage and high energy density, and are therefore CAMs linked with high performing EVs (Berg, 2015).

The metals of nickel, cobalt and manganese used in NMC have different properties and affect the performance of the battery cell in different ways. More specifically, increasing the amount of nickel is equivalent to increasing the specific capacity of the material which increases the *energy density* of the cell (potential energy to be stored per volumetric or gravimetric unit). For cobalt and manganese, their typical properties are contributing to better electric conductivity and structural stability, respectively (Schmuch et. al., 2018; Voronina et. al., 2020). This has led the industry to widely follow the strategy of maximizing the amount of nickel in the NMC-blend to get the most energy from the cell. Commonly, the proportions of nickel, manganese and cobalt are notated by the numbers following NMC – NMC-111 contains equal parts of nickel, manganese and cobalt, while NMC-811 contains eight parts nickel to manganese and cobalt (Schmuch et. al., 2018).

A polyanionic CAM which is widely used is *lithium iron phosphate*, LFP ($LiFePO_4$). LFP contains lithium, iron and phosphate and is a lower-cost alternative to NMC and NCA. Besides cost benefits, it also provides greater thermal safety and avoids nickel- and cobalt-related supply chain issues (Berg, 2015; Sripad et. al., 2021).

The cathode of a lithium-ion battery cell can also be constructed by combining two or several active materials. This can be of specific interest for EV manufacturers who want to achieve specific performance requirements (Berg, 2015). LMO is commonly used as a blend-material – LMO-NMC battery cells have been used in EVs such as Nissan Leaf, Chevy Volt and BMW i3 (Miao et. al., 2019; Schmuch et. al., 2018).

3.1.1.1.1 Future Development

Tidblad et. al. (2021) identifies two paths of future development for high energy density-CAM that satisfies the demands from the end-consumer: Ni-rich and Li-rich oxides. Ni-rich oxides are based on the NMC-technology described above and NMC-811 is mainly considered as the potential candidate for future generation of Ni-rich battery cells. Li-rich oxides have the structure $Li_{1+x}TM_{1-x}O_2$, where TM stands for transition metals (Ni, Co, Mn etc.), and contains a greater amount of lithium than the Ni-rich cathodes. In these paths for future development, Tidblad et. al. (2021) especially points to cobalt-free (Co-free) solutions as being especially promising.

Removing cobalt from the cathode is also highlighted by Schmuch et. al. (2018). They state that, regarding low-cost development, creating Co-free CAM is being discussed as a potential path, which would also be a more environmentally friendly option. The main reason these CAMs can reach lower cost levels is due to the reduction or elimination of cobalt, as it is the most expensive raw material in the cell (Schmuch et. al., 2018). Many of the low-cobalt CAMs also increase the levels of manganese compared to high-nickel NMC, which is a substantially cheaper metal than cobalt and nickel (see Table 4.3) (Zhao et. al., 2022). Fichtner (2022) describes that the current options of CAM that are Co-free are LFP, LMO, LNMO *(lithium nickel manganese oxide*) and NMX (*nickel manganese x*). The lastly mentioned is a

CAM developed by Chinese company SVOLT and contains 75% nickel and 25% manganese (SVOLT, 2021).

Further, Zhao et. al. (2022) have reviewed different alternatives of future development of Co-free cathode materials. Zhao et. al. disregard LFP and LMO for lacking sufficient performance and instead deem three options as the most promising: Co-free Li-rich oxides, Co-free Ni-rich oxides and LNMO. However, together with Voronina et. al. (2020), these papers highlight that there are several hurdles to overcome before Co-free CAMs can be used in practice. Regarding the three mentioned alternatives, Zhao et. al. (2022) concludes that LNMO face the least number of issues compared to Li-rich and Ni-rich.

A comparison of energy densities between above mentioned cathode materials can be observed in Figure 3.2. Reader should note that Figure 3.2 displays the energy densities on cathode level, and that the energy densities on cell level will be significantly lower. However, Figure 3.2 provides a valuable comparison between the capacities of the materials.

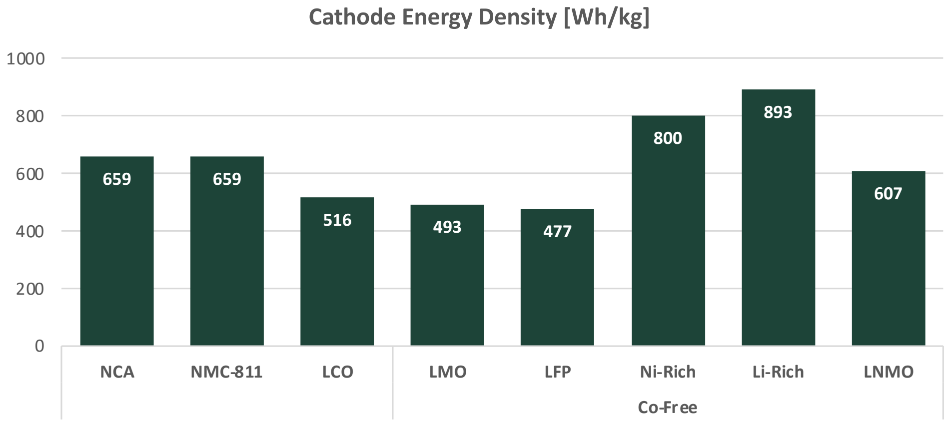


Figure 3.2. Comparison of energy density at cathode level for different materials (Zhao et. al., 2022). Chemical formulas: Ni-Rich = $Li[Ni_{0.9}Mn_{0.1}]O_2$; Li-Rich = $Li_{1.2}Ni_{0.2}Mn_{0.6}O_2$.

3.1.1.2 Anode Active Material

For lithium-ion batteries, possible *anode active materials* (AAMs) are carbons, alloys and oxides. Carbon, and more specifically graphite, is the most common material. However, alloys in the form of silicon are also appealing to the battery producers (Berg, 2015). Hence, these two will be further introduced.

Graphite is a crystalline material, which can either be natural or synthetic, with good ability to store lithium atoms. Despite having a lower capacity, it is used due to its proven stability and production (Berg, 2015).

Lithium can reversibly alloy with several different metals such as aluminum, silicon, antimony, magnesium, and zinc, which therefore could be candidate anode active materials. Among these, silicon stands out as one of the most attractive materials with high theoretical capacity and low supply risk. However, there exists electrochemical difficulties, such as significant volume expansion when alloying with lithium, that needs to be handled (Berg, 2015).

3.1.2 Non-active Materials

The *electrolyte* is situated between the electrodes in the battery cell and is the material through which the lithium-ions wander in charge and discharge cycles while electrons travel through an external circuit. Therefore, the main objective of the electrolyte is to conduct ions and not electrons. Additionally, the electrolyte also fills an important function in keeping the electrodes apart to avoid short circuits. The electrolyte consists of one or several lithium salts dissolved in one or several solvents, and can be of type liquid, gel, or polymer. For cells suitable for EV applications, the most common electrolyte is an organic liquid. Besides the salts and solvents, chemical additives are often added in order to obtain optimal performance (Berg, 2015).

A future potential substitute to liquid electrolyte is to use *solid-state electrolytes*. There are different options of solid-state electrolytes, but common advantages over liquid electrolyte include battery safety, chemical stability, and low cost. Another benefit is that solid-state electrolytes can work with high-energy-density electrodes, such as using Li-metal on the anode side (Tidblad et. al., 2021).

A drawback of the liquid electrolyte is its low mechanical strength, and this is countered for in the battery cell by a *separator*. A separator is placed in the electrolyte, between the electrodes, and is most often a porous membrane. As with the electrolyte, the separator should allow for ion conductivity while preventing any direct contact between the electrodes. Optimally, the separator should be as thin as possible, while maintaining its mechanical properties, to limit the mass and volume of the non-active part of the cell (Berg, 2015).

While the electrolyte facilitates the transport of lithium-ions between the electrodes, the *current collectors* have a similar objective for the electrons. The current collectors are thin foils of materials with high electric conductivity, to which the electrodes are coated. In charge and discharge cycles, the objective of the current collectors is to transfer electrons from the electrodes to the external circuit as effectively as possible. The most common current collectors used are aluminum for the cathode and copper for the anode (Berg, 2015; Duffner et. al., 2021).

3.1.3 Manufacturing Process

The current state-of-the-art large-scale battery cell manufacturing process follows three superordinate value-adding steps: electrode production, cell production and cell conditioning (Duffner et. al., 2021). Among different cell producers, producing cells with different form factors, the manufacturing process is still very similar (Liu et. al., 2021). The process of producing the cathode active material is not included in the above-mentioned steps, instead the cathode is an input material to the electrode production (Duffner et. al., 2021). The three steps of the cell manufacturing will be described in further detail below.

In the first step, electrode production, the cathode and the anode are produced. The cathode and anode are produced separate from each other; however, the production steps are similar (Duffner et. al., 2021). Initially, the active materials are mixed with conductive additive, binder, and solvent into a uniform slurry. The slurry is then coated onto both sides of thin sheets of aluminum or copper (the current collectors). Subsequently, the sheets of coated electrode are calendered to reach the desired thickness, cut to reach the desired dimensions, and finally sent through a vacuum oven to dry (Duffner et. al., 2021; Liu et. al., 2021).

In the cell production step, the internal structure of the cell is assembled. This entails that the sheets of electrodes are wounded or stacked layer by layer with a sheet of separator between every electrode. The assembly is then inserted into the housing before being filled with electrolyte and finally sealed (Duffner et. al., 2021; Liu et. al., 2021).

Lastly, in the cell conditioning phase, the cells are charged and discharged several times with different charging rates. The cells are then stored in controlled conditions during several weeks where quality measurements are performed in order to detect abnormal functionalities (Duffner et. al., 2021; Liu et. al., 2021).

3.1.4 Form Factors

The housing or case of the battery cell can be of several shapes (*form factors*). The components of a cell are put into a case of suitable form, which is usually made of aluminum or plastic (Berg, 2015). The most common form factors are cylindrical, prismatic and pouch cells, see Figure 3.2 below. Regardless of form, a group of cells are put together into a module, and multiple modules create a battery pack (Castelvecchi, 2021).

For automotive applications, the cell production is often done by battery cell producers, while the assembly of modules and packs are often done by the automotive OEMs. The reason for this being that the integration of the battery pack into the vehicle is crucial for the BEV's range and charging rate, hence something that the OEMs wants to control. Looking forward, integration of the battery pack is anticipated to become an even more essential part of the vehicle designs (Boston Consulting Group, 2018).

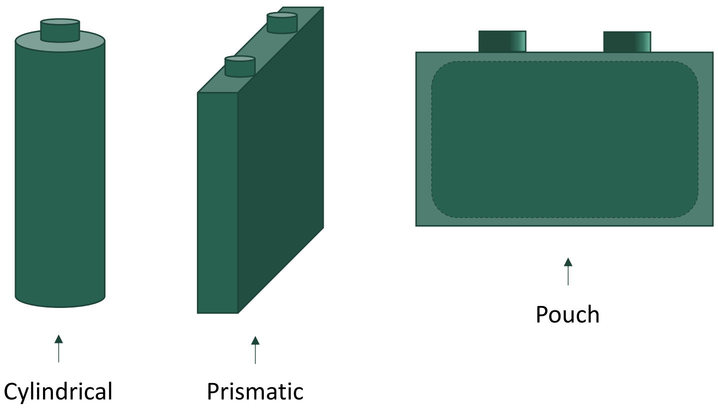


Figure 3.2. Schematic image of the three main form factors of lithium-ion batteries (adopted from Berg (2015)).

3.1.4.1 Cylindrical cells

In a cylindrical cell, the sheets within CAM and AAM are wounded into a roll, and usually put in an aluminum case (Berg, 2015; Miao et. al, 2019). The main advantage of cylindrical cells is that the production process is relatively simple, resulting in competitive production costs (Schröder et. al., 2017), while packaging and thermal issues are the main downsides. The problem with thermal management is due to the uneven distribution of heat within each cell during usage. This is partly managed by the voids that are created between the cylindrical cells when packing cells in the modules. The voids aid the cooling of the battery. Although, the inability to pack more tightly may result in an unrealistically big battery pack (Berg, 2015).

3.1.4.2 Prismatic

Similar to cylindrical cells, the prismatic cells are often cased in aluminum or hard plastics. Further, sheets in prismatic cells may be either wounded or stacked (Berg, 2015). A wound prismatic cell has an advantage regarding specific energy in relation to the alternatives (Miao et. al, 2019). Additionally, compared to cylindrical cells, the prismatic have a more uniform heat distribution and may be packed without the voids mentioned earlier. However, too close packaging may result in cells heating each other and needs to be taken into consideration in the design of the pack (Berg, 2015).

3.1.4.3 Pouch

The last design, pouch cell, usually has stacked sheets or utilizes a technique called Z-folding where the separator is fed continuously from a roll and sheets of electrode as stacked as a "Z". The sheets are then covered in a soft, flexible aluminum foil (Berg, 2015; Schröder et. al., 2017). Like the prismatic cell, the pouch cells have a relatively even heat distribution. Although, thermal management is still important (Berg, 2015). Furthermore, pouch cells have a relatively high specific energy (Miao et. al, 2019).

3.1.5 Carbon Footprint of Cell Production

As with other power demanding manufacturing processes, the production of lithium-ion batteries are subject to greenhouse gas emissions. Although this thesis does not deep dive into carbon emissions and life cycle assessments, there are valuable insights regarding origin of materials that needs to be understood. Hao et. al. (2017) have studied the greenhouse gas emissions from the production of lithium-ion battery cells for automotive applications in China, and their study entails a comparison between Chinese produced cells and cells produced in the US. More specifically, they compare three different battery chemistries based on the cathodes of LFP, NMC and LMO. The comparison can be observed in Figure 3.3.

Reader should note that Hao et. al. (2017) have calculated the American values through a data model. While this might contribute to some uncertainties regarding the absolute values, the relational differences are clear. Further, the comparison does not include European production. However, as a reference value, Northvolt's target by 2030 is to produce cells with the carbon footprint of 10 kg CO2-eq/kWh (Northvolt, n.d.c) – three times less emissions than the American production in Figure 3.3.

The first insight to be derived from Figure 3.3 is the great difference of greenhouse gas emissions from Chinese-based production and American-based production, with Chinese production emitting three times as much per kWh of storable energy. Further, it is notable that the cathode represents a substantial share of the total emissions of the cell production, especially in China. Looking at the different battery chemistries, LFP has the lowest emissions on cathode level but reaches the highest on the entire production process. However, the differences between the chemistries are subtle.

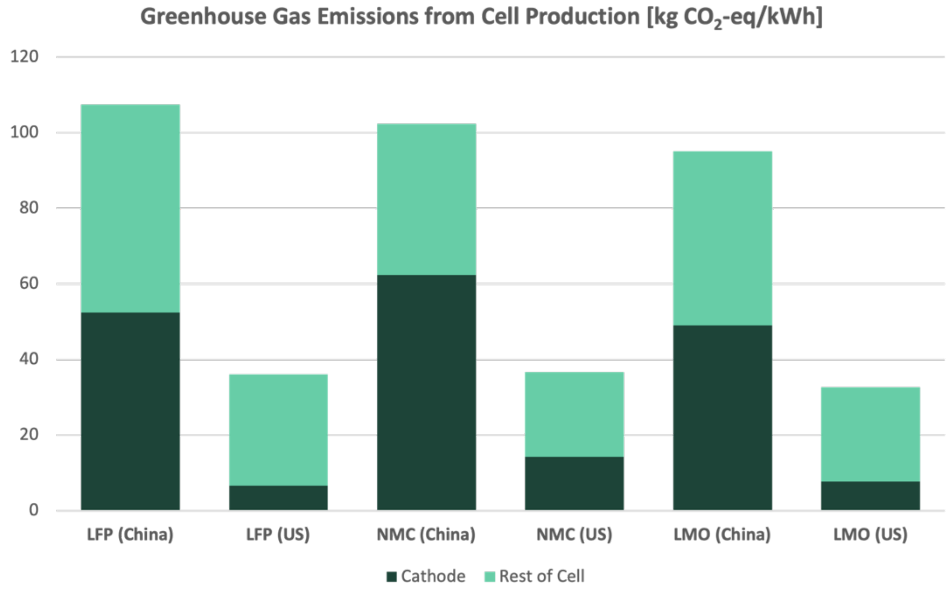


Figure 3.3. Calculated greenhouse gas emissions from cell production of three different cell chemistries in China and in the US (Hao et. al., 2017).

3.1.6 Performance Indicators

The technical performance of a specific battery cell or pack is measured though several aspects. According to reviewed literature, the main aspects of importance are energy density, power density, cost, safety and cyclability (Boston Consulting Group, 2010; IDTechEx, 2021; Masias et. al., 2021; Miao et. al., 2019; Salgado et. al., 2021), additionally performance at various temperatures is mentioned (Boston Consulting Group, 2010; Masias et. al., 2021).

As briefly mentioned, the energy density of a battery cell equals to the amount of energy (kWh) that can be stored per volumetric (L) or gravimetric (kg) unit. This aspect is determined by the cathode and the anode, and their respective potential of storing lithium atoms. Since the traditional anode materials have greater energy storing potentials, the major bottleneck of energy density lies in the cathode (Miao et. al., 2019). For the function of a BEV, the energy density of a battery cell is directly correlated with the range of the BEV. Currently, the gravimetric energy density at cell level is between 160-260 Wh/kg and the volumetric energy density at 450-730 Wh/L (Armand et. al., 2020; Tidblad et. al., 2021). The best performing BEVs have a range of around 600 km (Tidblad et. al., 2021).

Furthermore, cyclability represents the lifetime of the battery, and is currently at approximately 1000 cycles (Armand et. al., 2020; Tidblad et.al., 2021).

Lastly, power density correlates with fast charging (Tomaszewska et. al., 2019; Weiss et. al., 2021). Unlike energy density, where the major bottleneck is the cathode, the power density is more complex to optimize and it depends on the anode, cathode and electrolyte (Weiss et. al., 2021). Additionally, literature is clear with that there exists trade-offs between energy density and power density (Schmuch, 2018; Tomaszewska et. al., 2019; Weiss et. al., 2021). In 2020, fast charging was at the speed of 20-80% charged in 15-30 minutes (Armand et. al., 2020).

Future enhancements of the battery cell are expected within most of these performance indicators. According to Tidblad et. al. (2021), energy density is expected to reach 700 Wh/L on cell level for next generation BEVs with life span of 2000 cycles. The lifetime projection is supported by Armand et. al. (2020), although they present an even higher expected energy density in 2030 at 750 – 900 Wh/L on cell level. Furthermore, fast charging is expected to reach 10 to 15 minutes (Armand et. al., 2020; Marinaro et.al., 2020).

3.2 Beyond Lithium-ion Battery Cells

Looking beyond the lithium-ion battery cell, there are other potential technologies and alternatives currently researched. One being *sodium-ion battery cells*, which is structurally very similar to a lithium-ion cell but contains some important differences. First and foremost, instead of lithium-ions wandering between the electrodes in charge and discharge cycles, the sodium-ion battery cell, as the name suggests, utilizes sodium-ions for the same purpose. This difference implies altering chemistry and electrochemistry between the two cells. On the anode side, sodium-ion also uses carbon as active material. However, on the cathode side, the sodium-ion cell can use active material which are based on naturally abundant transition metals such as iron, manganese, vanadium, and titanium. This, in combination with sodium being significantly more abundant than lithium in the earth's crust, sodium-ion cells are set to be cheaper and more sustainable than lithium-ion cells. More specifically, projections state that a sodium-ion cell will likely be 10-20% cheaper than its lithium-ion counterpart. Performance-wise, the sodium-ion battery cell is not projected to reach the energy densities of high-performance lithium-ion batteries such as NMC-cells. Instead, when fully developed, the sodium-ion cell is expected to be similar to an LFP-based lithium-ion cell (Abraham, 2020).

4 Markets & Competitive Landscape

The following chapter provides a background to the EV and BEV markets, as well as the competitive landscape of battery cell manufacturers. Lastly, market development of CAM and risks in the supply chain are described.

4.1 Electric Vehicle Market

4.1.1 Market Development

The term EVs include four different types of vehicles. Besides battery electric vehicles (BEVs), this includes hybrid electric vehicles, plug-in hybrid electric vehicles and fuel cell electric vehicles. While BEVs rely entirely on stored energy in a battery pack as energy source, hybrid and plug-in hybrid vehicles also contain an ICE for propulsion of the vehicle. The difference between the last two is essentially that the battery in a plug-in hybrid can be charged by an external outlet, while the battery in a hybrid is only charged by regenerative braking. Finally, fuel cell electric vehicles rely on hydrogen-based fuel cells to drive the vehicle (Selvakumar, 2021). As mentioned, this thesis focused on BEVs.

Global sales of battery electric vehicles and plug-in hybrid electric vehicles have grown with an annual growth rate of 50% since 2012 and almost three million vehicles were sold in 2020, where BEVs are driving the expansion with two thirds of both the new registrations and the total stock of EVs. At country level, China is the dominating market with 40% of global sales in 2020. However, when looking at regions, Europe constitute the largest market with 47%, while the US trail behind at 10% of global sales (International Energy Agency, 2021; Mehta & Senn-Kalb, 2021).

In relation to ICE vehicles, the global EV sales share rose to a record 4.6% in 2020. Specific to the above-mentioned regions, EV sales in Europe amounted to 10%, China to 5.7% and the US to 2% of total vehicle sales (International Energy Agency, 2021).

The global EV market is forecasted to continue growing. Both in Europe and in China, the regional EV market share is expected to reach above 70% by 2030. The

US is expected to follow Europe and China with a small delay, and therefore reach around 65% EV market share in 2030 (McKinsey & Company, 2021).

4.1.2 Passenger Vehicle Classifications

The classification of vehicles between passenger, commercial, two- and three-wheel, and agricultural and forestry vehicles are clearly defined and widely accepted across continents to allow for the export of vehicles (European Commission, n.d.). However, a further classification of passenger cars in the EU has not been precisely defined. The narrowest segmentation that has been used by the European Commission (1999) is presented in Table 4.1.

Table 4.1. Classifications of vehicle segments (European Commission, 1999).

EU Classification
A: Mini Cars
B: Small Cars
C: Medium Cars
D: Large Cars
E: Executive Cars
F: Luxury Cars
S: Sport Coupés
M: Multi-Purpose Cars
J: Sport Utility Cars incl. off-road vehicles

As this degree project examined the mid-market of the automotive industry, there was a need to divide the market into low-, mid- and premium-segments. Before segmentation is presented, it is essential to define upon which aspects it was based. To some, low-, mid- and premium-segments are connected to a feeling or to a brand. To others, it might more be reflected upon specific features or looks of the vehicle. In order to make this distinction as tangible as possible, this research project primarily considered the segments of low, mid and premium to be divided by their market price as newly produced vehicles.

The assumptions made for this degree project regarding the segmentation can be found in Table 4.2. The division is based on the "Global Sales Segments" provided by IHS Markit (2022), which have similarities to the segments proposed by the European Commission. To get a comparable view of the price levels of the different segments and allow for categorization into low, mid and premium, price data from 229 BEVs from EV Database (2022) have been gathered and their averages were presented for their corresponding IHS segments. Based on this, it was assumed that A and B, C and D, and E and F were categorized into low, mid and premium respectively. Within the studied mid-market, C and D were further classified as "Lower Mid" and "Upper Mid". It should be noted that the D-Segment arguably could have been categorized in either mid or premium. However, for this project, it was assumed to belong to the mid-segment.

Table 4.2. Average price of IHS vehicle segments and assumed segment for this thesis. Most produced BEV models from IHS Markit (2022) and average prices from EV Database (2022).

IHS Global Sales Segment	***Most Produced BEV Models in Europe 2022***	***Average Price on German Market in USD (Std Dev)***	***Assumed Segment***
A-Segment	Fiat 500, VW up!, Smart Fortwo	26,996 (4,507)	Low
B-Segment	Peugeot 208, Peugeot 2008, Mini Cooper	36,645 (5,541)	Low
C-Segment	VW ID.3, VW ID.4, Renault Megane	49,866 (9,416)	Mid (Lower Mid)
D-Segment	Tesla Model Y, BMW i4, Mercedes EQC	61,374 (10,569)	Mid (Upper Mid)
E-Segment	BMW iX, Porsche Taycan, Audi e-tron	98,200 (21,227)	Premium
F-Segment	Maserati MC20, Lotus Evija	137,685 (33,536)	Premium

4.1.3 Vehicle Market Split

Following the segmentation made in Chapter 4, market shares and projections towards 2027 for BEVs are presented in Figure 4.1 and Figure 4.2. See Appendix B for complete presentation of assumptions in figures. The reader should note that the figures display the market share of produced vehicles in the regions, and not the amount of sold vehicles in the regions. Due to inter-continental trade of passenger vehicles, these figures will differ somewhat. However, from the perspective of a battery cell producer, the production of vehicles in the regions is arguably of most importance.

The forecast in Figure 4.1 shows that the BEV markets will experience rapid growth over the coming years – from 2022 to 2027 the total European BEV market will have a yearly growth of 37%. Regarding the segments' share in 2027, the mid-segment (C+D) will see the greatest growth and dominate the market with 66%. This despite the lower mid-segment (C) losing six percentage points over the coming five years. Instead, the upper mid-segment (D) will see substantial growth and account for almost every fourth BEV produced in Europe in 2027.

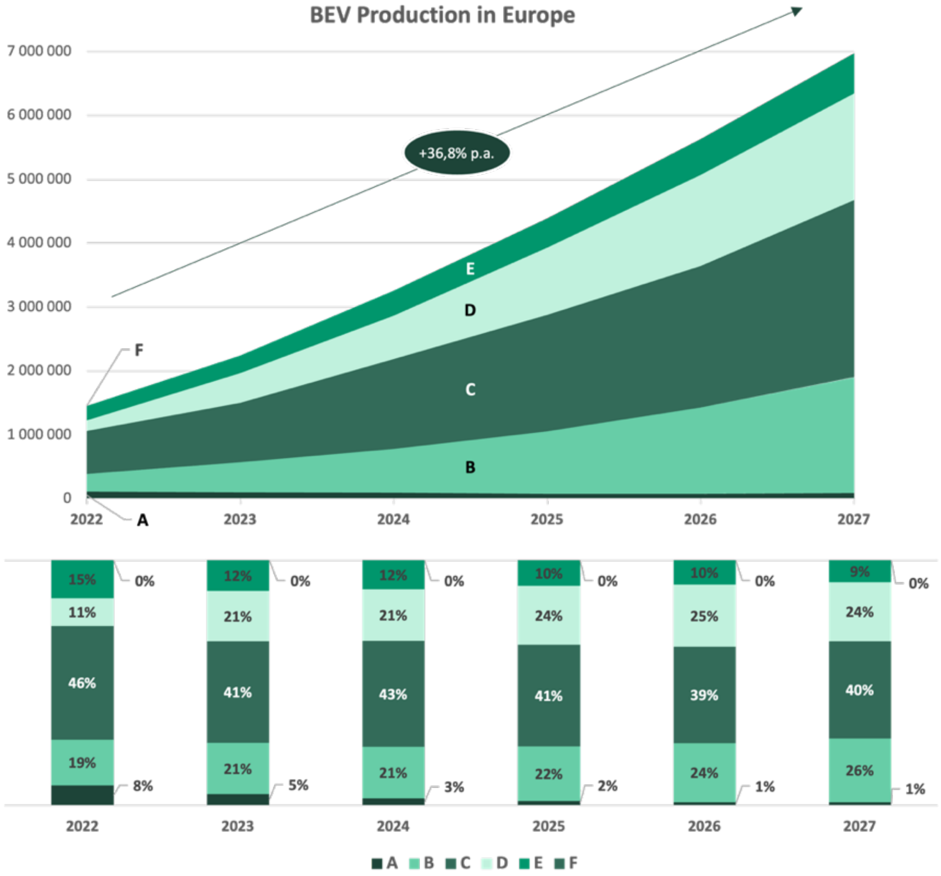


Figure 4.1. Forecast over passenger BEV production in Europe by units, with data from IHS Markit (2022).

Similarly, looking at Figure 4.2, the US BEV market will grow by 32% on a year-to-year basis towards 2027. The mid-segment (C+D) of the US market will be slightly larger, reaching 77%, with the upper mid-segment (D) accounting for four out of five produced mid-market BEVs by 2027.

A significant difference between the two markets is that American based OEMs produce and will produce much less low- and lower mid-market BEVs (A+B+C).

The forecast in Figure 4.2 even shows that the low segment (A+B) is negligible after 2025.

Also notable is the total size of the BEV markets in the different regions, with the US market being around 40% of the size of the European BEV market. Despite this, the upper mid-market segments (D) are similar in absolute values for the different regions.

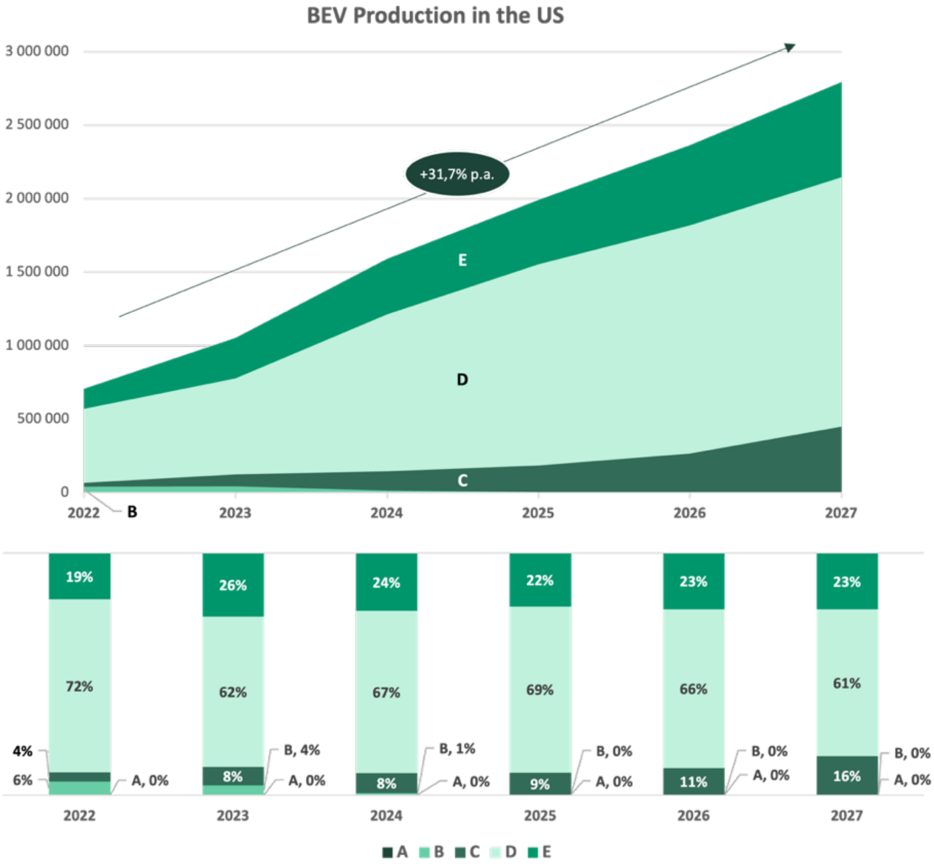


Figure 4.2. Forecast over passenger BEV production in the US by units, with data from IHS Markit (2022).

4.1.4 Business Models

The conventional business model of passenger vehicles implicates that the consumer buys and owns their own vehicle. In the transition to EVs, this business model has followed along despite being constrained by multiple barriers such as higher price premiums of EVs compared to ICEVs, additional costs of battery replacements, fast depreciation of EVs, limited charging infrastructure and limited driving range (Huang & Qian, 2021; Huang et. al., 2021). De Rubens et. al. (2019) explains this unmatching business model as the result of lack of knowledge of how to push EVs downstream and large nested investments in ICEV infrastructure and support networks.

de Rubens et. al. (2019) and Huang & Qian (2021) argue that the conventional EV-buying model is limited in driving wider adoption of EVs and innovative business models optimized for EV market delivery are required. Options that are discussed include vehicle leasing, battery leasing or business-to-consumer vehicle sharing. Battery leasing implicate that the consumer buys the actual vehicle but leases the battery. Vehicle leasing already exists on the ICE market and is when the consumer rents the entire vehicle for a longer duration. On the other hand, business-to-consumer vehicle sharing constitutes the shorter duration rents where the consumer is charged on a minute- or hour-basis (Huang & Qian, 2021; Huang et. al., 2021).

4.2 Lithium-ion Battery Cell Market

4.2.1 Competitive Landscape

As the demand for EVs surge, the demand for big batteries follow. Currently, the lithium-ion battery cell production for EVs is dominated by a few large players – CATL, Panasonic, BYD, LG Energy Solution, Samsung SDI, and SK Innovation. These large producers supplied 87% of batteries for the passenger EV market during the last six months of 2020 (Ulrich, 2021). Furthermore, a strong majority of the companies are rooted in Asia, and especially China. According to BloombergNEF (2020), China controls large shares of the supply chain globally – 80% of raw material refining, 77% of cell production capacity and 60% of manufacturing of components. The single largest competitor is currently Korean manufacturer LGChem followed by Chinese CATL (Palandrani, 2020).

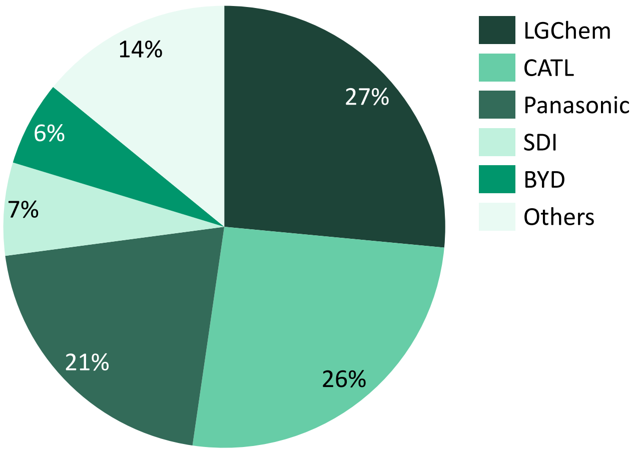


Figure 4.3. Competitors by market share in sales during January to August 2020 (Palandrani, 2020).

The rise in EVs has created demand to produce batteries near the automotive manufacturing. Consequently, battery factories are rapidly expanding to Europe (BloombergNEF, 2020). According to McKinsey & Company (2021), battery cell production in Europe in 2030 is announced to reach 965 GWh, and thereby slightly outweighing demand. Specifically, estimated demand in Europe amounts to 874 GWh – 90% of it being from passenger and commercial BEVs (McKinsey & Company, 2021).

Besides Asian battery cell producers expanding production to Europe, some entirely new companies (such as Northvolt) and backwards integrating OEMs have entered the industry. As of August 2021, there were 24 battery cell players with announced future production in Europe alone (McKinsey & Company, 2021). Another McKinsey & Company report (2022) anticipated that the global competitive landscape of battery cell producers will consolidate to around 10-15 players. They argue that the consolidation will be driven by the importance to achieve economies of scale to reduce production costs and compete on performance.

However, although production capacity in Europe for 2030 has been announced to meet demand, there is no guarantee that the complete volume of the announcements will be realized. Unforeseen events may cause delays and alter the actual production (McKinsey & Company, 2021).

4.2.2 Current Cathode Active Material Offering

As stated, lithium-ion battery cells are currently the dominating technology for energy storage in BEVs. Looking more specifically at the most used cathode chemistries in the battery cells, there are three cathode materials that constitute the majority of the market – NMC (nickel manganese cobalt), NCA (nickel cobalt aluminium) and LFP (lithium iron phosphate) (Greenwood et. al., 2021; Xu et. al., 2020). In some EVs released during the last decade, NMC and NCA cathodes have been blended with LMO (lithium manganese oxide) (Schmuch et. al., 2018).

Historically, NMC, with its high energy density, came to dominate the EV market in most of the world. However, the high safety of LFP has led it to being the favored cathode material in China. Hence, the global market of lithium-ion batteries for automotive applications appears to be split between LFP dominance in China and NMC dominance in the rest of the world (Greenwood et. al., 2021). However, American OEM Tesla and German OEM Volkswagen have both announced their intentions of employing LFP for a large fraction of their future EV production (Sripad, 2021).

4.2.3 Cost Structure of Lithium-ion Battery Cells

Since introduced in the 1990's, lithium-ion batteries have become 30 times less expensive (Castelvecchi, 2021). The cost of a battery cell is most often measured per kWh, to cater for comparisons between battery chemistries. Hence, on cell level, the cost per kWh is lower than on pack level due to the pack not adding any further energy storing capabilities to the battery. According to BloombergNEF (2021a), in 2021 the price of battery cells for BEVs was 97 USD/kWh on cell level, whereas the pack was priced at 118 USD/kWh. This gives that, in 2021, battery cells accounted on average for 82% of the total battery pack costs.

Furthermore, there are differences in cost between different battery chemistries. An LFP-based battery cell, which above was described as a low-cost option, was on average 30% cheaper than higher performing NMC-based cells in 2021 (BloombergNEF, 2021a). Since the market of battery cells for EVs is dominated by NMC and LFP, it is difficult to derive accurate cost levels of other potential battery chemistries, such as low-cobalt alternatives.

Breaking down the battery cell, the main cost constitutes of the cathode materials (Duffner et al., 2021). More specifically, a breakdown by BloombergNEF (2021b) (see Figure 4.4) shows that the cathode represents 51% of the total cost of the battery cell – double the value of the rest of the materials combined. The rest, 24%, is made up of labor, manufacturing, and depreciation.

Further, according to a report from Boston Consulting Group (2020), the battery accounts for around a third of the total value of a BEV belonging to the D-Segment.

This implies that the most expensive part of the battery cell, the cathode material, account for around 14% of the total value of the BEV. The complete chain of cost structures can be observed in Figure 4.4.

Moreover, the prices vary depending on region. In 2021 packs from China were cheapest with a price at 118 USD/kWh, while in the US and Europe battery pack prices were 40% and 60% higher respectively (BloombergNEF, 2021a). As mentioned, labor, manufacturing, and depreciation accounts for the second largest cost of the battery cell. When comparing labor costs in Europe and China, in 2020 the hourly rate in EU on average was 31.35 USD (28.5 EUR, conversion rate from March 2022) (Eurostat, 2021), whereas in China the minimum wage in January 2022 was set between 1.92 and 3.74 USD per hour (13-25.3 CNY, conversion rate from May 2022) (MOHRSS, 2022).

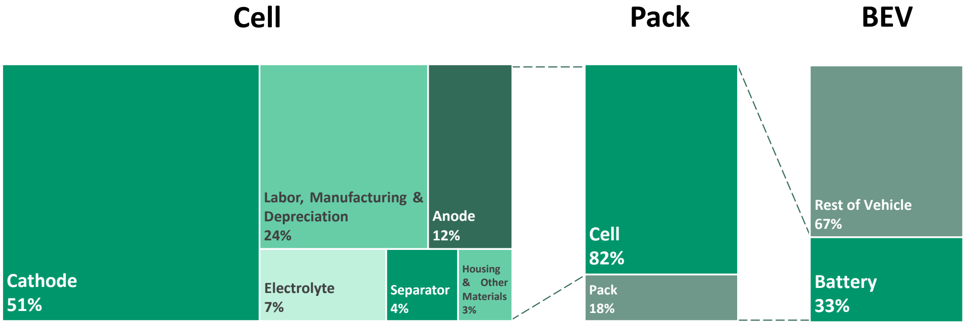


Figure 4.4. Cost structure from battery cell to BEV. Data from BloombergNEF (2021b), BloombergNEF (2021a) and Boston Consulting Group (2020).

Looking forward, battery pack prices have been projected to continue to decrease and BloombergNEF (2021a) expect that prices will fall below 100 USD/kWh by 2024. However, due to rising costs of the raw materials battery pack prices could start to rise during 2022 which would delay the time until prices fall below 100 USD/kWh (BloombergNEF, 2021a). In Figure 4.5 and Figure 4.6, projections of battery cell and pack costs or prices from existing literature are compiled and presented.

According to Figure 4.5, apart from two outliers, prior published literature expects lithium-ion battery cells to reach costs between 44-80 USD/kWh in 2030. Additionally, the battery pack counterparts are projected to reach costs between 58-120, excluding the pessimistic scenario from König et. al. (2021).

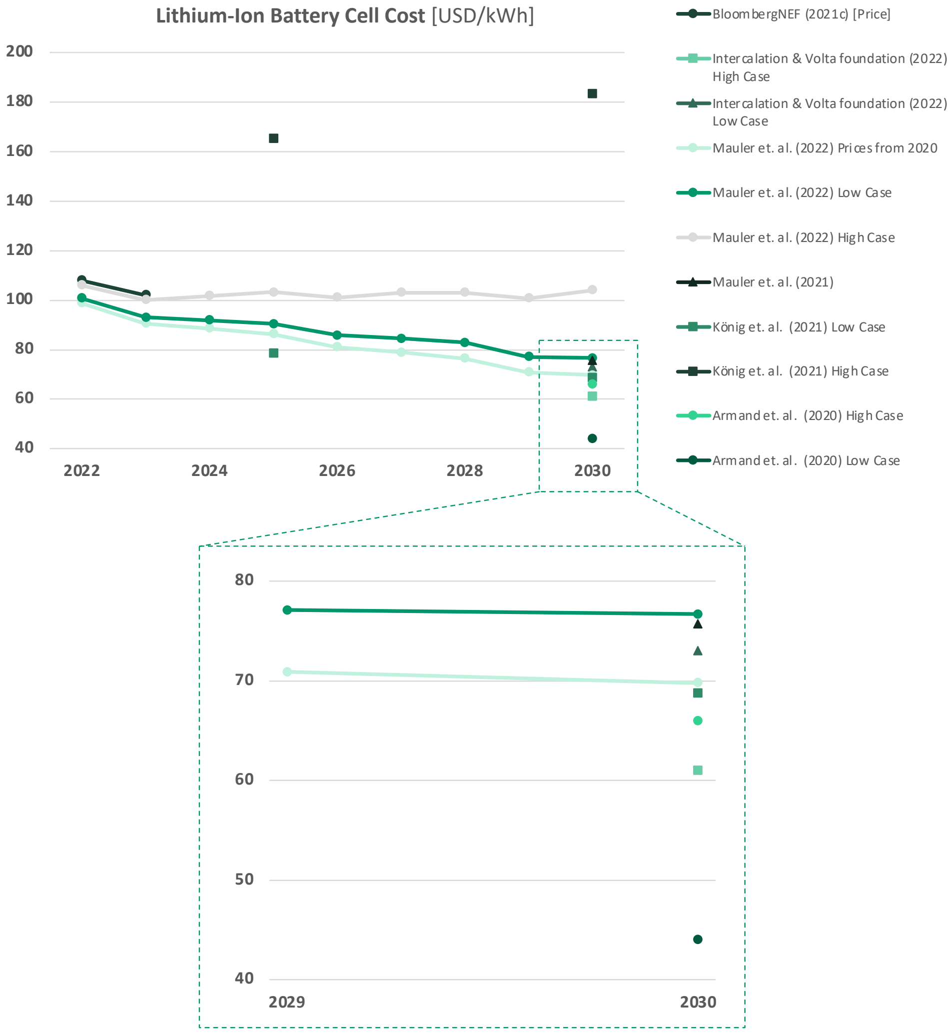


Figure 4.5. Battery cell cost expectations in USD/kWh between 2025-2030 according to existing literature. Exchange rate used for EUR to USD is 1.1, as conversion rates were retrieved beginning of March 2022.

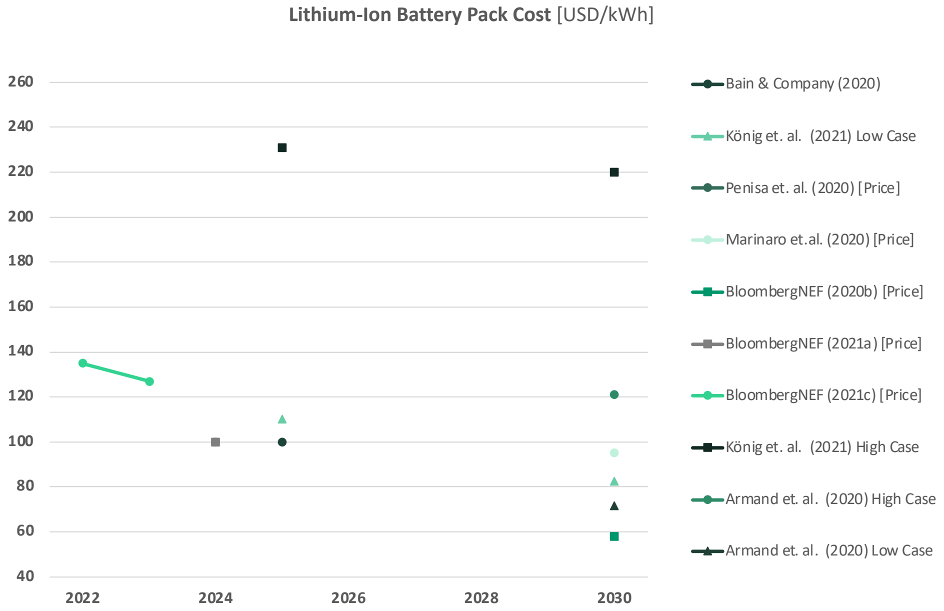


Figure 4.6. Battery pack cost expectations in USD/kWh between 2025-2030 according to existing literature. Exchange rate used for EUR to USD is 1.1, as conversion rates were retrieved beginning of March 2022.

4.2.3.1 Raw Materials & Supply Chain Risks

As mentioned, the prices on raw materials such as cobalt, nickel, manganese and lithium are rising. The industry is expected to meet a shortage in supply of battery materials in the future (Tyler-Dudley et. al., 2021). Especially lithium and cobalt are expected to become scarce, and by 2025 production capacities of these metals could be insufficient (Xu et. al., 2020). Moreover, during 2022, raw material prices spiked to extremely high levels for both lithium and nickel (Abuelsamid, 2022; Fastmarkets, 2022).

The most expensive material in the NMC battery is cobalt (Castelvecchi, 2021; Tyler-Dudley et. al., 2021). Additionally, the cobalt metal reserves are heavily geographically concentrated. Approximately 70% of the world's cobalt mine production originates from the Democratic Republic of the Congo (Castelvecchi, 2021; U.S. Geological Survey, 2021), where concerns regarding social issues related to the working conditions have been raised (Castelvecchi, 2021). However, although efforts to replace cobalt are continuously made, Xu et. al. (2020) states that a complete exclusion of the metal is deemed unlikely in upcoming years.

Due to expected scarcity of raw materials, battery manufacturers such as CATL and Tesla have started efforts to vertically integrate their supply chains. In addition, manufacturers are moving towards alternative chemistries, specifically LFP (Tyler-Dudley et. al., 2021).

4.2.3.2 Cathode Costs of Existing Battery Chemistries

To illustrate how the prices of raw materials affect the cost of the battery cell, a comparison of the cost of material for different cathode alternatives between 2020 and 2021 is presented in Figure 4.7. The cathodes included are NCA, NMC (111/442/532/622/811), LMO, LNMO, LR-NMC (Li-rich oxide with cobalt) and LFP. The cost of material for the cathodes includes material and preparation costs.

The different costs have been calculated through a bottom-up costing model brought forward by Wentker et. al. (2019), with the only modification being updating the prices of the raw materials to what is presented in Table 4.3.

Reader should note that the price of lithium in this model has been derived from lithium carbonate. Lithium is sold and used mainly in two forms – lithium carbonate and lithium hydroxide – and the lithium content and prices of these two forms differ. Using lithium carbonate as price base for the lithium in all cathodes in this model is a minor drawback since high energy density-cathodes such as NMC-811 prefer lithium hydroxide (McKinsey & Company, 2018). However, the authors deem this drawback to be of little importance to the figure and that it does not affect the insight derived from it.

From Figure 4.7, one can observe that the different cathode materials have different costs per energy. With 2020 raw material price levels, NCA and all the NMC-cathodes were the most expensive with costs of 31-40 USD/kWh. With the same price levels, the cathodes of LMO, LNMO, LR-NMC and LFP had lower costs of 21-26 USD/kWh.

From 2020 to 2021, several of the raw materials in Table 4.3 have seen aggressive growth. However, looking at how it impacts the battery cell costs, cobalt has the greatest effect – LMO, LNMO and LFP, the three cobalt-free CAMs in the figure, have smaller increases than the cobalt-containing CAMs.

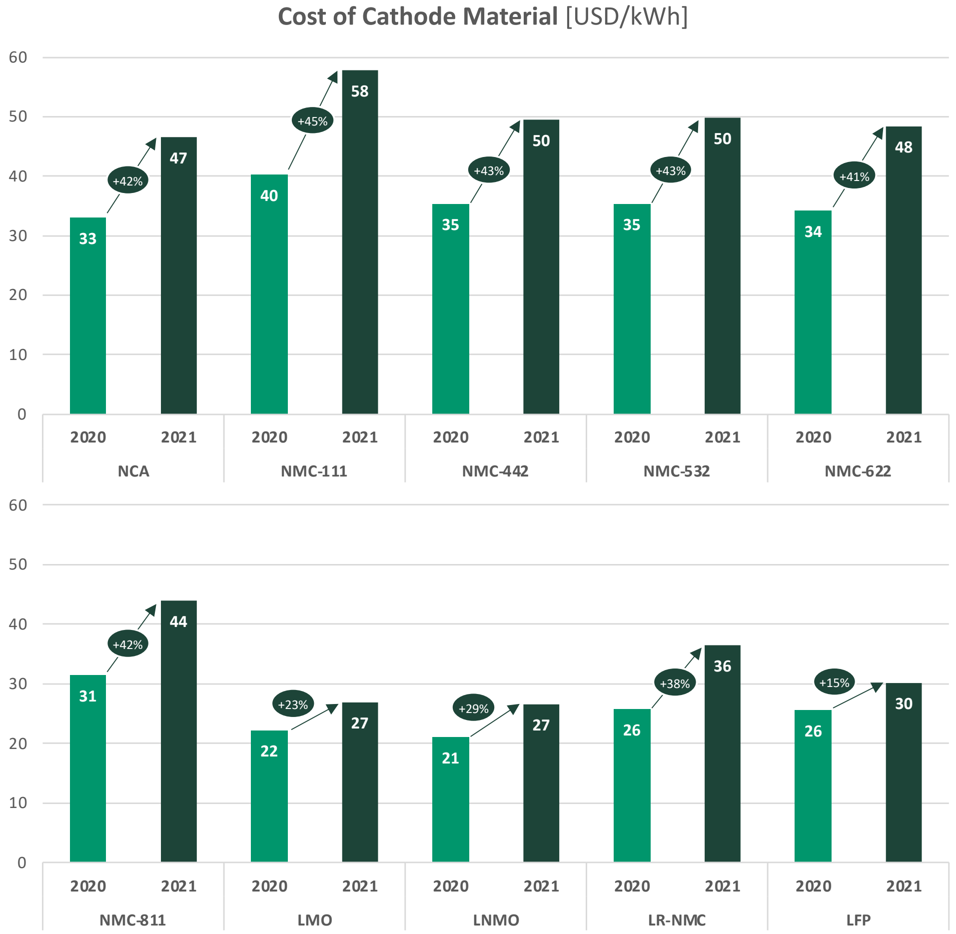


Figure 4.7. Costing model adapted from Wentker et. al. (2019) showing cost of different cathode materials. Chemical formula of LR-NMC: $Li_{1.15}Ni_{0.15}Mn_{0.55}Co_{0.15}O_{1.7}$

Table 4.3. Raw material prices extracted from EERE (2022) and US Geological Survey (2022).

Raw Material	*Average Price 2020 [USD/kg]*	*Average Price 2021 [USD/kg]*	*Difference*
Cobalt	33.07	55.12	+ 67%
Nickel	13.23	19.84	+ 50%
Manganese	2.45	2.62	+ 7%
Aluminum	1.77	2.20	+ 25%
Lithium (Li_2CO_3)	42.58 (8.00)	90.49 (17.00)	+ 113%

4.2.4 Regulations on European Lithium-ion Batteries

In 2020, the European Commission proposed a new *Batteries Regulation* which expected to replace the current *Batteries Directive* adopted in 2006. The old directive has been deemed outdated as technological developments, new socio-economic conditions and usage of batteries have changed the market (European Commission, 2020a). Additionally, the Batteries Directive only relates to the end-of-life phase of batteries, i.e., there are presently no requirements on sourcing, production, usage, or carbon footprint specifically for batteries in the EU (European Commission, 2020b).

The new Batteries Regulation aims to promote recycling and reuse of batteries, standardization of product requirements, creation of legal certainty on the market, and reduction of the environmental impact (European Commission, 2021). Moreover, the legislation will be mandatory for all batteries placed on the EU market, regardless of the battery's origin (European Commission, 2020a). Compulsory regulations will be placed on hazardous substances and sourced materials, CO2 emissions, labelling, performance, and recycling (European Commission, 2020c).

Specifically, starting July 1, 2024, all batteries in EVs will be labeled with a carbon footprint declaration. From the beginning of 2026, EV batteries will be labeled with a "carbon intensity performance class". Furthermore, from beginning of 2027 these batteries will have to conform to carbon footprint restrictions, in addition to providing a declaration of the amount of recycled cobalt, lead, nickel, and lithium within the battery. In 2030, the minimum share of recycled content of these raw materials will be specified (European Commission, 2020a).

4.2.5 Performance Indicators & Customer Preferences

In Chapter 3, the main aspects defining the performance of a battery pack is described. Alongside the technological aspect of the performance, customer and end customer preferences will be related to these aspects as well. According to a study by Deloitte (2022), end customers located in Germany and the US favored range above all other aspects of the battery in a BEV. The importance of range is supported by both Tidblad et. al. (2021) and Wicki et. al. (2022). Additionally, besides range, prior literature mentions affordable prices, charging speed and infrastructure, and sustainability as important aspects to drive BEV adoption amongst end customers (Tidblad et. al., 2021; Wicki et. al., 2022).

Moreover, according to projections on future end customer needs by Tidblad et. al. (2021), the main improvement potential of the battery cell performance exists in energy density, cycle life and fast charging.

5 Conceptual Frameworks

The following chapter provides a thorough background of the frameworks used to structure the gathered information and conduct the analysis.

5.1 Thematic Frameworks

5.1.1 RQ 1: Customer Preferences

Based on the technological and preferred aspects of a battery pack portrayed in Chapters 3 and 4, a structure of the most crucial factors affecting customer satisfaction was created – including price, range, fast charging, sustainability and cyclability. These aspects were further confirmed in discussion with supervisors at Northvolt. Furthermore, in Chapter 4 it became clear that the rise of new business models could be an important aspect of the future BEV market. Hence, to structure the analysis of RQ 1, the thematic framework displayed in Figure 5.1 was constructed.

Additionally, as the focus is placed on Europe, an additional theme regarding the differences with the American market was added.

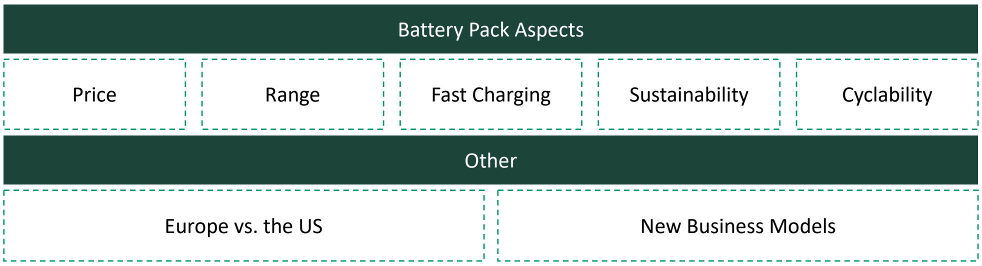


Figure 5.1. Base for structuring data gathering and analysis for RQ 1.

5.1.2 RQ 2: Battery Technology Alternatives

In order to structure the analysis of the second RQ regarding future battery technology satisfying the BEV mid-market, another framework of relevant themes based on the information provided in Chapter 3 was created. The themes included CAM, AAM, other aspects (i.e., form factor, process, and non-active materials) and lastly a category for future technologies that are under development.

Figure 5.2. Base for structuring data gathering and analysis for RQ 2.

5.2 Theoretical Frameworks

5.2.1 Diversification

Ansoff (1957) describes the term *diversification* as being associated with a change in a firm's products and/or markets. A further distinction within diversification can be made between *related* and *unrelated* diversification, where the distinction is made based on the diversification's relation to the existing products and activities. A related diversification implies that the industry to be diversified into has important similarities with the firm's current industry – unrelated diversification being the opposite (Kennedy, 2020). As this degree project examined the outlook for a European premium battery cell producer to expand its offering to battery cells for the BEV mid-market – which can be regarded as a related diversification – this thesis utilized theories of diversification strategies. The following theories and frameworks was used as a base for structuring the analysis of RQ 3.

In order to decide whether a business should follow along with diversification, Porter (1987) formulated three essential tests which need to be fulfilled in order for the diversification to create maximum value. The first test, the Attractiveness Test, states that the markets or industries to be diversified into need to be structurally attractive. An appropriate framework to assess the attractiveness of an industry is Porter's Five Forces model (Kennedy, 2020). Secondly, the Cost-of-Entry Test checks whether the returns to be generated from the diversification outgrows the cost of entry. Finally, the Better-Off Test states that the current business and the diversified business should gain competitive advantages and synergies from each other in some way. Otherwise, the two businesses are better off completely separated (Porter, 1987).

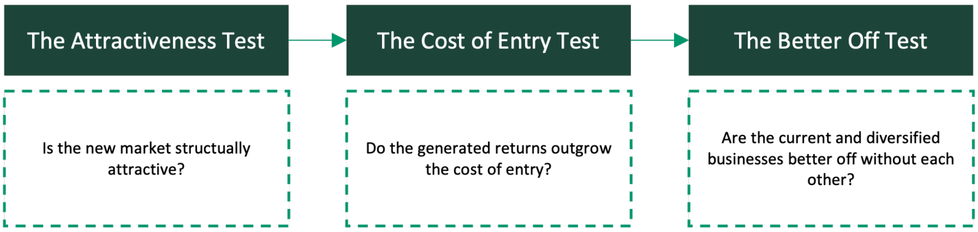


Figure 5.3. Porter's Three Tests (adopted from Porter (1987)).

5.2.2 Porter's Five Forces

As mentioned, to understand whether diversification is likely to be successful it is crucial to understand the competitive landscape of which the industry is built upon. For this master thesis, the framework of Porter's Five Forces was used to map the competitive situation of a European battery cell manufacturer on the mid-market. The foundation of the framework is that in all industries a few forces determine the competitive opportunities and limitations – competition amongst current competitors, threats of new entrants, buyer power, supplier power and lastly threats of substitutes. Hence, it is necessary to understand the five different forces to formulate a successful company strategy (Porter, 1979). Porter (1979) further argues that profitability in an industry is determined by the strongest of the five forces.

Furthermore, Porter (1979) explains several factors affecting the strength of the various forces. A summary of the most relevant factors strengthening each force are seen in Figure 5.4 below.

Competition Amongst Current Competitors	Threats of New Entrants	Buyer's Power	Supplier's Power	Threat of Substitutes
☐ High fixed costs ☐Many competitors of similar size ☐High exit barriers ☐Slow market growth ☐Low switching costs between manufacturers	☐Small capital requirements ☐Low product differentiation ☐No economies of scale ☐Easy access to distribution channels ☐No cost-advantage of early entrants	☐Big volume purchases ☐Undifferentiated products ☐Price sensitive buyers ☐Buyers could vertically integrate ☐The product does not save the buyer money ☐The quality of the product is insignificant to the buyer	☐Only few suppliers ☐Suppliers are highly differentiated ☐Supplier could vertically integrate forward ☐The industry is not an important customer	☐Substitutes improves performance to lower costs ☐Substitutes emerge from high profit industries

Figure 5.4. Porter's Five Forces and factors strengthening each force (Porter, 1979).

5.2.3 Porter's Generic Strategies

As a tool to help assess whether a European premium battery cell manufacturer would benefit from diversifying into a mid-market battery cell offering, the theory of Generic Strategies by Porter (1985) has been used. This well-cited theory is directed at the *relative positioning* of firms within an industry. According to Porter, this positioning determines whether a firm will experience above or below average profitability in its industry.

There are two essential ways in which a firm can achieve competitive advantage to its competitors – either by *cost advantage* or by *differentiation*. In order words, either by offering a lower price than competitors, or by being unique along dimensions which are valuable to customers and rewarded with a premium price. All a firm's strengths or weaknesses are ultimately a function of its impact on either of these two ways of competitive advantage (Porter, 1985).

When the two forms of competitive advantage are combined with the target scope of the industry in which the competitive advantage is to be achieved, four generic strategies for achieving above-average performance in an industry are formed. Namely, *cost leadership*, *differentiation*, *cost focus* and *differentiation focus*, and can be viewed in Figure 5.5. Cost leadership and differentiation seek competitive advantage in a broad range of industry segments, whereas the focus strategies target a narrower part of the industry and tailor its offering towards them (Porter, 1985).

Which generic strategies that are feasible and which actions to undertake to implement a specific strategy vary widely from industry to industry. However, a firm which fails to implement any of the generic strategies find themselves *stuck in the middle*. This position is generally a recipe for below-average performance since the firm will always compete at a disadvantage – if a firm that is stuck in the middle would stumble upon a profitable product or buyer, the cost leaders, differentiators, and focusers will quickly eliminate the spoils. Since the generic strategies are fundamentally different in their ways of creating and sustaining competitive advantage, firms will usually have to decide among them. Following more than one generic strategy at a time is likely a path towards getting stuck in the middle (Porter, 1985).

The only way a firm that is stuck in the middle can be profitable is if the structure of the industry is highly favorable – such as high growth and demand greatly exceeding supply – or if its competitors are also stuck in the middle. However, as industries mature, the performance gap between firms with generic strategies and firms that are stuck in the middle tend to widen as it exposes ill-conceived strategies that have been forgiven by rapid industry growth (Porter, 1985).

The risk of becoming stuck in the middle is particularly great for focusers once they have dominated their target segment. Since focus strategies involves deliberately limiting sales volume, success can make focusers lose sight of their generic strategy and compromise its focus strategy for the sake of growth. In these cases, Porter argues that focusers are better off growing to other industries where they can utilize their focus strategies (Porter, 1985).

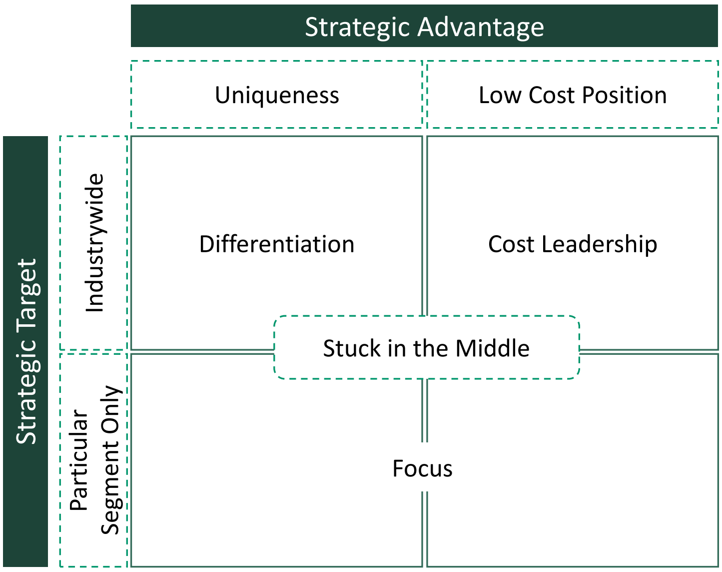


Figure 5.5. Porter's Generic Strategies (adopted from Porter (1985)).

5.2.4 RQ 3: Outlook on Competitiveness

The third and final RQ aimed at investigating the outlook for a European premium battery cell producer to be competitive on battery cells for the BEV mid-market. To argue for a theoretical framework upon which the analysis of RQ 3 was based, certain aspects have to be clarified and defined.

Firstly, the meaning of "competitive" must be stated. In this thesis, the authors regarded "being competitive" as achieving what Porter (1985) refers to as *sustainable competitive advantage*. A firm achieves this by positioning itself in an industry in a way where the firm earns an above-average profitability.

The foundation of the analysis was based upon Porter's Three Tests for diversification, see Figure 5.3. Even though this framework is generally applied in corporate strategy, rather than competitive strategy, the authors of this thesis argue that it still is applicable for two reasons: (1) The total sizes of the European and American BEV markets (several million BEVs on each market, according to Figure 4.1 and 4.2) implicate that the premium- and mid-segments are two individual large markets, and (2) the demand and therefore product offering in the two segments are likely to be different. Based on these attributes, it is reasonable to regard a mid-market offering and a premium offering as separate businesses within a business, hence validating the use of a corporate strategy framework such as Porter’s Three Tests. Further, Porter’s Three Tests was only used as a structure for the supporting, competitive strategy frameworks.

In order to assess the first test in Porter’s Three Tests, the Attractiveness Test, Porter’s Five Forces was used as suggested by Kennedy (2020).

The second test of Porter’s Three Tests, “The Cost of Entry Test”, was disregarded for this thesis. The reason was that a European premium battery cell producer is already present in the industry and therefore is not subject to the large investments of entering the battery cell industry. Diversifying into a new segment with a potentially new product would of course incur costs for a business, however, that these costs would exceed the profits to be gained has been disregarded.

For the third and final test, the Better-Off Test, Porter’s Generic Strategies has been used as a supporting framework. The test implies, as mentioned, that the current and diversified business should gain competitive advantages of each other – otherwise, the businesses are better off as separate business units. To put this in the context of competitive strategy, the authors found similarities with Porter’s Generic Strategies through the fact that a business which attempts to follow two different generic strategies may find themselves stuck in the middle, as mentioned above. When stuck in the middle, the firm does not have a sustainable competitive advantage compared to competitors following a single generic strategy and therefore the two offerings would be better off as separate business units. Hence, if the premium offering and the potential mid-market offering cannot be undertaken with the same generic strategy, the better off test will fail.

The final consolidated framework for RQ 3 can be observed in Figure 5.6.

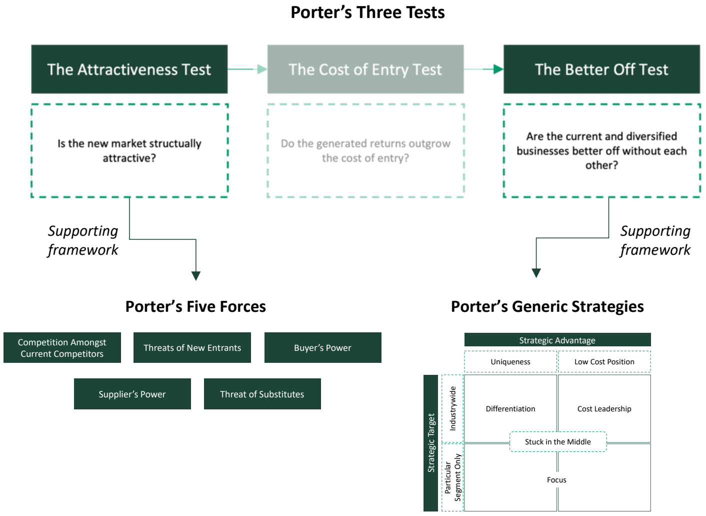


Figure 5.6. Combination of frameworks for structuring data gathering and analysis for RQ 3.

6 Analysis

The following chapter addresses the main results from the conducted interviews. Additionally, the results are related to existing literature presented in prior chapters. The analysis follows the structure of the previously presented conceptual frameworks.

6.1 RQ 1: Customer Preferences

In the previous chapter, frameworks for understanding and analyzing the various RQs were presented. As mentioned, once the interviews and data gathering were complete, the authors structured and grouped the data in the relevant categories.

As understood by the literature, from the perspective of automotive OEMs, the most important performance aspects of a battery pack are price, range, fast charging, cyclability and sustainability. Hence, interviewees with an expertise in the automotive sector and a connection to the OEMs were asked to rate the relative importance of the characteristics for both premium- and mid-market BEVs, see synthetized result in Figure 6.1 below. A full list of individual answers and calculations can be found in Appendix C.

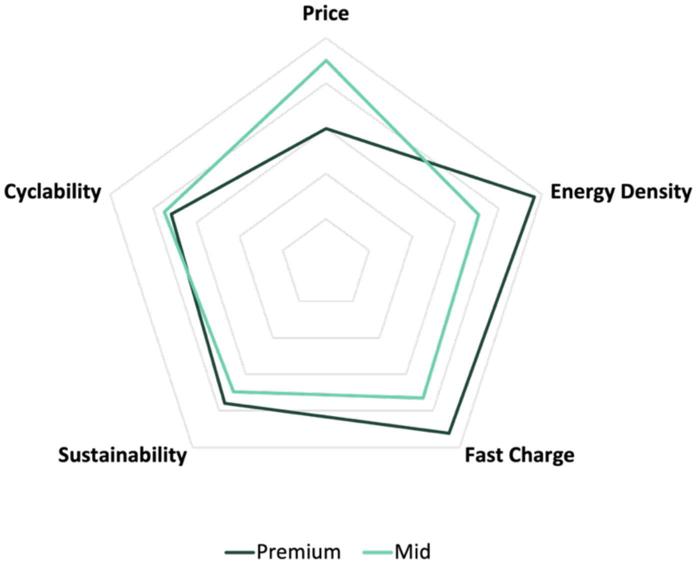


Figure 6.1. Result of interviewees rating of various characteristics of premium- and mid-market battery packs from the perspective of automotive OEMs. Further away from the center indicates higher importance.

Evidently, customers are believed to value a lower price over range (energy density) and fast charging for mid-market batteries, whereas the cyclability and sustainability are of more similar importance for the premium- and mid-segments.

An aspect that was discussed frequently during interviews was how the segments of battery cells and the segments of BEVs will not strictly correlate. In other words, a lower-cost battery cell aimed for mid-market applications will not only be applicable for mid-market BEVs, but also be of interest for low-market and premium BEVs. This segment-overlap will of course be applicable the other way around, i.e., low-cost and premium battery cells being used in mid-market BEVs. The interviewees meant that the reason for this overlap is that OEMs value having their customers being able to choose battery specification for their vehicle. As it is unclear how a potential overlap may affect market shares, this thesis has considered the overlap to be uniform and thereby not affecting the market shares for battery cells for low, mid, and premium BEVs.

6.1.1 Price

As seen in the rating of battery pack characteristics, price was deemed the most important factor for the mid-market. Most interviewees deemed that European produced mid-market battery cells will need to reach costs of approximately 55-75 USD/kWh on cell level until 2030 to satisfy demand (see Figure 6.2). The average of the by interviewees provided values amounted to 65 USD/kWh. Out of nine respondents providing values, five believe that the cost 2030 will be 60 USD/kWh or lower. However, interviewees express reservation regarding if these levels are possible to realize.

Another factor affecting the final price of the battery cell, and commonly mentioned during interviews, is raw material prices. As mentioned, during 2022 the raw material prices of both lithium and nickel spiked to unprecedented levels (Abuelsamid, 2022; Fastmarkets, 2022). It became clear during the interviews that it is crucial to secure a supply chain where both geopolitical risks and scarcity of material or mining capacity is minimized. Lithium was mentioned as a material that is relatively abundant but lacks in mining infrastructure – creating a shortage of supply during coming years. One key aspect of securing supply mentioned several times, which aligns well with a sustainability perspective, was recycling of cathode material.

In relation to information from literature gathered on potential future cost levels, presented in Chapter 4, the results are aligning well with the interview results on cell level. Disregarding the outlier from Mauler et. al. (2022), where a pessimistic raw material price scenario is used, battery cell costs are expected to reach 60-80 USD/kWh in 2030 according to existing studies. However, it should be noted that the results from prior academic studies do not relate to lower-cost batteries in particular, and the results there could hence be comprehended as an upper limit for the lower-cost batteries in scope of this study.

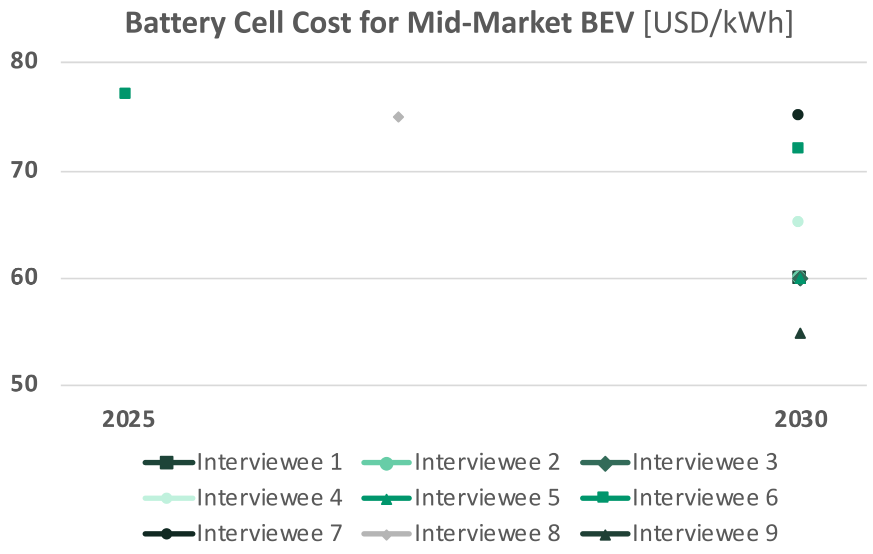


Figure 6.2. Cost expectations in USD between 2025-2030 according to interviews.

6.1.2 Range

Among interviewees, range (and therefore energy density) stood out as one of the most important aspects. This is aligned with prior research on the subject, such as Deloitte (2022), where end customers in the US and Germany favored range above all other factors. Most interviewees argued that range will be more important for premium vehicles, and less important for the mid-market in favor of price, whereas a few rather argued that range will converge across segments.

However, despite the importance of range, it was mentioned in the interviews that the need for range will plateau around 500 km, given that fast charging infrastructure is adequately established. The belief was supported with the argument that most drivers will need to make a stop anyway after a few hours in the car. Although, it was brought up during a few interviews that the range specification on the battery pack and the actual obtained range may differ, depending on conditions such as temperature. Hence, it should be noted that interviewees were likely discussing the real range of the vehicle when mentioning sufficiency around 500 km.

6.1.3 Fast Charging

As mentioned, fast charging is described as an important part of a BEV. Especially range anxiety is expected to be eased by more access to fast charging. The interviews pointed to an expectation on fast charging reaching around 15-20 min to charge the battery from 10 to 80 % for mid-market vehicles in 2025-2030. This aligns, and is even slightly longer charging times than believed possible according to the literature study that mentioned 10-15 min (Armand et. al., 2020; Marinaro et.al., 2020).

6.1.4 Sustainability

Regarding sustainability of the batteries, the interview subjects provided a somewhat scattered image. Although most respondents rated the aspect as mediocre for mid-market vehicles, there is a difference in accompanying comments on the importance. One interviewee explained “sustainability will be a question of money”, another agreed that “the dirtier batteries will probably be in the cheaper cars”. Whereas some respondents reasoned that “sustainability is really important for the lower-cost option, it must be sustainable” and that ”regarding sustainability, the end consumers are fairly educated and the OEMs know this”.

6.1.5 Cyclability

The aspect of cyclability is not given much attention during interviews. One interviewee explained that cyclability is already good enough, and further mentioned that there is a need to keep the same cyclability or even higher for mid-market batteries. This indicates the expectation of a slight increase from current demands on batteries that account to a cyclability of 1000 cycles (Masias et. al., 2021).

6.1.6 The US

As stated in the scope of this study, the focus is placed upon the European automotive market. However, during the interviews some crucial differences amongst the two markets customers' needs have been identified. Firstly, in contrast to the European market, as seen in Figures 4.1 and 4.2, the American market has a smaller share of low-segment vehicles. During interviews, multiple respondents noted that due to the passenger vehicles being larger, and hence heavier in general, additional expectations are placed on the battery pack performance, especially range. In addition, it was noted that the US BEV market is harder to predict and will probably demand longer range than its European counterpart.

6.1.7 Upcoming Business Models

During interviews, new business models were not discussed to great extent. However, in contrast to literature on the subject two interviewees explained that "trends show business models will stay the same". This differs from opinions presented by Huang & Qian (2021) and de Rubens et. al. (2019), where innovative business models are seen as necessary for broad EV adoption.

Another interviewee mentioned car sharing and autonomous vehicles will increase utilization rates of the vehicles and thereby making the total cost of ownership lower for especially premium BEVs.

Lastly, briefly mentioned were the models of battery-swapping and battery as a service (battery-leasing). The views on these varied greatly as one interviewee believed it to be the future of BEVs, whereas two others believed the need for capital would be too big to realize such models.

6.2 RQ 2: Battery Technology Alternatives

6.2.1 Cathode Active Material

As mentioned in Chapter 3 and 4, the CAM constitutes the most expensive part of the battery cell and the biggest bottleneck for cell performance. The importance of choosing an appropriate CAM for a battery cell for the mid automotive market has been validated through the interviews.

Connecting to the output from RQ 1 displayed in Figure 6.1, it is clear that the customers are expected to have altering demands for premium and mid-market BEVs. OEMs expect to pay a lower price per kWh, while sacrificing performance on energy density and fast charging capabilities. Due to the great impact of the CAM on battery cell characteristics, and cost in particular, this leads to the CAM of a mid-market battery cell not being able to maintain the high-nickel CAM (e.g. NMC-811) that fulfils demand for premium BEVs – a lower-cost alternative is required.

CAM alternatives for a lower-cost battery cell for the mid-market that have been raised through the interviews can be categorized into three areas: LFP, Low-Co Ni-Mn oxides, and Old Gen NMC. A comparison between the three based on the interviews is presented in Table 6.1 and the different categories will be further described below.

Table 6.1. Comparison of LFP, Low-Co Ni-Mn oxides and Old Gen NMC cathodes based on the interviews.

	LFP	*Low-Co Ni-Mn oxides*	*Old Gen NMC*
Pros	• Low cost • Existing technology • More stable raw material markets • Good cyclability, reliable	• Good energy density • Lower carbon footprint • Similar competence to NMC	• Good energy density • Existing knowledge • Existing technology • Lower carbon footprint • Can produce in-house
Cons	• Higher carbon footprint • No European supply chain • Different from current competence • Low energy density • May not be possible to produce in-house • Old technology with low development potential	• Not widely implemented in BEVs • Uncertain technology • Unstable raw material markets	• Expensive • Unstable raw material markets

6.2.1.1 LFP

LFP has been extensively mentioned during the interviews and it is clear that it is the obvious low-cost CAM alternative on the global market today. Interviewees meant that, together with NMC and NCA, LFP is an existing and proven chemistry that is widely used in BEVs. However, there are several issues to LFP that have been highlighted during the interviews.

First, the interviewees had a similar perception of the characteristics of LFP as the literature described in Chapter 3 – LFP has a lower energy density than NMC cells but outperforms NMC on both cost and cycle life. One interviewee also highlighted that LFP has issues with fast charging. This cannot be confirmed nor denied with the literature study.

One of the major issues with LFP is that there is no supply chain for LFP present in Europe. Instead, the vast majority of LFP comes from China. The absence of a European supply chain has been mentioned throughout the interviews as a great barrier for a European producer to source and produce LFP battery cells.

Another frequently mentioned flaw with LFP, which goes hand in hand with the supply chain issue, is its carbon footprint. The common opinion is that LFP from China comes with a substantially greater carbon footprint compared to NMC produced in Europe. This is validated by Figure 3.3 where an LFP cell produced in

China emitted 11 times more than Northvolt's emission targets for 2030. The Chinese LFP cathode alone caused five times the emissions compared to same target (Hao et. al., 2017). As explained by one interviewee: "Without a European ecosystem, LFP cannot be done sustainably enough for Northvolt". Not taking region in consideration, an interviewee outside the Northvolt organization specifically mentioned that "regarding climate footprint, LFP would be more sustainable than nickel and cobalt". This statement is also somewhat validated by Figure 3.3, where it is shown that, on cathode level, LFP emits less than NMC (Hao et. al., 2017).

The fact that LFP does not contain the critical metals of nickel and cobalt has frequently been mentioned as a strength for LFP in its hedging of raw material price fluctuation. It has been stated that materials used in LFP are more abundant on Earth and therefore less sensitive to limitations in raw material extractions, resulting in a more reliable supply chain than nickel and cobalt. However, LFP still contains lithium and is exposed to the supply risks that lithium entails.

Two other aspects that have been brought up, but less frequently, are related to weight and age of the technology. The first mentioned concerns the fact that LFP has a relatively low gravimetric energy density which implicates that a large mass is required to reach the battery size required on pack level. Interviewees meant that this issue would make LFP a bad alternative for larger vehicles. The second aspect concerns the fact that LFP is a technology which was developed a long time ago and therefore is a strategically bad choice for future generations of battery cells. More precisely, one interviewee said, "it makes no sense to go back 15 years in time, there are other options to reach low cost", while another interviewee stated, "the potential of the CAM of LFP is maxed out".

The case of LFP as the CAM for a lower-cost battery cell for mid-market BEVs can be well summarized as one interviewee emphasized: "LFP is more a business risk than a technical risk".

6.2.1.2 Low-Co Ni-Mn Oxides

The category of Low-Co Ni-Mn oxides includes nickel and manganese-based CAM where the amount of cobalt has been heavily decreased or eliminated completely. As described in Chapter 3, potential low-cobalt CAMs also has reduced amounts of nickel compared to high-nickel NMC. The reduction of cobalt in oxide CAMs have been highlighted by several interviewees as a potential path to reaching a lower-cost battery cell. As mentioned in Chapter 3, this view is shared by Schmuch et. al. (2018) and Tidblad et. al. (2021). Specific CAMs that have been mentioned in interviews include NMX and LMO. However, according to the technological review, also LNMO and other Li-rich and Ni-rich alternatives could be included in this category, even though it was not mentioned during interviews.

The reduction of cobalt and nickel has secondary effects besides lowering the cost of the cell. Several interviewees mentioned that the two metals are linked with problematic and unsustainable mining – both regarding environmental and social aspects. For cobalt, this is aligned with previously mentioned from Castelvecchi (2021). In addition, the metals' supply chains come with uncertainties regarding prices and securing supply. Even though nickel and cobalt are crucial to produce a high performing battery cell, the interviewees agreed on the fact that reduction of these metals in favor of manganese, if adequate performance is reached, is widely positive.

As with most parameters within the battery cell, the reduction of cobalt does not solely imply positive effects, instead it is subject to tradeoffs. Interviews highlighted that cobalt has important functionality in maintaining the structure of the CAM and consequently there are technical uncertainties associated with these CAMs. This is similar to what Xu et. al. (2020) stated regarding that complete elimination of cobalt will be difficult in coming years. Another interviewee pointed out that these CAMs, and more specifically NMX, have not been commercialized or implemented in BEVs and therefore have inherent uncertainties. These opinions are aligned with Voronina et. al. (2020) and Zhao et. al. (2022).

6.2.1.3 Old Gen NMC

The final group of cathodes that have been brought up during the interviews are old generation NMC. The term old generation implies previous versions of NMC cathodes in the evolution towards higher and higher nickel contents. More specifically, the CAMs that have been mentioned during the interviews include NMC-532 and NMC-622.

The obvious reason why these materials have been suggested during interviews are that these materials exist today and have successfully been deployed into BEVs. Further, interviewees meant that the characteristics of these CAMs, especially the energy density, would be suitable for mid-market EVs. Additionally, Northvolt employees recognized the fact that they already possess the capabilities and competences to produce these types of CAMs.

The main downside with old generation NMC which was highlighted by all interviewees is that old generation of NMC are suspected to be too expensive for mid-market applications. This view correlates well with the cost model by Wentker et. al. (2019) in Figure 4.7.

6.2.1.4 Make or Buy?

Due to the high monetary value of the CAM and its effect on performance, battery cell producers have a choice whether to source the CAM or produce it in-house. When this decision was discussed with the interviewees, several perspectives were lifted. One interviewee highlighted that having the production of CAM in-house has a decisive effect on cost parity – without CAM in-house, a cell producer cannot reach the same cost levels as competitors with internal CAM production. Complementary to this opinion, another interviewee emphasized that there are advantages from a sourcing perspective with having some CAM production in-house and some outsourced since it creates multiple sources of supply. Finally, a third interviewee argued that it is of most importance that the CAM can be sourced locally, regardless of being produced in-house or outsourced.

6.2.2 Anode Active Material

As opposed to the CAM, the AAM has not been frequently mentioned or discussed during the interviews. In fact, when asked about aspects within battery technology that are to be modified for lower-cost battery cells, the AAM has seldom been given any attention. This lack of information and opinions regarding changes needed to the AAM is in itself an insight – CAM and other parts of the battery cell are more important to modify in order to create a lower-cost battery cell.

From the few interviewees that gave any attention to the AAM, they all agreed that increasing amounts of silicon to the graphite is expected. More specifically, one interviewee was convinced that the price of silicon will drop in the future, substantially decreasing the cost per energy for high energy density cells to long-term reach cost parity with low energy density cells.

A final remark that was made on the AAM was concerning the sustainability impact of natural graphite, which the interviewee argued was underrated. Between natural and synthetic graphite, the interviewee meant that natural graphite implicates better cell performance, but a more negative climate impact.

From this input, the only conclusion available is that, for a lower-cost battery cell, the anode will likely not be subject to change into innovative, new materials. Instead, graphite in combination with increasing amounts of silicon is expected.

6.2.3 Future Technologies

When discussing what future technologies that could be relevant to implement for lower-cost battery cell solutions, the interviews brought up two different technologies: solid state and sodium-ion battery cells. Regarding solid state, interviewees inside and outside of the Northvolt organization agreed that the solid state technology will be postponed in time and not be viable within five years. More specifically, one interviewee stated: "OEMs expect cell prices of 60 USD/kWh by 2025 – I cannot imagine that solid state technology will meet that target". Instead, more focus from the interviews have been put on sodium-ion cells, which one interviewee believed will exist within five years.

Where sodium-ion cells have been mentioned, it has been labeled as a promising technology in its early stages. Interviewees meant that sodium-ion cells will have significant cost reduction potential due to the removal of expensive and supply chain problematic metals such as lithium and copper. Regarding the performance of sodium-ion battery cells, interviewees believed that it will be similar to LFP and therefore suitable for budget applications. Overall, the interviewees’ view of sodium-ion cells matches with previously stated theory by Abraham (2020).

6.2.4 Other Aspects

6.2.4.1 Recycling

A subject that has been frequently mentioned by interviewees when discussing battery technology and chemistries for lower-cost battery cells is the recycling of battery cell materials. In general, interviewees regard recycling as something important, mainly due to two aspects: sustainability and raw material price hedging. Interviewees widely agreed that increasing the recycling of battery cells that have reached their end-of-life is one of the greatest levers to create sustainable battery cells. In addition to the sustainability, the fact that recycling can contribute to a lower dependency on raw material mining has been clearly pointed out as a strength. Interviewees highlighted that this could mitigate raw material supply risks, as well as potentially be an economically viable option if the recycling can be done at lower costs than market prices. It has also been made clear that different battery chemistries have different potentials of economically viable recycling, whereas LFP is exemplified as a chemistry with a bad recycling business case and cobalt-containing cells are deemed more advantageous. Finally, several interviewees also stated that there likely will not be a choice regarding recycling – regulations on EU-level will eventually make it a pre-requisite. This is in line with the new Batteries Regulation proposed by the European Commission in 2020 presented in Chapter 4.

6.2.4.2 Process & Other Materials

Besides modifying the cathode material, another way to reduce costs, which has been mentioned by several interviewees is to simplify the production process and the non-active materials involved in the cell. The reduction of steps in the production process is even emphasized by one interviewee as “the best way to reduce costs”. An interviewee highlighted that reducing the amount of non-active material in the cell will both lower the cost of materials involved, and reduce the steps needed in the production process. Regarding the process, another interviewee also underlined the importance of reaching high volumes to really benefit from economies of scale and that this will be fundamental to reach competitive cost levels – aligning well with the outlook on market consolidation by McKinsey & Company (2022).

6.2.4.3 Form Factors

The form factors available for a battery cell – most often cylindrical, prismatic or pouch, which were described in Chapter 3 – was not frequently mentioned by interviewees. Conversely, when it was brought up it was it was deemed as not of specific importance to cost. This partly contradicts Schröder et. al. (2017) who state that cylindrical cells have a simple and cost-efficient production process. Another interviewee mentioned that cylindrical and prismatic – which are the most common form factors for EVs – are the most suitable for automotive applications.

6.2.4.4 Alternative Solution

Another aspect that was brought up during the interviews, although not as frequently, was an alternative way of reaching the demanded performance of a mid-market BEV. More specifically, using expensive, high energy density cells but using a lower number of cells and thereby lowering the total amount of energy to be stored in the battery pack. While this approach may work in theory, one interviewee mentioned that there would be practical limitations such as shortage of voltage. Another interviewee highlighted that OEMs want to have the same number of cells for a premium and mid-market BEV due to efficiencies in vehicle integration costs.

6.3 RQ 3: Outlook on Competitiveness

The analysis of the competitive landscape and strategic possibilities on the electric automotive mid-market was conducted through the Porter's Attractiveness Test and the Better Off Test, with the supporting frameworks Porter's Five Forces and Generic Strategies.

6.3.1 Porter's Five Forces

To understand the market dynamics of the automotive battery mid-market, and conduct the Attractiveness Test, interviewees knowledgeable of the market provided their view of the various aspects of competition, threats from entrants, customers, suppliers, and substitutes. In Figure 6.3 below, an overview of the applied framework from Chapter 5 is provided based on the interviews.

Competition Amongst Current Competitors

- ☑ High fixed costs
- ☐ Many competitors of similar size
- ☑ High exit barriers
- ☐ Slow market growth
- ☐ Low switching costs between manufacturers

Threats of New Entrants

- ☐ Small capital requirements
- ☐ Low product differentiation
- ☐ No economies of scale
- ☐ Easy access to distribution channels
- ☐ No cost-advantage of early entrants

Buyer's Power

- ☑ Big volume purchases
- ☐ Undifferentiated products
- ☑ Price sensitive buyers
- ☑ Buyers could vertically integrate
- ☑ The product does not save the buyer money
- ☐ The quality of the product is insignificant to the buyer

Supplier's Power

- ☑ Only few suppliers
- ☐ Suppliers are highly differentiated
- ☐ Supplier could vertically integrate forward
- ☐ The industry is not an important customer

Threat of Substitutes

- ☐ Substitutes improves performance to lower costs
- ☐ Substitutes emerge from high profit industries

Figure 6.3. Overview of Porter's Five Forces in the automotive battery mid-market based on interview insights.

The more aspects that are fulfilled in each category, the bigger is the force and impact of that aspect on the market. Consequently, as seen in the figure above, the buyer's, in this case the automotive OEMs, have a relatively strong impact on the market followed by competition among competitors. On the other hand, there is no pressing threat of new entrants or substitutes on the market.

6.3.1.1 Competition Amongst Current Competitors

For a premium battery producer in Europe, the main competition is deemed to be competitors from Asia – especially Chinese competitors were mentioned during interviewees. As stated in Chapter 4, the market is growing rapidly, with the mid-market expected to grow in upcoming years. Hence, the competition between battery producers on the market becomes less intense. This is fortified by an interviewee stating that until 2030 there will not be enough production capacity to satisfy the entire market demand. However, this statement contradicts the expected demand and planned production capacity on the European market presented in the report from McKinsey & Company (2021).

Furthermore, the market was described to currently have a low level of standardization – contributing to a high switching cost between producers. Nevertheless, the battery cells are expected to become more standardized as the market matures.

However, another aspect that interviewees reached consensus upon is that there is not enough competence on the market. Hence, producers are competing to attract the existing talent within battery technology. Additionally, this is stated to be especially crucial for the European and American market as there is a bigger lack of competence there compared to on the Asian equivalent.

6.3.1.1.1 Competition with Chinese producers

Majority of interviewees highlighted Chinese players as the main competition. There is an uncertainty and disbelief whether a European producer will be able to compete on price with Chinese produced batteries. Some interviewees further argued that it may not be crucial to be completely on cost parity as other values can be offered such as sustainability and risk mitigation. Nevertheless, it is clear that to be price competitive, there needs to be a more mature supply chain established in Europe, and the European producer needs to obtain the same scale advantages as a Chinese competitor.

Besides Chinese competitors currently having a cost advantage due to local supply chains and economies of scale, multiple interviewees mentioned the cheap labor as a key difference. This is in accordance with the comparison between average labor wages in the EU and minimum wages is China presented in Chapter 4. One interviewee also stated that CAPEX and machinery is less expensive in China. Conversely, it was explained during multiple interviews that access to cheap (and clean) energy is crucial, which is available in Europe and especially in the Nordics.

On the other hand, geopolitical risks and upcoming regulations were mentioned as factors causing incentives for European and US customers to source batteries more locally, even at a premium. As a consequence, as described in Chapter 4, Asian competitors are establishing factories in Europe. This provides some differences regarding a European player's competitive possibilities. According to multiple interviewees it was believed that these competitors will have difficulty attracting necessary talent, as well as potential issues adapting to the European regulations. Additionally, labor and energy costs will be on par if factories are based in the same country. One interviewee also believed that the supply chains and technology will be the same is this situation, whereas others stressed that Asian competitors will have an advantage as they already have established supply chains and factory blueprints from Asia. In summation, interviewees believed that the potential to compete on cost with Asian competitors is better when all factories are based in Europe.

6.3.1.2 Threats of New Entrants

Moving towards the second force, threat of new entrants, it was deemed relatively low. During the interviews two main reasons for the low threat are mentioned. Firstly, as mentioned in previous section, there is a lack of competence in the industry, which will act as a barrier for new entrants. Secondly, there is a need for plenty of capital to enter the market.

According to several interviewees, it is currently more difficult to gain momentum on the market, as other players are becoming large and starting to benefit from economies of scale. Hence, new entrants will not have this advantage, leaving them unfit to compete.

Additionally, one interviewee mentioned new entrants on the European market would be a positive contribution, as “this would force more supply chains to localize in Europe”.

6.3.1.3 Buyer’s Power

Interviewees all agreed that there is some threat from buyers (customers), especially in the long term. Multifarious interviewees mentioned that customers are price sensitive and will most likely choose the cheapest alternative on the market.

Another aspect of the customer’s power is that there was an agreement amongst interviewees that OEMs do want to vertically integrate. The reason behind customers wanting to enter the market is to capture more of the value, as the battery account for a third of the BEV’s value (Boston Consulting Group, 2020), when their core competence of producing ICEs become obsolete. However, several interviews revealed that, currently, customers lack the competence to enter the market. Hence, it is not seen as an immediate threat, although it does raise concerns for the future. Some interviewees mentioned OEMs desire to acquire knowledge of battery production as a reason for the many joint ventures between OEMs and battery producers.

Additionally, established in the interviews, the quality of the battery is of great importance for the customers, as well as securing a reliable supply. Hence, customers in Europe and the US highly value closeness to suppliers and want to source locally according to interviews.

6.3.1.4 Supplier’s Power

On the supplier side, especially the suppliers of CAM were in focus. The view on the threat that these suppliers would vertically integrate according to interviewees was not completely aligned. A few believed that it was possible for CAM producers to enter the battery production market. Although, most interviewees stated that producers of CAM are not a threat at all, predominately due to a lack of knowledge regarding battery production. One interviewee mentioned that CAM production is the more profitable end of the supply chain, and suppliers are hence likely to stay there. Another interviewee that did not see suppliers as a threat mentioned that it may be more reasonable for them to enter the recycling stage of the battery as it is closely related to CAM production.

As priorly stated, a lack of raw material supply is expected in the future, and some of the important metals used in battery production is geographically concentrated – such as cobalt in the Republic of Congo (Castelvecchi, 2021). This aspect, providing power to suppliers, is agreed upon by interviewees that explain a current lack of European battery supply chain. During the interviews it is mentioned that there are several risks for the battery producers when sourcing: geopolitical risks, raw material price uncertainties and difficulty to secure low carbon footprint. It is agreed that there is a need for a clean supply chain.

6.3.1.5 Substitutes

Substitutes on the battery mid-market were seldom discussed during the interviews. The few interviewees that mentioned substitutes to lithium-ion batteries stated that they believe that it is unlikely for a substitute to compete, but if there was such an alternative available at scale, customers would be interested.

Additionally, one interviewee declared that the demand for batteries will be larger than production capacity in 2030. Hence, the need for alternative fuels such as biofuels and diesel will remain. However, this does not align with the predictions of demand done by McKinsey & Company (2021) where announced European production capacity is expected to be sufficient in 2030.

6.3.1.6 The US market

According to interviews, the most prominent difference between the European and US market is level of maturity. It was explained that there are especially fewer battery producers on the US market, hence less competition. That the US market is less mature is supported by McKinsey & Company (2021) who states that the American is delayed in its EV development and will reach similar market penetration, but later in time.

6.3.2 Porter’s Generic Strategies

Whether a European premium battery producer would be better off expanding into the mid-market was analyzed through Porter’s Generic Strategies. According to the framework, a company should focus their strategy on one of the four quadrants, see Figure 5.5.

For a European premium battery producer, such as Northvolt, the unique selling points are used to compete and gain customers. For example, according to the interviews, Northvolt gains competitive advantage due to their European origin, sustainable product, and recycling ambitions. Hence, it is argued that a European premium producer will be in the strategic quadrants of either *differentiation* or *differentiation focus*. The difference between these strategies is whether the entire market is in scope, or if a specific segment is targeted and activities are tailored for this segment. According to Porter’s theory, when entering the automotive mid-market, the premium producer should continue to be unique and either target a segment of the market or the entire mid-market – depending on the current generic strategy.

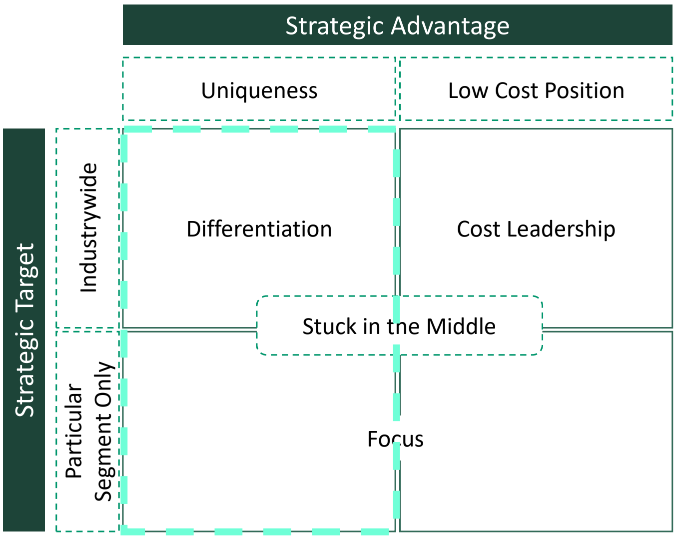


Figure 6.4. Porter’s Generic Strategies with the two quadrants applicable on a European premium battery cell producer marked (adapted from Porter (1985)).

During interviews, multiple respondents agreed that it would be crucial to keep the unique selling points for the mid-market offering as well, such as providing a sustainable option. However, most interviewees were not concerned that moving into a broader target segment or product portfolio could have a negative impact on the company’s performance. Instead, having a lower-cost option, especially based on an alternative chemistry, is expected to lower supply chain risks and capture more of the market growth.

However, it should be noted that the battery industry is currently experiencing rapid growth. In addition, a major share of the growth is expected to occur within the mid-segment as presented in Figure 4.1. Furthermore, it is explained by Porter that during extreme market growth, companies utilizing multiple strategies may regardless be successful. Although as the market matures, companies lacking strategic focus risk getting stuck in the middle and fall behind.

7 Discussion

The following section will provide a further discussion of the results and insights presented in the analysis. First, the match between customer expectations and technological alternatives are discussed, followed by importance and possibilities of strategic alignment. Lastly, risks and possibilities of entering the mid-market are examined.

7.1 Customer Expectations & Technological Limitations

In the first part of the analysis, the interviewees' responses to customer demand and preferences were presented. Through Figure 6.1, which displayed how the interviewees believed that demand from OEMs will differ from a mid-market BEV to a premium BEV, it became clear that the demand on the battery cell for the two vehicles differ. More specifically, the results show that OEMs expect to pay a lower price for a mid-market battery cell and in turn accept a lower energy density and lower fast charging capabilities. This implicates that there is a need for a lower-cost battery cell compared to the high-performing premium cells currently available.

The second part of the analysis targeted the potential battery technologies that could satisfy the previously stated demands. In line with the literature presented in the background, the interviewees agreed that the cathode represents the most important aspect of battery technology that affects the cost and performance of the battery cell. Hence, the opinions from the interviews on cathode materials were categorized into three categories: LFP, Low-Co Ni-Mn oxides and Old Gen NMC. Each of the categories of cathode materials have its inherent advantages and disadvantages, which were presented in Table 6.1. However, how these aspects relate to the customer demands and in turn affect their viability as options will now be further elaborated on.

LFP, being an existing low-cost chemistry, has its obvious advantages of having a lower cost than NMC alternatives and being an existing technology that functions in BEVs. Regarding its performance, LFP has clearly a lower energy density than the cathodes in the other two categories. Theory and interviews agreed that this performance is fully sufficient for low-end BEVs and might also be suitable for mid-market applications. Diving deeper into the mid-market and its two subparts, lower and upper mid (C- and D-segments), it is reasonable to assume that the performance of LFP will likely be a better fit for the lower mid than upper mid – even though it could be sufficient for the entire mid-market. A more pressing issue with LFP is the absence of a European supply chain and in turn the dependency on Asian suppliers. The fact that the cathode production currently is not done on European soil implicates that the LFP material will be subject to a carbon footprint greater than what is expected of NMC produced in Europe. As stated in the analysis, the opinion whether sustainability would be of high importance to OEMs regarding their mid-market BEVs was unclear. Likely, the sustainability of the battery cells will be of different importance to different customers. In summary, when looking at the advantages and disadvantages of LFP in contrast to the predicted demand from OEMs, LFP is still regarded as a potential battery cell option for mid-market BEVs.

With Low-Co Ni-Mn oxides, several of its advantages point to it being a promising candidate for mid-market BEV applications. The chemistry has potentials of reaching lower cost than high performing NMC (see Figure 4.7), energy density greater than LFP (see Figure 3.2) and more similar to NMC in battery chemistry than LFP. All of these aspects resonate well with the demands from OEMs regarding mid-market BEVs. To make a similar comparison as with LFP regarding the subsets of the mid-market, it is reasonable to assume that Low-Co Ni-Mn oxides will primarily be attractive for the upper mid-segment, given its potentially higher cost and higher energy density in relation to LFP. But at the right price levels, it may be appealing to the entire mid-market. The major disadvantages with this category of CAMs are its uncertainties and lack of proven performance. Even though LNMO, and NMX are technologies that exist today, they have not been widely commercialized in BEVs. However, with the time frame being 2025-2030, Low-Co Ni-Mn oxides are still regarded as potential candidates.

The final category of CAMs, Old Gen NMC, has advantages of being a technology which exists in BEVs today and has performance aspects that matches the expected demand. However, as both the cost modeling in Figure 4.7 and some interviews state, it will be expensive. Figure 4.7 shows that, looking solely at the cathode, it will be even more expensive per kWh than NMC-811, which is regarded as state-of-the-art technology. Old Gen NMC will also contain more of the critical metal cobalt than its newer generations, going against the trend of reducing cobalt in order to reach lower costs. From what this thesis has found, and that OEMs are predicted to demand a lower price from cells to their mid-market BEVs than their premium BEVs, Old Gen NMC will not be a competitive option as cathode material for a mid-market battery cell.

7.2 Competitive Cell Offering

7.2.1 Aligning Cell Chemistry with Unique Selling Points

As been established through the theories presented by Porter, a firm that attempts to follow two different competitive strategies simultaneously will likely find themselves stuck in the middle. This, in turn, implies below-average profitability in the industry and not achieving a sustainable competitive advantage. In the case of a European premium battery cell producer, it was in the previous chapter highlighted that the product diversification into lower-cost battery cells for the BEV mid-market should follow the same competitive strategy as the premium offering for the firm to remain competitive. This will be especially important due to the relatively high force of competition on the automotive battery mid-market and suspected future consolidation.

A possible way of maintaining the competitive strategy aligned with the new offering is to keep the unique selling points, upon which the firm is differentiating on, similar. For a European premium battery producer with sustainability as the core value entering the mid-market, this would mean keeping the sustainability and quality high even though offering a lower performing product.

Connecting back to the alternative of battery cell chemistries, this would imply that the chemistry chosen for a mid-market offering should be of high quality and have good sustainability aspects. The two categories of CAM that were deemed to satisfy customer demand – LFP and Low-Co Ni-Mn oxides – have some different properties regarding these aspects. Regarding quality, LFP has been described in interviews as “reliable” and exists in the market today. Low-Co Ni-Mn oxides have its uncertainties regarding commercial production. However, these differences are not regarded as significant enough for a chemistry to be disregarded at this point. For the aspect of sustainability, however, the differences are clearer. Low-Co Ni-Mn oxides have similar materials as NMC CAMs that are being produced sustainably today. Hence, there is potential to produce the Low-Co Ni-Mn oxide in a sustainable manner. However, the fact that LFP currently lacks a European supply chain, producers are left with the option of sourcing LFP CAM from China with a great carbon footprint. Offering an LFP cell to the mid-market with such a carbon footprint will clearly go against the unique selling point of high sustainability. This leads to the conclusion that without a European supply chain, a European premium battery cell producer will not be able to include an LFP cell in its offering and remain competitive based on sustainability as a unique selling point. The implication of this is that the category of CAM both meeting the expected demands of OEMs and following the same competitive strategy as a sustainable, premium offering, is Low-Co Ni-Mn oxides.

In theory, a European premium battery cell producer would be able to have the same competitive strategy for their premium offering and their mid-market offering by differentiating on completely different aspects. E.g., offering a very sustainable premium product while at the same time offering a mid-market product which is unsustainable but with valuable, short lead times. However, as high sustainability is set as scope for this thesis, this theoretical approach will be disregarded. In either way, the authors suspect that being inconsistent with a unique selling point such as sustainability could result in a weakened brand and company credibility overall.

7.2.2 Potential Competitive Strategies

As stated above, a diversification into the BEV mid-market for a premium producer should follow the same competitive strategy. Looking at the framework of Porter's Generic Strategies, it was established that a premium battery cell producer reaches competitive advantages by differentiating rather than offering the lowest price. Hence, to maintain the same competitive strategy the new venture should be based upon either *differentiation* or *differentiation focus*, depending on the strategy of the premium offering. Therefore, in the following sections the implications of these two generic strategies are discussed separately.

7.2.2.1 Differentiation

The generic strategy of differentiation implies targeting the entire market, and not a particular segment of the market. Hence, if the premium offering follows this strategy, so should the mid-market offering. This implies offering a product that would target both the lower and upper mid-market (Segment-C and Segment-D according to Figure 4.2). The entire mid-market is expected to represent over 60% of the BEV production in Europe, with the lower mid-segment being the greater sub-segment.

For a European producer valuing sustainability, keeping the sustainability aspect high for the entire mid-market might be troublesome. As the *Battery Regulation* is not in full force until 2030 (European Commission, 2020a), competitors may offer less sustainable products at lower prices. This is likely to be preferred by many customers, especially in the lower end of the mid-market, based on the assumption that the price sensitivity increases towards the lower end of the market. Therefore, to be competitive on the broader mid-market the price of the battery cell must be on par with competitors.

With current technology outlook, interviewees explained that Asian-produced cells based on LFP technology will be the most low-cost alternative on the market and that European based cell suppliers will have a hard time reaching the same price levels. More specifically, it is likely that Low-Co Ni-Mn oxide-based cell chemistry with good sustainability aspects will not reach such cost levels. Consequently, a European premium producer with an industrywide target may not be able to value sustainability and simultaneously be competitive on the broader mid-market. At least not while there is no European LFP supply chain in place.

Therefore, offering a low-cobalt chemistry cell to the entire mid-market might still be a choice that generates sales volumes and profits while the market grows. However, without a clear and consistent strategy the company risks losing focus and falling behind competitors when the market growth stagnates.

7.2.2.2 Differentiation Focus

With the generic competitive strategy of differentiation focus, the scope of the focal firm changes from industry wide to targeting a particular segment of the market and tailoring its activities to that segment.

For a European premium battery cell producer, it is reasonable to assume that the mid-market segment of interest if applying a focus strategy, would be the upper mid-segment (D-Segment). This segment is likely closer to the customers of the premium offering. It is also believed that the upper mid-market would value sustainable solutions and quality higher than their lower mid counterparts, which would simplify the task of maintaining the unique selling points. Additionally, the upper mid-segment in Europe is expected to experience the greatest growth of all segments in upcoming years, as seen in Figure 4.1.

Based on the same assumption as above, that price sensitivity increases towards the lower end of the market, the upper mid-segment would be less likely to value an unsustainable low-cost offering than the lower mid-segment. Additionally, it might be that the performance of low-cost LFP would not be sufficient for the demands of the upper mid-market. In these regards, the most suitable mid-market cell option for a European premium battery cell producer – Low-Co Ni-Mn oxides – might be especially suitable for the upper mid-market. More specifically, this could entail cathode materials such as LNMO, LMO or NMX.

7.2.3 Potentials & Risks of Entering the Mid-Market

7.2.3.1 Mid-Market Potential

From the analysis made of the market attractiveness it is concluded that the mid-market is attractive to enter for an established premium producer. The main reason is the extensive growth that is expected in the upcoming years, in combination with low threats of new entrants and substitutes. The principal threat on the market is customers vertically integrating, and competitors reaching lower price points. However, the customers currently lack competence to enter battery production, and upcoming regulations in combination with unique selling points may mitigate the risk of offering a premium price compared to the largest competitors.

Moreover, by not entering the market the producer risks losing potential revenue streams from a growing promising market to competitors. As the mid-market is expected to become the largest market for BEVs, it will be a substantial part of the entire EV battery cell market. Another reason in favor of offering a lower-cost battery cell as a premium producer is that developing an alternative chemistry to the high nickel cathodes will potentially mitigate supply chain risks. Less cobalt and nickel will result in a safer supply and reduced social issues within the supply chain.

Furthermore, if the supply chain for a lower-cost battery cell is established in Europe, this may further appeal to customers seeking mitigation of geopolitical risks. Consequently, aiding the company in the competition on the mid-market.

7.2.3.2 Mid-Market Risks

With the right strategy, there is positive potential of entering the mid-market, although, several risks are identified related to such a venture.

Firstly, if the producer fails to communicate the sustained unique selling points of the new offering, existing customers may perceive the company as less premium. Another risk is that the company itself may get torn between different focuses and the strategy becomes blurred.

Secondly, depending on which battery technology and CAM the producer will chose to develop, competence requirements may differ from current capabilities. Especially if the new CAM is not similar to the premium offering. Hence, there may be a risk of not attracting the right knowledge to be competitive.

Another aspect that should be mentioned is the risk of lack of need for specific lower-cost batteries. According to some interviews, an alternative to lower-cost batteries for the mid-market could be to utilize the current premium technology, but in smaller quantities – lowering both cost and performance.

Lastly, raw material price spikes and future geopolitical developments may prolong the adoption of BEVs. Thereby, the growth of the mid-market may not be as rapid as expected.

7.2.3.3 The US Mid-Market Potential

The above reasoning is mainly applicable on the European market. However, looking to the US market, the information gathered throughout the thesis point to similar conclusions.

Firstly, the competitive environment in the US have been explained to be less intense and mature compared to the European and Asian battery markets – with less competitors. This strengthens the argument that the American market would be attractive to enter. However, as the other aspects of the US mid-market are rarely mentioned and hence not completely investigated, the actual attractiveness of the US mid-market is left unanswered.

Regarding the importance of strategic alignment, this is expected to be crucial regardless of market, and hence maintaining the sustainability aspect is still important. For the US market, potentials of producing sustainable batteries are assumed to be similar to Europe, and better than in China (see Figure 3.3). Additionally, as mentioned during interviews, the American end customers are expected to demand better performance, especially concerning the range of the batteries. Therefore, as LFP has relatively low energy density, and the aspect of sustainability is still important, the option of Low-Co Ni-Mn oxides may be most suitable for the US mid-market as well.

8 Conclusions

The following chapter will present a final answer to each of the RQs, in addition to suggestions for future research and limitations on the conducted study.

8.1 Answers to RQs

8.1.1 RQ 1

What are the customer expectations on performance, sustainability (environmental and social), and price of battery cells for the BEV mid-market?

This thesis found several dimensions to answer this first RQ. Firstly, the conclusion has been made that there exists a need for a different type of battery cell for a mid-market BEV compared to a premium BEV. For mid-market BEVs, price has been identified as the single most important aspects for OEMs. In comparison with the cell demand for a premium BEV, OEMs expect to pay a lower price per kWh for a mid-market cell, while sacrificing performance on energy density and fast charging capabilities. Regarding the cyclability of the cell, similar cycle counts are expected. While the above accounts for demands of European based OEMs, the thesis found that the most likely difference for American based OEMs is that they will demand more range and therefore greater energy densities and/or larger pack sizes.

Whether sustainability will be regarded as of more or less importance for a mid-market BEV cell than for a premium BEV cell has not been made clear through this thesis. Instead, a rather scattered image has been portrayed which has resulted in an uncertainty in how the OEMs will value sustainability for mid-market cells. However, with price being the most important aspect for mid-market cells, OEMs might be more reluctant to pay a premium for sustainability aspects for cells for their mid-market BEVs.

Regarding the cost on cell level for mid-market BEVs, 60-80 USD/kWh is expected in 2030 looking at both published literature and interviews. In terms of price, this interval will naturally be slightly higher. However, recent and upcoming raw material price fluctuations will likely have great impact on the predicted price decrease.

8.1.2 RQ 2

What are potential alternatives of battery technology satisfying the demand of a mid-market BEV?

In order to reach a price level satisfying the demand from OEMs on battery cells for mid-market BEVs, the CAM was identified as the most important aspect to modify. Additionally, simplifying cell design and process steps, as well as reaching production capacities leveraging economies of scale, will be further important cost reducing levers.

Three groups of suitable CAMs were identified: LFP, Low-Co Ni-Mn oxides and Old Gen NMC. Each category has its inherent advantages and disadvantages which have been elaborated upon. Through the analysis and discussion, LFP without a European supply chain was deemed too unsustainable and Old Gen NMC was concluded too expensive. This leaves Low-Co Ni-Mn oxides as the most promising category of CAMs for mid-market BEV applications. As there are several potential options with reduced amount of cobalt among oxide cathodes, further investigation is required to find a specific CAM that fulfils customer requirements and is commercially viable.

Regardless of choice of CAM, recycling of included cell materials has been found to be of great importance in order to (1) create a truly sustainable battery and (2) hedge for raw material price and supply uncertainties.

8.1.3 RQ 3

What is the outlook for a European premium battery cell producer to be competitive on the BEV mid-market?

The investigation of the third RQ through Porter's Five Forces and Generic Strategies resulted in the conclusion that the automotive battery cell mid-market is structurally attractive to enter for a European premium battery cell producer and that the outlook for competitiveness will depend on strategic alignment with the premium offering. Further, the upper mid-segment is deemed the most promising.

The structural attractiveness of the automotive battery cell mid-market was concluded through the fact that the market is growing, while displaying low threats of new entrants, suppliers, and substitutes. The strongest forces on the market will be competition and future willingness of buyers (customers) to vertically integrate.

Furthermore, for a European premium battery producer with a prerequisite to keep sustainability high, the most promising sub-market to enter is deemed to be the upper mid-market. This is since customers in the upper mid-segment are believed to be more similar to the premium customers – hence less price sensitive for sustainable cell offerings – than customers in the lower mid-segment. In addition, the upper mid-market is expected to grow substantially during upcoming years.

Strategically, it was described that a premium producer should follow the same competitive strategy when entering the mid-market as used on the premium market to obtain sustainable competitive advantage. In practice, the thesis found that for a premium producer, the unique selling points should be maintained to increase chances of succeeding on the market.

Due to the overall BEV market being projected to experience significant growth the coming decade, strategically unaligned offerings are likely to still be profitable. However, not achieving a sustainable competitive advantage in the industry will be a risk when growth stagnates, and the market consolidates.

8.2 Implications of Thesis on The UNSDGs

Related to the UNSDGs it has been established that the passenger vehicle transport sector stands for a large part in greenhouse gas emissions (United Nations, 2021). Stated in the introduction, the scope of this thesis related to mainly the goals 11 – Sustainable Cities and Communities, 12 – Responsible Consumption and Production, and goal 13 – Climate Action. Although, many other goals were touched upon as well. To reach these goals, there is a need for sustainable and affordable options to ICEs.

The thesis was somewhat inconclusive on the demand for sustainable alternatives from customers. However, the alternative CAMs sustainable potentials were discussed, and the conclusions revealed that there are sustainable options to produce lower-cost batteries – especially the option of Low-Co Ni-Mn oxides. The thesis also elaborated upon the importance of recycling that is economically beneficial and that recycling the CAM can mitigate supply chain risks and rising raw material prices. Thereby, the results further contribute to incentives for the battery industry to increase recycling efforts.

8.3 Limitations, Validity & Reliability

Due to the restricted scope of the thesis, some limitations of the study have been identified. First, as explained in Chapter 5, only two out of three of Porter's tests were applied to the market in question. Another limitation of the research is the granularity available when dividing the automotive market into low, mid, and premium vehicles. The division used in the thesis placed the entirety of the D-segment within the mid-market. However, closer review of the individual vehicles in the D-segment indicates that some models may be more suited as part of the premium market.

When addressing the validity of the research, it is noted that the limitation on granularity of the division of segments may have affected the expected market size. Additionally, the limited number of interviews can be argued to decrease the validity of the findings. Furthermore, most interviews were internal at Northvolt, which may cause a bias related to the company. As mentioned, when describing the method in Chapter 2, there has been a lack of interviews directly with customers due to difficulty reaching these people. This may affect the validity, as the opinions of customers were gathered though mainly second-hand sources.

Furthermore, some questions related to reliability occurs as interviews were only conducted once with each interviewee due to the limited timeframe of the thesis. This restricts the possibility to confirm findings through comparing answers from the same interviewee over time. As the interviews may be influenced by the researcher's and respondent's biases, it is not possible to guarantee that repeating the study would yield the same results. However, besides increasing validity, broadening the number of interview subjects could have helped mitigate this risk.

Lastly, despite various shortcomings of the thesis, through the triangulation of information from interviews and literature, valuable results have been obtained. The research provides a comprehensive overview of expectations on performance, future technological possibilities, and evaluation of the attractiveness of the automotive battery cell mid-market. The results are valuable for all European battery producers with ambitions to move from the premium BEV market to the mid-market – while being mindful of their environmental footprint.

8.4 Future Research

Throughout the research process, questions relevant to the subject but out of scope for this thesis were discovered.

Firstly, the analysis of the interviews described that there will likely exist an overlap between what type of battery cells that will be used in different BEV segments. In other words, a premium car might also use lower-cost battery cells designed for mid-market BEVs and vice versa. In this thesis, the authors assumed that this overlap would be uniform and thereby not affect the market shares of the different battery cells' potential addressable markets. However, this assumption should be challenged, and the authors argue that a better understanding of the total addressable market for mid-market battery cells will be obtained by investigating the true nature of this overlap.

Another aspect which may limit the market for battery cells based on lower-cost chemistries is the potential usage of current premium battery technologies in less quantities. This option should be further explored in depth, as this study only briefly introduced the alternative.

Lastly, before entering the battery cell mid-market it is of importance to examine the various chemistries' possibilities to be recycled in an economically viable manner. As described in the analysis, it is important to mitigate supply chain risks and strengthen the sustainable offer through recycling of the CAM. The incentive for recycling increases with the value of the recycled material and should hence be included in the choice of lower-cost chemistry. In addition, other aspects of cost reduction on lithium-ion batteries not related to the CAM should be further examined. In particular, possible process improvements should be investigated as they account for the second largest battery cell cost (see Figure 4.4).

9 References

Abraham, K. M. (2020). How Comparable Are Sodium-Ion Batteries to Lithium-Ion Counterparts?. *ACS Energy Lett. 5: 3544−3547.* https://dx.doi.org/10.1021/acsenergylett.0c02181

Abuelsamid, S. (2022). Spiking Nickel Prices Could Accelerate Use Of Iron Batteries. *Forbes*. Retrieved April 19, 2022, from https://www.forbes.com/sites/samabuelsamid/2022/03/11/spiking-nickel-prices-could-accelerate-use-of-iron-batteries/?sh=61e41aa2b508

Abdelbaky, M., Peeters, J. R., Duflou, J. R. & Dewulf, W. (2020) Forecasting the EU recycling potential for batteries from electric vehicles. *Procedia CIRP, 90: 432-436.* https://doi.org/10.1016/j.procir.2020.01.109.

Ansoff, H. I. (1957). Strategies for Diversification. *Harvard Business Review, September–October, 1957.*

Armand M., Axmann P., Bresser D., Copley M., Edström K.,Ekberg C.,Guyomard D., Lestriez B., Novák P., Petranikova M., Porcher W., Trabesinger S., Wohlfahrt-Mehrens M. & Zhang H. (2020). Lithium-ion batteries – Current state of the art and anticipated developments. *Journal of Power Sources, 479.* https://doi.org/10.1016/j.jpowsour.2020.228708

Aytan, S. K. (2022). *Business Research Methodology*. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-030-76857-7

Bain & Company. (2020). *Electric and Autonomous Vehicles: The Future Is Now*. Bain & Company. Retrieved May 16, 2022, from https://www.bain.com/insights/electric-and-autonomous-vehicles-the-future-is-now/

Berg, H. (2015). *Batteries for Electric Vehicles*. Cambridge, United Kingdom: Cambridge University Press. https://doi.org/10.1017/CBO9781316090978

Blomkvist, P. & Hallin, A. *Method for engineering students* (1st ed.). Lund, Sweden: Studentlitteratur

BloombergNEF. (2020). *China Dominates the Lithium-ion Battery Supply Chain, but Europe is on the Rise*. Retrieved Febuary 22, 2022, from https://about.bnef.com/blog/china-dominates-the-lithium-ion-battery-supply-chain-but-europe-is-on-the-rise/

BloombergNEF. (2021a). *Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite*. Retrieved Feburary 22, 2022, from https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite/

BloombergNEF. (2021b). *Battery Breakdown*. Retrieved May 09, 2022, from https://www.bloomberg.com/news/newsletters/2021-09-14/ev-battery-prices-risk-reversing-downward-trend-as-metals-surge

BloombergNEF. (2021c). *Battery Price Declines Slow Down in Latest Pricing Survey*: *BNEF's 2021 survey is a wake-up call for the battery industry — prices may not necessarily fall every year.* Retrieved May 16, 2022, from https://www.bloomberg.com/news/articles/2021-11-30/battery-price-declines-slow-down-in-latest-pricing-survey

Boston Consulting Group. (2010). *Batteries for Electric Cars Challenges, Opportunities, and the Outlook to 2020.* Retrieved April 25, 2022, from https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/file36615.pdf

Boston Consulting Group. (2018). *The Future of Battery Production for Electric Vehicles*. Retrieved March 9, 2022, from https://www.bcg.com/publications/2018/future-battery-production-electric-vehicles

Boston Consulting Group. (2020). *Shifting Gears in Auto Manufacturing*. Retrieved May 09, 2022, from https://www.bcg.com/publications/2020/transformative-impact-of-electric-vehicles-on-auto-manufacturing

Brink, H.I.L. (1993). Validity and reliability in qualitative research. *Curationis, 16(2): 35-38.* https://doi.org/10.4102/curationis.v16i2.1396

Brink, P. J. (1991). Issues of reliability and validity. *Qualitative nursing research: A contemporary dialogue, 164-186.*

Castelvecchi, D. (2021). Electric cars and batteries: how will the world produce enough? *Nature, 596: 336-339.* https://doi.org/10.1038/d41586-021-02222-1

de Rubens, G. Z., Noel, L., Kester, J. & Sovacool, B. K. (2019). The market case for electric mobility: Investigating electric vehicle business models for mass adoption. *Energy, 194.* https://doi.org/10.1016/j.energy.2019.116841

Denscombe, M. (2010). *The Good Research Guide* (4th ed.). Maidenhead, United Kingdom: Open University Press.

Duffner, F., Mauler, L., Wentker, M., Leker, J. & Winter, M. (2021). Large-scale automotive battery cell manufacturing: Analyzing strategic and operational effects on manufacturing costs. *International Journal of Production Economics, 232*. https://doi.org/10.1016/j.ijpe.2020.107982

Deloitte. (2022). 2022 *Global Automotive Consumer Study: Tracking key trends in the automotive industry*. Retrieved May 18, 2022, from https://www2.deloitte.com/global/en/pages/consumer-business/articles/global-automotive-consumer-study.html

EERE. (2022). *Price the material used for cathodes in electric vehicle lithium-ion batteries between 2015 and 2021 (in U.S. dollars per pound)* [Graph]. In Statista. Retrieved May 05, 2022, from https://www.statista.com/statistics/1294777/battery-cathode-material-price/

European Commission. (1999). *Regulation (EEC) No 4064/89 Merger Procedure*. Retrieved February 27, 2022, from https://ec.europa.eu/competition/mergers/cases/decisions/m1406_en.pdf

European Commission. (2020a). *Questions and Answers on Sustainable Batteries Regulation*. Retrieved May 15, 2022, from https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_2311

European Commission. (2020b). *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020*. Document 52020PC0798. Retrieved May 15, 2022, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020PC0798

European Commission. (2020c). *Green Deal: Sustainable batteries for a circular and climate neutral economy*. Retrieved May 15, 2022, from https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312

European Commission. (2021). *Sustainable batteries in their full life-cycle: a step forward towards circular economy and climate neutrality*. https://doi.org/10.2779/430546

European Commission. (n.d.). *Vehicle categories*. Retrieved February 27, 2022, from https://ec.europa.eu/growth/sectors/automotive-industry/vehicle-categories_en

Eurostat. (2021). *Average hourly labor cost in selected European countries in 2020 (in euros)*. In Statista. Retrieved May 19, 2022, from https://www.statista.com/statistics/1211601/hourly-labor-cost-in-europe/

EV Database. (2022). Retrieved April 7, 2022, from https://ev-database.org/

Fastmarkets. (2022). *Lithium prices rose more than 400% in 2021; supply agreements failed to keep up*. Retrieved April 19, 2022, from https://www.fastmarkets.com/insights/lithium-prices-rose-more-than-400-in-2021-supply-agreements-failed-to-keep-up

Fichtner, M. (2022). Recent Research and Progress in Batteries for Electric Vehicles. *Batteries and Supercaps*, *5(2)*. https://doi.org/10.1002/batt.202100224

Greenwood, M., Wentker, M & Leker, J. (2021). A region-specific raw material and lithium-ion battery criticality methodology with an assessment of NMC cathode technology. *Applied Energy, 302*. https://doi.org/10.1016/j.apenergy.2021.117512

Hair, J. F., Page, M. & Brunsveld, N. (2020). *Essentials of Business Research Methods* (4th ed.). Routledge.

Huang, Y. & Qian, L. (2021). Consumer adoption of electric vehicles in alternative business models. *Energy Policy, 155.* https://doi.org/10.1016/j.enpol.2021.112338

Huang, Y., Qian, L., Soopramanien, D. & Tyfield, D. (2021). Buy, lease, or share? Consumer preferences for innovative business models in the market for electric vehicles. *Technological Forecasting & Social Change, 166.* https://doi.org/10.1016/j.techfore.2021.120639

Höst, M., Regnell, B. & Runeson, P. (2006). *Att genomföra examensarbete*. Lund, Sweden: Studentlitteratur

IDTechEx. (2021). *Volkswagen's Long-term, High-Manganese Cathode Strategy*. Retrieved April 25, 2022 from https://www.idtechex.com/de/research-article/volkswagens-long-term-high-manganese-cathode-strategy/23431

IHS Markit. (2022). *E-Mobility – Battery Cell Supplier Database*.

Intercalation & Volta foundation. (2022). *The Battery Report 2021.* Retrieved May 16, 2022, from http://109ee710-a8f3-4a8a-9952-28554c7df7a5.usrfiles.com/ugd/109ee7_775f8efa3d034d439124b5431ff095a1.pdf

International Energy Agency. (2021). *Global EV Outlook 2021*. Retrieved February 22, 2022, from https://www.iea.org/reports/global-ev-outlook-2021

Kennedy, R. (2020). *Strategic Management*. Blacksburg, VA: Virginia Tech Publishing. https://doi.org/10.21061/strategicmanagement CC BY NC-SA 3.0

König, A., Nicoletti, L., Schröder, D., Wolff, S., Waclaw, A. & Lienkamp, M. (2021). An Overview of Parameter and Cost for Battery Electric Vehicles. *World Electric Vehicle Journal, 12(1)*. https://doi.org/10.3390/wevj12010021

Liu Y., Zhang, R., Wang, J. & Wang, Y. (2021). Current and future lithium-ion battery manufacturing. *iScience, 24(4)*. https://doi.org/10.1016/j.isci.2021.102332

Marinaro, M., Bresser, D., Beyer, E., Faguy, P., Hosoi, K., Li, H., Sakovica, J., Amine, K., Wohlfahrt-Mehrens, M. & Passerini, S. (2020). Bringing forward the development of battery cells for automotive applications: Perspective of R&D activities in China, Japan, the EU and the USA. *Journal of Power Sources, 459.* https://doi.org/10.1016/j.jpowsour.2020.228073

Masias, A., Marcicki, J. & Paxton, A. W. (2021). Opportunities and Challenges of Lithium Ion Batteries in Automotive Applications. *ACS Energy Lett*, 6(2): 621-630. https://doi.org/10.1021/acsenergylett.0c02584

Mauler, L., Duffner, F. & Leker, J. (2021). Economies of scale in battery cell manufacturing: The impact of material and process innovations. *Applied Energy, 286.* https://doi.org/10.1016/j.apenergy.2021.116499.

Mauler, L., Lou, X., Duffner, F. & Leker, J. (2022). Technological innovation vs. tightening raw material markets: falling battery costs put at risk. *Energy Advances, 1: 136-145*. https://doi.org/10.1039/D1YA00052G

Mehta, D. & Senn-Kalb, L. (2021). *In-depth Report: eMobility 2021*. Statista. Retrieved Febraury 22, 2022, from https://www.statista.com/study/49240/emobility/

McKinsey & Company. (2018). *Lithium and cobalt – a tale of two commodities*. Retrieved May 16, 2022, from https://www.mckinsey.com/~/media/mckinsey/industries/metals%20and%20mining/our%20insights/lithium%20and%20cobalt%20a%20tale%20of%20two%20commodities/lithium-and-cobalt-a-tale-of-two-commodities.pdf

McKinsey & Company. (2021). *Why the automotive future is electric*. McKinsey Center for Future Mobility. Retrieved February 1, 2022, from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/why-the-automotive-future-is-electric

McKinsey & Company. (2022). *Capturing the battery value-chain opportunity*. Retrieved March 9, 2022, from https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/capturing-the-battery-value-chain-opportunity

MOHRSS. (2022). *Minimum wage per hour in China as of January 2022, by region (in yuan per hour.* In Statista. Retrieved May 19, 2022, from https://www.statista.com/statistics/233886/minimum-wage-per-hour-in-china-by-city-and-province/

Miao, Y., Hynan, P., von Jouanne, A. & Yokochi, A. (2019). Current Li-Ion Battery Technologies in Electric Vehicles and Opportunities for Advancements. *Energies*, *12(6): 1074*. https://doi.org/10.3390/en12061074

Nitta, N., Wu, F., Lee, J. T. & Yushin, G. (2015). Li-ion battery materials: present and future. *Materials Today, 18(5): 252-264.* https://doi.org/10.1016/j.mattod.2014.10.040

Northvolt. (n.d.a). *About*. Retrieved May 17, 2022, from https://northvolt.com/about/

Northvolt. (n.d.b). *Northvolt Chronicles*. Retrieved May 17, 2022, from https://chronicles.northvolt.com/

Northvolt. (n.d.c). *Environment*. Retrieved May 21, 2022, from https://northvolt.com/environment/

Palandrani, P. (2020). *Four Companies Leading the Rise of Lithium & Battery Technology*. Global X. Retrieved Febuary 24, 2022, from https://www.globalxetfs.com/four-companies-leading-the-rise-of-lithium-battery-technology/

Penisa, X.N., Castro, M.T., Pascasio, J.D.A., Esparcia, E.A. Jr., Schmidt, O. & Ocon, J.D. (2020). Projecting the Price of Lithium-Ion NMC Battery Packs Using a Multifactor Learning Curve Model. *Energies, 13(20)*. https://doi.org/10.3390/en13205276

Porter, M. E. (1979). How Competitve Forces Shape Strategy. *Harvard Business Review, March – April, 1979*.

Porter, M. E. (1985). *Competitive Advantage: Creating and Sustaining Superior Performance*. New York: The Free Press

Porter, M. E. (1987). From Competitive Advantage to Corporate Strategy. *Harvard Business Review, May, 1987*.

Salgado, R., Danzi, F., Oliveira, J., El-Azab, A., Camanho, P. & Braga, M. (2021). The Latest Trends in Electric Vehicles Batteries. *Molecules, 26*. https://doi.org/10.3390/molecules26113188

Selvakumar, S. G. (2021). Electric and Hybrid Vehicles – A Comprehensive Overview. *2021 IEEE 2nd International Conference on Electrical Power and Energy Systems (ICEPES)*. https://doi.org/10.1109/ICEPES52894.2021.9699557

Schmuch, R., Wagner, R., Hörpel, G., Placke, T. & Winter, M. (2018). Performance and cost of materials for lithium-based rechargeable automotive batteries. *Nature Energy*, *3: 267–278*. https://doi.org/10.1038/s41560-018-0107-2

Schröder, R., Aydemir, M. & Seliger, G. (2017). Comparatively Assessing different Shapes of Lithium-ion Battery Cells. *Procedia Manufacturing, 8*. https://doi.org/10.1016/j.promfg.2017.02.013.

Sripad, S., Bills, A. & Viswanathan, V. (2021). The Iron Age of Automotive Batteries: Techno-economic assessment of batteries with lithium metal anodes paired with iron phosphate cathodes. https://doi.org/10.1149/osf.io/fx4p9

SVOLT. (2021). *Completely cobalt-free battery cells from svolt roll off the production line.* Retrieved May 16, 2022, from https://svolt-eu.com/en/completely-cobalt-free-battery-cells-from-svolt-roll-off-the-production-line/

The Royal Swedish Academy of Sciences. (2019). *They developed the world's most powerful battery.* Retrieved February 11, 2022, from https://www.nobelprize.org/prizes/chemistry/2019/popular-information/

Tidblad, A.A., Edström, K., Hernández, G., de Meatza, I., Landa-Medrano, I., Jacas Biendicho, J., Trilla, L., Buysse, M., Ierides, M., Horno, B.P., et al. (2021). Future Material Developments for Electric Vehicle Battery Cells Answering Growing Demands from an End-User Perspective. *Energies, 14(14)*. https://doi.org/10.3390/en14144223

Tomaszewska, A., Chu, Z., Feng, X., O'Kane, S., Liu, X., Chen, J., Ji, C., Endler, E., Li, R., Liu, L., Li, Y., Zheng, S., Vetterlein, S., Gao, M., Du, J., Parkes, M., Ouyang, M., Marinescu, M., Offer, G. & Wu, B. (2019). Lithium-ion battery fast charging: A review. *eTransportation, 1*. https://doi.org/10.1016/j.etran.2019.100011

Tyler-Dudley, D., Ferguson, J., Liu, S. and Valdez, K. (2021). *CATL: China's Battery King*. Harvard Business School.

Ulrich, L. (2021). *The Top 10 EV Battery Makers CATL, LG Chem, and Panasonic control 69 percent of the market*. IEEE Spectrum. Retrieved Feburary 22, 2022, from https://spectrum.ieee.org/the-top-10-ev-battery-makers

United Nations. (2018). *Accelerating Sdg 7 Achievement Policy Brief 16 Interlinkages Between Energy And Transport*. Retrieved May 13, 2022, from https://sustainabledevelopment.un.org/content/documents/17501PB16.pdf

United Nations. (2021). Sustainable transport, sustainable development. *Interagency report for second Global Sustainable Transport Conference*.

United Nations. (n.d.a). *The 17 Goals*. Retrieved May 23, 2022, from https://sdgs.un.org/goals

United Nations. (n.d.b). *Sustainable transport*. Retrieved May 13, 2022, from https://sdgs.un.org/topics/sustainable-transport

United Nations. (n.d.c). *Ensure sustainable consumption and production patterns*. Retrieved May 13, 2022, from https://unstats.un.org/sdgs/report/2021/Goal-12/

University of Washington. (n.d.). *Lithium-ion battery*. Retrieved February 11, 2022, from https://www.cei.washington.edu/education/science-of-solar/battery-technology/

U.S. Geological Survey. (2021). *Mineral commodity summaries 2021: U.S. Geological Survey*. https://doi.org/10.3133/mcs2021

US Geological Survey. (2022). *Average lithium carbonate price from 2010 to 2021* (in *U.S. dollars per metric ton)* [Graph]. In Statista. Retrieved May 05, 2022, from https://www.statista.com/statistics/606350/battery-grade-lithium-carbonate-price/

Voronina, N., Sun, Y-K. & Myung, S-T. (2020). Co-Free Layered Cathode Materials for High Energy Density Lithium-Ion Batteries. *ACS Energy Letters, 5(6): 1814-1824*. https://doi.org/10.1021/acsenergylett.0c00742

Weiss, M., Ruess, R., Kasnatscheew, J., Levartovsky, Y., Levy, N. R., Minnmann, P., Stolz, L., Waldmann, T., Wohlfahrt-Mehrens, M., Aurbach, D., Winter, M., Ein-Eli, Y. & Janek, J. (2021). Fast Charging of Lithium-Ion Batteries: A Review of Materials Aspects. *Adv. Energy Mater., 11(33)*. https://doi.org/10.1002/aenm.202101126

Wentker, M., Greenwood, M. & Leker, J. (2019). A Bottom-Up Approach to Lithium-Ion Battery Cost Modeling with a Focus on Cathode Active Materials. *Energies, 12(3): 504*. https://doi.org/10.3390/en12030504

Wicki, M., Brückmann, G., Quoss, F. & Bernauer, T. (2022) What do we really know about the acceptance of battery electric vehicles? – Turns out, not much. *Transport Reviews*. https://doi.org/10.1080/01441647.2021.2023693

Xu, C., Dai, Q., Gaines, L., Hu, M., Tukker A. & Steubing B. (2020). Future material demand for automotive lithium-based batteries. *Communications Materials*, *1*. https://doi.org/10.1038/s43246-020-00095-x

Zhang, J., Zhang, L., Sun, F., & Wang, Z. (2018). An Overview on Thermal Safety Issues of Lithium-ion Batteries for Electric Vehicle Application. *IEEE Access, 6: 23848–23863*. https://doi.org/10.1109/ACCESS.2018.2824838

Zhao, H., Lam, W.-Y. A., Sheng, L., Wang, L., Bai, P., Yang, Y., Ren, D., Xu, H. & He, X. (2022). Cobalt-Free Cathode Materials: Families and their Prospects. *Advanced Energy Materials, 12(16)*. https://doi.org/10.1002/aenm.202103894

Appendix A Interview Guide

This appendix contains the most frequently asked questions during the semi-structured interviews, categorized into subjects.

A.1 Interview Guide

A large part of the data collection for this thesis has consisted of expert interviews with knowledgeable people within the battery cell and EV industries. This has included both employees within the Northvolt organization, as well as researchers and industry experts outside of Northvolt.

Since the scope of this thesis has been quite broad, the three RQs span over different areas. Consequently, all interviewees have not been able to contribute to all RQs – instead, they have contributed within their area of expertise. This implicates that the interview guides were adjusted based on the interviewee.

Below, a generic interview guide is presented with the most frequently asked questions.

A.1.1 Battery Cell Market

- In the market for EVs, several OEMs have taken initiative of moving the production of batteries in-house. Do you think that this evolution could constitute a threat for battery cell producers?

- Does the same threat exist from the suppliers to battery cell producers?

- Looking at the threats of new entrants to the market for battery cell production, how big is that? What are the main barriers?

- How likely is it that customers will choose a substitute to lithium-ion batteries for their mid-market BEVs from 2025 and onwards?

- Asian battery producers have a head start on European battery producers when it comes to low-cost batteries, what speaks for the fact that European based players will be able to be competitive on this market?

- Do European based customers value sourcing battery cells from Europe?

A.1.2 Battery Technology

- What are the most important aspects of battery technology in order to create a lower-cost battery cell?

- What cathode materials are more suitable for lower-cost battery cells?

- What do you believe will be an appropriate form factor for lower-cost cells?

- Are any other changes considered relevant, such as other active/non-active materials?

- When looking at different battery chemistries for lower-cost options, how important is the ability to recycle materials after end-of-life?

- How important is the possibility to produce the CAM in-house in the choice of chemistry for lower-cost cell option? What is required for a new type of cathode to be produced?

- What future battery technology evolutions do you think could be used in lower-cost batteries for mid-market BEVs?

A.1.3 Cost Structure

- What do you believe the target cost (USD/kWh) of a European lower-cost battery for the mid-market will be (2025-2030)?
  - Cell level vs. pack level?
  - Cost vs. price?

- How will the cost structure of battery cell production differ between Asian producers and European producers like Northvolt?
  - Will European based players be able to produce at cost parity with Asian based players?
  - Will European based players be able to produce at cost parity with Asian players based in Europe?

- How do the current raw material fluctuations affect the cost of the battery cell?

A.1.4 Battery Cell Characteristics & Customer Demand

- On a high level, what are the most important aspects that the OEMs demand from a battery cell for mid-market EVs?

- Do you believe that the quality, performance and cost of the batteries correlate with this segmentation of passenger vehicles? In other words, does the premium cars have more expensive batteries, than the mid-market cars, and so on?

- Do OEMs value sourcing different quality battery cells from the same supplier? In other words, sourcing both a more expensive high energy density cell, and a lower cost, lower energy density cell from the same supplier?

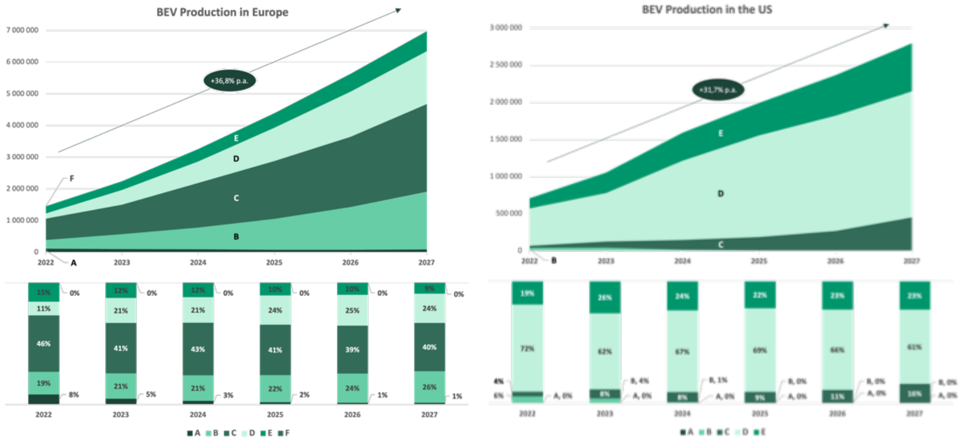
- How will OEM demands differ from European and US based OEMs?

- *Excel exercise where the aspects of Cost, Energy Density, Fast Charging, Cyclability and Sustainability are to be ranked from 1-5 for a Premium and Mid-Market BEV from the point of view of a European OEM.*

Appendix B Assumptions for Market Segmentation

This appendix contains an explanation of the assumptions made to create the segments low, mid, and premium used in the projections based on the data from IHS Markit.

B.1 Assumptions for Figure 4.1 & 4.2



The following translations of segments were made. Since the scope of the project was passenger vehicles, excluding commercial vehicles, HVAN (heavy van) and the listed vehicle models were excluded from the data.

IHS Markit Segment	Report Segment
A-Segment	Low
B-Segment	Low
C-Segment	Mid (Lower)

D-Segment	Mid (Upper)
E-Segment	Premium
F-Segment	Premium
HVAN	*Excluded*

Excluded Models	Arrival Van Canoo Delivery Vehicle Citroen Jumpy Citroen Berlingo Fiat Scudo Fiat Ducato Fiat Doblo Ford Transit Iveco Daily MAN TGE Mercedes-Benz Citan	Mercedes-Benz Sprinter Mercedes-Benz Vito Mercedes-Benz Metris Mitsubishi Fuso Canter Nissan NV300 Nissan Interstar Nissan Primastar Nissan NV200 Opel Vivaro Opel Combo Peugeot Expert	Peugeot Partner Renault Trafic Renault Kangoo Renault Master StreetScooter Work Toyota ProAce Volkswagen Transporter Volkswagen Crafter Volkswagen Caddy

Appendix C Results From Rating of Performance Indicators

This appendix contains an in-depth presentation of interviewees' ratings on the various performance indicators discussed throughout the thesis. The individual responses are provided, as well as the method used to compare and normalize the values.

C.1 Table of Individual Ratings

Table B.1. Overview of each interviewee's rating of the various performance indicators for a premium battery pack on a scale of 1-5.

Interviewee	*Price*	*Energy Density*	*Fast Charging*	*Sustainability*	*Cyclability*
A	3	5	5	4	4
B	2	5	3	3	3
C	4	5	4	5	4
D	4	5	5	3	4
E	2	4	5	3	3
F	4	3	5	4	3
G	4	4,2	3	4	3
H	3	5	4	2	4
I	2	5	5	4	4
J	3	4,5	4,5	4,5	3,5
K	3	4,5	4,5	4	3
L	3	5	5	4	3

Table B.2. Overview of each interviewee's rating of the various performance indicators for a mid-market battery pack on a scale of 1-5.

Interviewee	*Price*	*Energy Density*	*Fast Charge*	*Sustainability*	*Cyclability*
A	5	3	5	4	3
B	4	3	3	3	4
C	5	4	3	3	3
D	5	4	5	3	4
E	4	3	3	3	3
F	5	3	3	4	3
G	5	3	2,5	3	3
H	4	4	3	2	3
I	3	4	4	4	4
J	4,5	2,5	3	4	4,5
K	5	3,5	4	3	4
L	4	3	3	4	4

For each of the performance aspects rated, interviewees were provided with reference ranges to guide the ratings. The ranges were created through values obtained in the literature review, as well as in collaboration with Northvolt supervisors.

Table B.3. Reference numbers for the various performance aspects.

Aspect	*Reference Range (rated 1-5)*
Price	150 USD/kWh – 50 USD/kWh
Energy density	400 Wh/l – 750 Wh/l
Fast charging	30 min – 10 min (10-80%)
Cyclability	500 – 2000 cycles
Sustainability	N/A

C.2 Normalization of Values

Even though reference values were provided to the interviewees when answering the performance indicators, the authors cannot guarantee that these were taken into consideration in the answers. Hence, the absolute values cannot be regarded as representative to a specific value in price, energy density etc. However, the relativity of ratings between aspects and between the segments are of more interest. Therefore, the ratings were normalized in order to be made comparable.

The values were normalized in two ways, both between the aspects in a segment and for every aspect between the segments. In an isolated segment, all aspects were normalized to price (see Table B.4 and Table B.5). For the comparison between the segments, the values were normalized to the premium BEV (see Table B.6). For the three tables, averages for every aspects were calculated.

Table B.4. Values retrieved when calculating the relative difference between price and other aspects for a premium BEV.

Interviewee	*Price to Price*	*ED to Price*	*FC to Price*	*Sust. to Price*	*Cycl. to Price*
A	1,00	1,67	1,67	1,33	1,33
B	1,00	2,50	1,50	1,50	1,50
C	1,00	1,25	1,00	1,25	1,00
D	1,00	1,25	1,25	0,75	1,00
E	1,00	2,00	2,50	1,50	1,50
F	1,00	0,75	1,25	1,00	0,75
G	1,00	1,05	0,75	1,00	0,75
H	1,00	1, 67	1,33	0,67	1,33
I	1,00	2,50	2,50	2,00	2,00
J	1,00	1,50	1,50	1,50	1,17
K	1,00	1,50	1,50	1,33	1,00
L	1,00	1,67	1,67	1,33	1,00
Average	-	1,61	1,53	1,26	1,19

Table B.5. Values retrieved when calculating the relative difference between price and other aspects for a mid-market BEV.

Interviewee	*Price to Price*	*ED to Price*	*FC to Price*	*Sust. to Price*	*Cycl. to Price*
A	1,00	0,60	1,00	0,80	0,60
B	1,00	0,75	0,75	0,75	1,00
C	1,00	0,80	0,60	0,60	0,60
D	1,00	0,80	1,00	0,60	0,80
E	1,00	0,75	0,75	0,75	0,75
F	1,00	0,60	0,60	0,80	0,60
G	1,00	0,60	0,50	0,60	0,60
H	1,00	1,00	0,75	0,50	0,75
I	1,00	1,33	1,33	1,33	1,33
J	1,00	0,56	0,67	0,89	1,00
K	1,00	0,70	0,80	0,60	0,80
L	1,00	0,75	0,75	1,00	1,00
Average	-	0,77	0,79	0,77	0,82

Table B.6. Values retrieved when calculating the relative difference between every aspect from a premium BEV to a mid-market BEV. I.e. the table shows the increase/decrease in importance of every aspect for a mid-market BEV compared to a premium BEV.

Interviewee	*Price*	*Energy Density*	*Fast Charging*	*Sustainability*	*Cyclability*
A	1,67	0,60	1,00	1,00	0,75
B	2,00	0,60	1,00	1,00	1,33
C	1,25	0,80	0,75	0,60	0,75
D	1,25	0,80	1,00	1,00	1,00
E	2,00	0,75	0,60	1,00	1,00
F	1,25	1,00	0,60	1,00	1,00
G	1,25	0,71	0,83	0,75	1,00
H	1,33	0,80	0,75	1,00	0,75
I	1,50	0,80	0,80	1,00	1,00
J	1,50	0,56	0,67	0,89	1,29
K	1,67	0,78	0,89	0,75	1,33
L	1,33	0,60	0,60	1,00	1,33
Average	1,50	0,73	0,79	0,92	1,04

C.3 Merged Figure

In order to allow for a comparable figure where the anticipated demand for a premium and mid-market BEV can be shown in relation to each other, one value needed to be asserted. Therefore, the aspect of price for a premium BEV was set to the value 3 on a scale from 1-5. From this value, the rest of the aspect values for a premium BEV were calculated by the average values from Table B.4. Thereafter, the results from the premium BEV were multiplied by the averages in Table B.6 in order to retrieve the values for the mid-market BEV. See Table B.7 for final values. Reader should note that the asserted price-value of the premium BEV has no effect on the figure outcome, since no absolute values are of interest.

Table B.7. Final values for Figure 6.1. Bold indicates asserted value.

BEV	*Price*	*Energy Density*	*Fast Charging*	*Sustainability*	*Cyclability*
Premium	**3,0**	4,8	4,6	3,8	3,6
Mid	4,5	3,5	3,6	3,5	3,7

It should also be noted that an alternative way of retrieving the values in Table B.7 would be use Table B.6 to retrieve the price-value for the mid-market BEV, and then use the averages from Table B.5 to retrieve the rest of the aspect values for the mid-market BEV. While these two alternatives do not result in identical values (error margin of ~0,05), the resulting figure and in extent the insights derived from it, would be the same.