Securing Lithium Foil Supply in a Future Imbalanced Market

A strategy suggestion for a prospective battery cell manufacturer

Master of Science Thesis
in the Supply Chain Management Programme

ELVAR ÖRN JÓNSSON
FREDRIK LARSSON

Department of Technology Management and Economics
Division of Supply and Operations Management
CHALMERS UNIVERSITY OF TECHNOLOGY
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ELVAR ÖRN JÓNSSON
FREDRIK LARSSON

Tutor, Chalmers: Jens Laage-Hellman

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Division of Supply and Operations Management
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NAME A. FAMILYNAME

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Department of Technology Management and Economics
Division of Supply and Operations Management
Chalmers University of Technology
SE-412 96 Göteborg, Sweden
Telephone: + 46 (0)31-772 1000

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ABSTRACT

Global challenges related to climate change have emphasized the need for taking actions to reduce carbon dioxide emissions. The automotive industry has responded to this need by starting a transition towards vehicle electrification. Due to this, the demand for lithium has increased remarkably in the past years and indications point towards continuity in that trend for the years to come. The battery sector, with suppliers to the automotive industry in the forefront, are estimated to contribute to a significant future increase in lithium demand which is creating challenges for lithium producers to build up capacity at a sufficient speed. Country specific policies are also preventing producers from utilizing lithium reserves to the degree they wish.

As this thesis is structured around the context of a specific battery supplier to the automotive industry and its recently acquired R&D company, the challenging market circumstances were considered from the perspective of these companies and a lithium foil supply strategy was suggested. The proposed strategy means buying lithium foil from two established suppliers and maintain the relationship with each of them in different manners where one should be efficiency oriented while the other R&D oriented. The suggested strategy makes it possible to remain flexible as technology evolves while securing access to lithium resources. Furthermore, the strategy allows for potential future in-house activities as internal knowledge increases.

Keywords: *Lithium ion battery, lithium foil, lithium supply chain, lithium market analysis, supply strategy*.

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Elvar Örn Jónsson & Fredrik Larsson

ABBREVIATIONS

ADU - Arbitrary Dimension Unit

APU - Arbitrary Price Unit

CEO - Chief Executive Officer

GBC - Global Battery Corporation

GSB - Golden State Batteries

LCE - Lithium Carbonate Equivalent

NPD - New Product Development

R&D - Research and Development

RFQ - Request for Quotation

RQ - Research Question

TSD - Technical Supply Discussion

VP - Vice President

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1. INTRODUCTION

In this chapter, the topic of the thesis is introduced. Firstly, a short background is provided describing why the topic is of importance followed by a problem description and later on a company description to set the scene. Then, the purpose and research questions related to the thesis are presented. Lastly a short explanation of the delimitations used when conducting the thesis is presented.

1.1 Background

In recent years, the impact of climate change has gotten more focus than ever before which has led to several extensive ways of trying to mitigate the carbon dioxide ($CO2$) emissions. One way of doing so, has been vehicle electrification. One of the greatest challenges for automobile companies pursuing vehicle electrification related to getting electrical vehicles popular on the market, is to develop the battery technology. Developing this technology means making batteries with high energy density, reliable cycle life performance, high safety and low production cost. In many cases automobile companies and their affiliate battery firms focus on a technology known as lithium ion battery technology where most of these affiliates work as new product development firms (NPD firms) with continuous R&D rather than with full scale production. As can be understood from the name lithium ion battery, lithium is an important component and is used in both the anode and the cathode of batteries. In recent years, lithium has grown to be of great importance for many industrial sectors such as the ceramics & glass industry, the battery industry, lubricants & greases, air treatment and a few more (Jaskula, 2016), making lithium a very valuable commodity for many companies. The demand for lithium is growing, mostly due to the rising demand for electrical vehicles where lithium ion batteries are used, hence the battery industry is projected to have a 58% share of the end lithium supply in 2025 (Center for Energy Economics, 2015) compared to the 31% it had in 2013 (Hykawy et al., 2015). While the battery sector is increasing rapidly, the lithium supply market itself is very slow in terms of upscaling because of high investing requirements and political boundaries. Due to this, a rapid increase in demand can be expected to occur, meaning that a lot of companies from different industry sectors (especially from the battery sector), dependent on lithium, will have a hard time competing about it. When that happens, companies dealing with lithium ion battery development need to make sure that they have already secured their supply of lithium for future production. As the competition on the lithium supply market gets tougher, lithium ion battery companies should develop their supply strategy. Not only for securing lithium supply but also for solving technology uncertainties related to the batteries of which they are developing. Research has shown that working in collaboration with suppliers is a way of accelerating the product development (Melander, 2014) meaning that NPD firms can differentiate themselves from competitors, hence this is a good approach for NPD firms when developing lithium ion battery technology.

1.2 Problem Description

As mentioned, companies working with lithium ion batteries are in need to secure the supply of lithium. The challenges of which these companies are facing on the lithium supply market relate to a number of aspects. Firstly, lithium is used for many different applications where the second largest share goes to the battery sector (Jaskula, 2016). In the battery sector there is also an internal split which lithium ion battery firms have to consider (Hykawy et al., 2015). Hence, it is important for firms to get an understanding for where the demand comes from. Secondly, the number of actors on the lithium raw material market is quite small. There are few actors controlling the lithium supply and basically deciding the availability of lithium, hence the lithium market can be defined as an oligopoly (Forbes, 2015). Thus, lithium ion battery companies have to take this into consideration when trying to secure the future lithium supply. Thirdly, it is important to understand the steps in the technical process of lithium from origin all the way to final product. Lithium can take many different routes of which have variations in cost, origin, technical capabilities etc. Lastly, the origins of which lithium comes from are countries which are politically unstable, where governmental restrictions are common regarding how much lithium that is allowed to be extracted (Jaskula, 2016; Center for Energy Economics, 2015). Due to this, large battery customers are trying to get around the limited supply of lithium. One example is the company Tesla, which is building their own gigafactory in order to control its lithium supply and reduce costs related to lithium (Forbes, 2015).

1.3 Company Description

One company which is a lithium ion battery developer is Golden State Batteries (GSB). GSB is a small technology company with approximately 40 employees, located in the San Francisco Bay Area, CA. It was founded in 2007 to make a new generation lithium ion batteries based on a solid polymer electrolyte technology which was invented by researchers at Lawrence Berkeley National Laboratory. GSB has the exclusive license to this technology. The technology has many advantages compared to the conventional battery technology; it is safer, has higher energy density, is lighter and more reliable (GSB homepage, 2015a). By developing batteries with this technology, GSB reaches three different markets or applications; transportation i.e. for use in electrical vehicles, electrical grid i.e. for use in renewable power sources such as wind/solar and conventional electrochemical energy storage solutions (GSB homepage, 2015b). GSB was acquired in 2015 by Global Batteries Corporation (GBC), a large European manufacturing company with approximately 350 000 employees worldwide and global operations in many fields. The aim of the acquisition was to develop the solid polymer electrolyte technology even further, mainly focusing on creating battery technology for the transportation market as in electrical vehicles. The aim of the acquisition was to develop GSB's technology into a full scale production at GBC while GSB would still develop the technology further as an R&D company. Due to the characteristics of the company, GSB can be viewed as a NPD firm, implying that they try to transform a market opportunity into a product available for sale (Krishnan et al., 2001), in this case the solid polymer electrolyte solution. It is also evident since the company is currently putting a lot of emphasis on R&D in the technology rather than producing high volumes.

Throughout this thesis technology uncertainty is mentioned. Uncertainty refers to something that is doubtful or unknown (Merriam-Webster, 2015) hence technology uncertainty relates to unknown factors related to the technology of which GSB is developing. The technology uncertainty in this thesis represents the unknown origin/cause of impurities and defects which engineers at GSB detect in the lithium material, caused by element X. Moreover it also represents the company's ability to make incremental development since the impurities and defects are hampering the performance of the end product (the battery cell).

1.4 Purpose and Research Questions

This thesis was conducted in a way that it deals specifically with GSB/GBC as an organization and aims to help this organization with a specific issue. The lithium ion battery which GSB develops consists out of four parts; an anode (made of lithium foil), a cathode, a separator and a current collector. At the starting point of the thesis, the company was in need of developing their supply strategy for the anode material, i.e. supply of lithium foil, for two reasons; (1) the lithium foil is an important component in the battery, hence securing the supply of lithium foil is vital and (2) they currently had some technological uncertainties in terms of impurities and defects in the lithium which made the battery cell performance go down. As stated by the CEO of GSB:

> "*We have had some internal discussion and we would like to focus your thesis project on the supply of lithium metal foil for the anode in our batteries. This is a very important topic for GSB and has many layers. It involves supply of raw materials, different techniques for foil fabrication (which vary by supplier), material purity and supplier joint development projects.*"

In more concrete terms, GSB wanted to analyze the lithium supply market which would function as a base for developing the lithium foil supply strategy and secure future lithium foil supply. The supply strategy was also to be constructed in a way that would enable GSB to overcome the technological uncertainties related to their batteries. Everything should be viewed from a future upscale situation where GBC would produce the battery cells and GSB would continue with R&D. Thus the purpose of this thesis was formulated as:

"The purpose of this thesis is to suggest how GSB/GBC should secure their future supply of lithium foil"

In order to fulfill the purpose, it was broken down into two research questions (RQ):

1. What are the characteristics of the current lithium supply market and what does it look like?

2. How should GSB construct the supply strategy of lithium foil for their next generation lithium ion batteries?

The outcome of RQ1 functioned as a base for RQ2. The research questions are answered in *chapter 4* and *chapter 5* respectively. In addition to the research questions, design questions were created based on the theory used in the thesis (see *section 2.1.6* and *section 2.2.6*) as a support for collected data. The choice of theory (see *chapter 2*) was based on the purpose.

1.5 Delimitations

This thesis has only studied a specific organization, meaning that the conclusions might not be applicable in other contexts. Despite this, the findings from this thesis might be of relevance to other developers of lithium ion batteries which in this case could be larger organizations but also other NPD firms. In addition to the NPD context, it should be mentioned that this thesis has only been looking into product development and not process or service development. This thesis refers a lot to the designation "technology uncertainty". There are various types of uncertainties, for instance technology, market, organizational and commercial uncertainty (Melander, 2014). The writers have chosen to focus only on technology uncertainty because that relates to the kind of uncertainties of which GSB/GBC is exposed to (see *section 1.2*). Moreover, the lithium ion battery technology of which the company is developing consist of many different parts; an anode, a cathode, a separator and a current collector. However, this thesis is focused on suggesting a supply strategy for the anode material only; i.e. the lithium foil.

2. FRAME OF REFERENCE

This chapter aims to review literature, published research and concepts of relevance used for answering the two research questions presented in *section 1.4*. In addition, *section 2.3* was added which explains a tool called MCDA matrix which was used in *chapter 5* for selecting suppliers. In *section 2.1.6* and *section 2.2.6* design questions were formulated for the purpose of guiding the data collection. The design questions are based on the literature in each section.

2.1 Supply Market Analysis

This section provides a literature review of important aspects and knowledge related to conducting a supply market analysis. The literature presented in this section aims to support answering research question one:

What are the characteristics of the current lithium supply market and what does it look like?

2.1.1 Definition and Scope

In order to make a supply market analysis and determine what aspects to include, it is important to understand what such an analysis really means. Van Weele (2010:p.131) defines a supply market analysis as:

> *"...the systematic gathering, classification and analysis of data considering all relevant factors that influence the procurement of goods and services for the purpose of meeting present and future company requirements".*

Hence it is the current state of the company and its requirements that dictates the scope of the supply market analysis. Another definition of how to analyze a market is provided by Gadde et al. (2001) who put more emphasis on the interplay between actors on a specific market, an approach which is called the industrial network approach. According to the industrial network approach, the main concern is to understand the role of a single company in terms of the overall structure, meaning that activity links, resource ties and actor bonds are analyzed i.e. by looking at the market in terms of networks. In this thesis a combination of Van Weele's (2010) definition and Gadde et al.'s (2001) network approach is combined in order to achieve a robust supply market analysis.

2.1.2 How to Describe a Supply Market

As mentioned, the supply market analysis was done by combining the network approach by Gadde et al. (2001) and the supply market research by Van Weele (2010). In this section a further explanation of how these two approaches describe a market is provided.

<u>The Industrial Network Approach</u>

The industrial network approach is characterized by a number of nodes (business units) which are connected to each other though threads (relationships) (see *figure 1*). What happens in one relationship will affect other established relationships in a positive or negative way and at the same time that specific relationship is dependent on what is happening in relation to others (Håkansson et al., 2002).

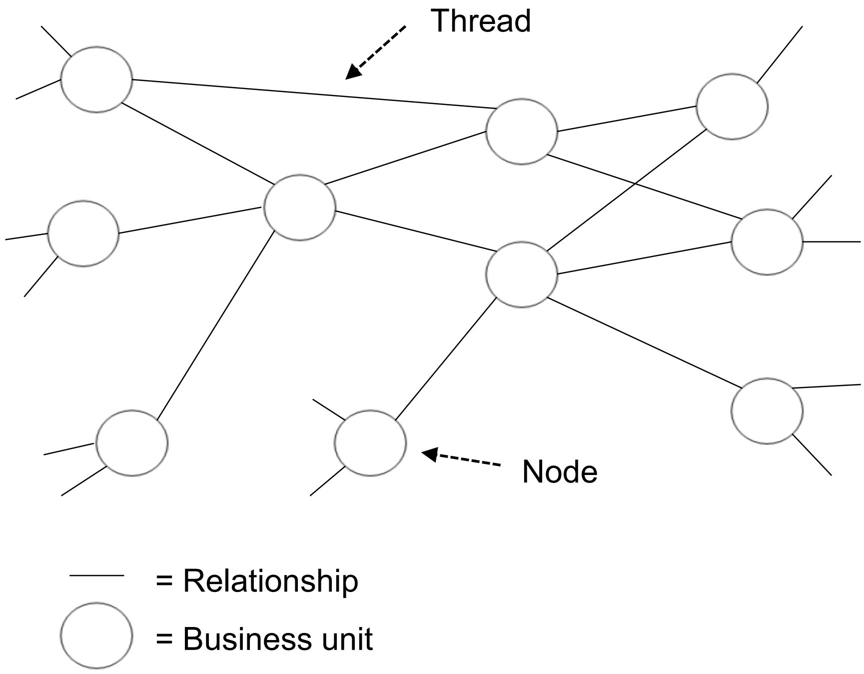


Figure 1 - The Industrial Network Approach

When looking at relationships in a network, the ARA-model (developed by Håkansson et al., 1992) is used. ARA is the abbreviation of Activities, Resources and Actors (see *figure 2*) which together are used to analyze a single relationship in the network (Ford et al., 2002). When using the ARA-model one looks at how activities link, how resources tie and how actors bond. In fact, both nodes and threads have their individual level of heaviness regarding the density of each of the ARA model building blocks. Hence, if one relationship is heavy on resources, knowledge and understanding, it takes up capacity which could otherwise have been used in different settings. This means that nodes that are not directly connected through threads are still affected through other relationships in the network. The heaviness of a relationship as it appears today is the results of interaction, adaptation and investments that have happened in the past. The intensity between the three segments is what distinguish one relationship from another.

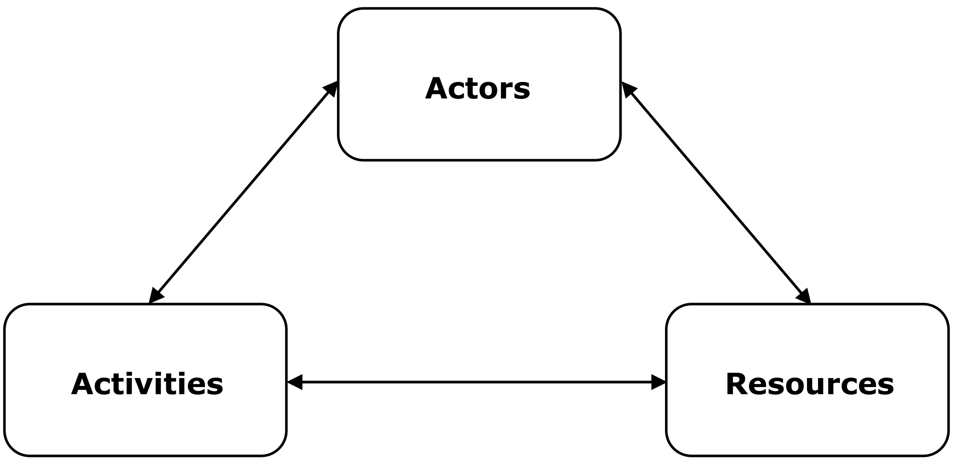


Figure 2 - The basic outline of the ARA model

Ford et al. (2002) provided a comprehensive description of the model which is used to further elaborate on each of the model's building blocks. Activity links describes the interdependent activities which take place in a relationship, these can be related to production, distribution or other activities. Resource ties includes the resources which are shared between two actors and can either be physical or more ordinary in form of knowledge. Innovation is for example more likely to happen in situation when resources are shared across boundaries of an individual firm. Lastly, actor bonds results from interaction between two actors. Doing business requires communication and through those interactions the social content becomes a part of the relationship. Through time a mutual trust is built which is a fundamental aspect for a relationship to grow. No company in the network approach works in isolation which is why only looking at one company and try to optimize their activities does bring limited benefits (Ford et al., 2002). Gadde et al. (2001) discussed the network approach and strategies related to being part of a network. One could analyse the situation today and draw a conclusion of where to position itself in the network. However, constant developments, motivation for companies to improve and companies seeking for new opportunities make the network unstable. Therefore what is the best approach today might not be optimal tomorrow which implies the time dependency when studying networks.

Supply Market Analysis

Van Weele (2010) describes a supply market as relationships between suppliers and buyers that are determined by underlying patterns of goods and services i.e. the external structure. The external structure consists of a number of links that are connected via markets, where links are companies or institutions. When looking at the external structure one can distinguish between industrial branches and industrial columns. The industrial branch being the horizontal relationship of organizations that experience each other as effective competitors while the industrial column being the serie of companies in which the consecutive stages of production of an economic product take place (Van Weele, 2010). An industrial column is also known as the supply chain.

When describing a market one should look at factors that determine the degree of availability of a certain product which cannot be affected by a single company i.e. external factors. Example of these external factors are: number of customers and buyers on a market, number of suppliers, the stock situation of the product in question, speed of technological innovation and the market structure. The market structure is especially important since it is the total set of conditions in which a company sells its products (Van Weele, 2010). The market is the total of supply and demand, where central aspects are the number of suppliers, the number of buyers and the degree of product differentiation.

2.1.3 Market Structure and Oligopoly

The set of conditions which a firm operates in creates the market structure. These conditions are external factors which together create a structure which Van Weele (2010) distinguished between and categorized into four groups depending on the interplay between external factors. This includes number of suppliers and buyers as well as the degree of product differentiation. These categories are; pure competition, monopolistic competition, oligopoly and monopoly. The two categories mentioned first are favourable for the buying firm as the number of suppliers is considerably high while the following two are characterized by a low number of suppliers which hold majority of the power. As mentioned in *section 1.2*, the lithium market can be defined as an oligopoly hence oligopoly will only be described in further detail.

An oligopoly market structure appears in situations where the number of suppliers and product differentiation is limited. The reason for the low number of actors on the supplier side is mainly due to high market barriers. This market structure can take different forms depending on the relationship between presented actors, all of which are usually familiar with each other's behavior. The result is prices that are not decided by general market principles but rather created through silent agreements or by a price leader which other actors accept to follow (Van Weele, 2010). By that, firms operating within an oligopoly market structure are usually able to maintain higher prices compared to a pure competition market structure. Given the "fixed" price, firms usually apply two different assumptions, either Cournot assumption where they take the outputs from other firms as given or Bertrand assumption where other firm's prices are taken as given. Depending on what assumption is chosen the firm will either profit-maximize its output level or price respectively (Helpman et al., 1985). Helpman et al. (1985) discussed that there is no general model of oligopoly and therefore impacts of that structure can appear in different ways. In that sense, the oligopoly situation where suppliers try to make their products stand out by differentiation is referred to as a heterogeneous oligopoly (Van Weele, 2010).

2.1.4 A Buying Firm's Influence on a Supplier

The power of the buyer or seller is closely tied to the interdependence of the partners in a relationship (Wilson, 1995) and affects a company's access to a specific product. To assess a company's position on a market one should take the company's position relative to other companies in the surrounding network into account (Van Weele, 2010). Wilson (1995) defined power imbalance as the ability of one partner to get the other partner to do something they would not normally do. Power imbalance is directly related to the degree of one partner's dependence on the other partner. Even though a company might order tens of millions of euros of a product from a supplier it might not have any negotiating position because there are other buyers that order a lot more from the same supplier (Van Weele, 2010). To understand and analyze the power position for a specific company, the typology of the market structures matrix can be used (see *table 1*). The outcome of this matrix will give a hint towards what power position a company is currently in.

Table 1 - The power position for a specific company on a market (Adapted from Van Weele, 2010:p.130)

Number of suppliers \ Number of buyers	One	Few	Many
One	Bilateral monopoly, 'captive market' (spare parts)	Limited supply monopoly (fuel pumps)	Supply monopoly (gas, water, electricity)
Few	Limited demand monopoly (telephone exchanges, trains)	Bilateral oligopoly (chemical semi-manufacturers)	Supply oligopoly (copiers, computers)
Many	Demand monopoly (weapons systems, ammunition)	Demand oligopoly suppliers (component automobile industry)	Polypolistic competition (office supplies)

= demand stronger than supply
= demand and supply more or less in balance
= supply stronger than demand

2.1.5 Supply Market Risks

Van Weele (2010) emphasized the importance for firms to conduct market research in order to evaluate the market and how external factors are evolving. As a benefit from increased connectivity and the large role of the internet, market research can be conducted more efficiently and faster than it used to be. According to Van Weele (2010) a couple of factors should get extra attention in order to assess potential risks and maintain competitiveness. Not all factors can be controlled or affected by companies themselves but ability to assess these factors and gain understanding of what is affecting them is very valuable. High speed of technological developments result in decisions being made on which competencies are of strategical importance. Competencies of less strategical importance are increasingly allocated to external suppliers resulting in higher dependencies and lost know-how over time as new technology evolves. As globalization has increased, supply market dynamics can be unpredictable and in some cases very fragile. Therefore, companies have to understand the relation between supply and demand and what factors that are likely to affect those parameters as this has direct impact on the price level. Globalization and increased cross border transactions has created a new area to pay attention to. Such concerns relate to high inflation, government deficits in some countries and fluctuating exchange rates when various currencies are involved in transactions. These factors have arisen alongside with international trade. Last but not least, changes in tax regimes and regulations regarding offsetting part of sales volume to support regional business in the exporting country should also be kept in mind. (Van Weele, 2010)

Van Weele's (2010) variables can be classified in accordance to the market risk groups created by Miller (1992) which state that risks are either firm-specific, industry-specific or appear in the general environment. Discussions provided by both authors were conducted on a similar level with the main difference being at the general environment level. In that sense, Miller (1992) went into more details about aspects such as natural, social and political uncertainties while that discussion was left out by van Weele (2010).

2.1.6 Design Questions

In this section, design questions are presented which have been used as a guide for data collection. The first research question has been broken down into the following, more specific design questions:

- *What requirements does GSB/GBC have regarding the content of the market analysis?*
- *What does the supply market network for lithium foil look like?*
    - *What production processes are needed?*
    - *What actors are present in the network?*
    - *What other industries contribute to lithium demand?*
- *What does the oligopoly look like and what is making the market situation sustain?*
- *How is power imbalance affecting network relationships?*
- *What types of supply market risks are present at the lithium market?*

2.2 Supply Strategy

This section provides a literature review on aspects related to creating a supply strategy i.e. the aspects presented here will constitute the supply strategy in this thesis. The literature presented in this section aims to support answering research question two:

How should GSB construct the supply strategy of lithium foil for their next generation lithium ion batteries?

2.2.1 Why and How to Structure a Supply Strategy

Creating a supply strategy is something that has been increasing in terms of importance during the last years. The reason being that competitiveness and profit-generating capacity of a firm highly depends on the ability to handle the supply side (Gadde et al., 2001). Gadde et al. (2001) explain that purchasing has a direct effect on a firm's profitability since purchasing accounts for a substantial part of firm costs. Furthermore, there is an indirect impact since internal costs are affected by occurrences in the interface between a firm and its supplier. Lastly, suppliers are providers for firms in terms of resources and technology in general, hence they have an impact on a firm's revenue too. Van Weele (2001) stress that supply strategies are of importance because the risk profile of a firm is dependent on the choice of supply strategy. Making decision solely based on economic and financial consideration might affect a firm negatively. According to Gadde et al. (2001) the main issue when it comes to creating a supply strategy is to decide what activities and resources to handle in-house versus outsource to suppliers. Moreover Gadde et al. (2001) explains that it is also important to analyze the different types of relationships a firm can have with supplier(s) and how they impact benefits and costs. It is also important to review the structure of the supply network in terms of what suppliers to select and how many e.g. single versus multiple sourcing.

2.2.2 Make or buy

A make or buy decision and an insourcing or outsourcing decision might at first sight seem to be the same thing. However they are not and therefore the distinction is made before going into more details about the concepts. The main difference is related to the point in time when those decisions are made. In that sense, make or buy is the initial decision that has to be made which can be reversed later by either outsource something that is made in-house or by insourcing something that initially was bought (Wawasan, 2009). Historically the make or buy decision was not seen as a strategical importance and therefore commonly left in the hands of purchasers which at that point were often people unqualified for other positions hence they were put in purchasing in order to have something to do. This has though changed as purchasing accounts for a significantly large share of company's income in many industries so nowadays the make or buy decision is usually taken on managerial level. In order to make an educated decision many aspects need to be considered where a trade-off between different factors is usual.

In the early 1900, the business approach was very focused on vertical integration meaning that suppliers were acquired leading to an increase in in-house activities. However in late 1900 the trend shifted towards more buying and more recently some of which has being in-housed again. So obviously there is a high level of complexity involved in that decision. Making is believed to allow for more production flexibility and control but also increases the risk of lock-in effects as new technology emerges in the external network. On the other hand buying requires less investments but if the wrong decision is made it is harder to reverse a buy decision into make then the opposite. (Gadde et al., 2001)

As mentioned earlier, the make or buy decision can be reversed by deciding upon outsourcing or insourcing. Although, the outsourcing and insourcing discussions are out of the scope of this thesis the concept will still be described briefly. Also the outsourcing matrix (see *figure 3*) is presented as it gives good inputs into what factors to consider when taking the make or buy decision.

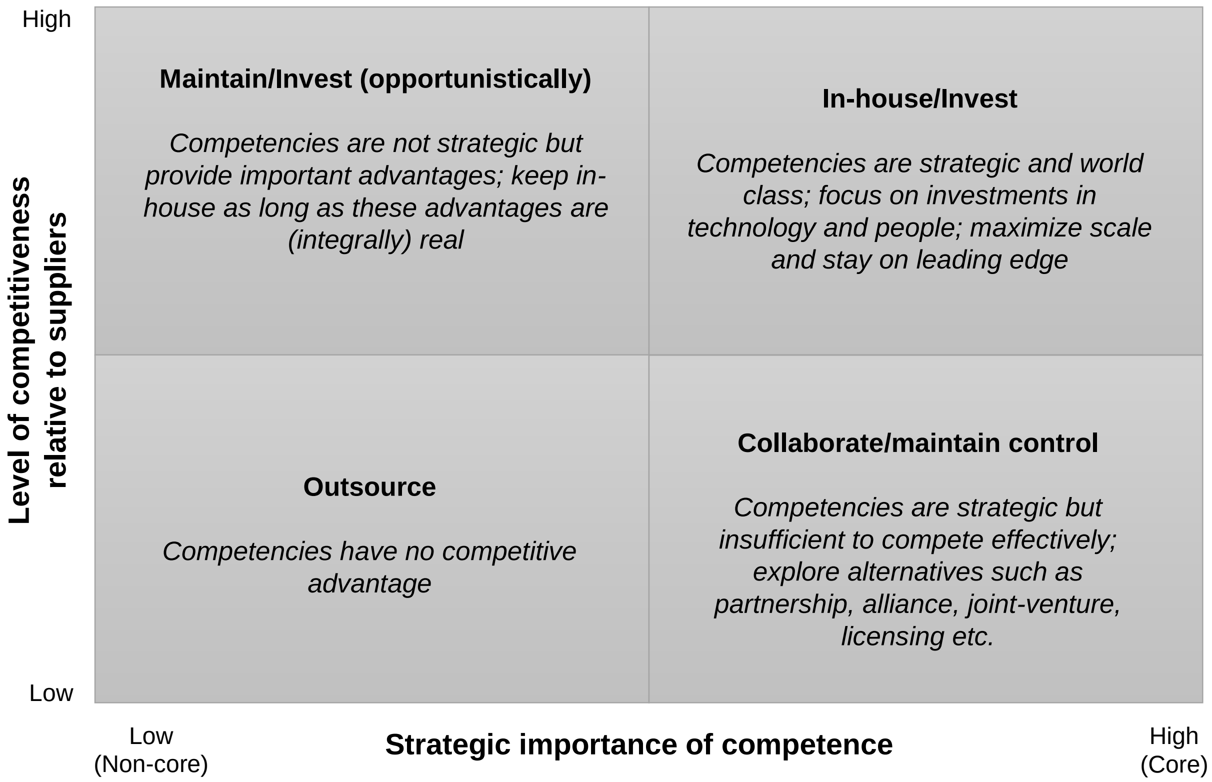


Figure 3 - The outsourcing matrix (Van Weele, 2010:p.165)

The matrix, which has two defined axes (1) level of competitiveness relative to supplier and (2) strategic importance of competence (Van Weele, 2010), is certainly helpful in that decision making although there are also plenty of other factors to consider as well. The model only considers outsourcing while the insourcing decision also remains important. To give a broader perspective it is recommended by Gadde et al. (2001) to be supplemented into the matrix. The matrix is highly based on assessments on whether or not a specific process is part of core competency. Evolving core competencies is of strategical importance for companies for two reasons, firstly to maximize return on internal investments by focusing on something which is already developed and secondly to increase the entry barriers for others (Gadde et al., 2001). Advantages and disadvantages related to outsourcing and insourcing are mainly related to investments, competency, control and risks (Van Weele, 2010). Decisions on this topic can only be based on what is known at the time when the decision is made and should therefore constantly be reconsidered as companies shift their focus and new technology emerges (Gadde et al., 2001).

2.2.3 Sourcing Strategy - Single versus Multiple Sourcing

Another part of a supply strategy is decisions related to the design of the supply network. One of those is the choice between single and multiple sourcing. In this section a description of each concept will be provided followed by discussions about how these two approaches can be combined in order to compensate each other.

Single sourcing is defined by Van Weele (2010) as purchasing a product from one supplier only, while the multiple sourcing approach is defined as when companies have two or more suppliers for each product. Understandably each method has its pros and cons and depending on the context one method is favored over the other. On one hand, single sourcing tends to provide lower indirect cost which is obtained through higher supplier involvement while on the other hand one of the biggest advantage of going for multiple sourcing is to mitigate risk. Other aspects mentioned by Gadde et al. (2001) are summarized in *table 2*.

Table 2 - Advantages related to single and multiple sourcing (Adapted from Gadde *et al.*, 2001)

Advantages of single sourcing	**Advantages of multiple sourcing**
Price advantages due to economies of scale	Lower risk related to failure at one plant such as strikes, fire, quality and delivery problems
Personal relationship can be established, more effective communications	Competitive situation among the suppliers can be developed; no one can afford being complacent
Administration work at buyer's office reduced	For standards items: no additional tooling cost is involved and there are often no advantages for added volume
Close relationships can results in mutual cost reduction effort	Buyer protected against monopoly and advantages of having two sources of new ideas and materials
Buyer-tied research can be undertaken	No moral commitment since the supplier is not relying too heavily on only one buyer
Tool and pattern or fixture costs are reduced and long-run tools may be used	Increased flexibility in case of large additional call-off or decreases in needs
Lower transportation cost, common pools can be established where pallets are used	Part business can be used as a base load in conjunction with which a smaller supplier may be developed
Quality control easier since only one location	
Scheduling easier	

This topic will not be covered without mentioning the impacts this type of decision will have on the size of the supplier base. As early as 1988 a researcher named Newman discovered trends within companies which increasingly went from multiple to single sourcing as an action to reduce the supplier base. However, unforeseen incidents in recent years have opened up the eyes of companies towards the risk obtained through single sourcing. Due to different characteristics of products single or multiple sourcing decisions have to be made on an individual or group level depending on the simplicity of segmentation. (Gadde et al., 2001)

Combining multiple and single sourcing is another approach which aims at getting the benefits from both methods at the same time (Gadde et al., 2001). Parallel sourcing strategies falls under that category as it combines multiple and single sourcing. It acts as single sourcing since each component for specific product model is only supplied from one supplier. However, if the same component is also needed for other product models an alternative supplier should be used. On one hand this means that, if parallel strategy is used, the number of suppliers increases considerably and full benefits of economies of scale are not reached. If on the other hand, a relationship is already in place with another capable supplier it contributes to risk mitigation. Similarly this approach can be extended to cover a product group. Gadde et al. (2001) described this approach in the context of seat sourcing at one actor in the automotive industry. Seats accounting for approximately one-third of their car models were sourced from one supplier and another one-third from a different actor. Furthermore, the remaining seats were sourced to the actor which had shown better performance in the past, evaluated from a number of criteria including the degree of assistance to the other supplier. This approach created a competitive tension between the suppliers while at the same time they had to collaborate as they were responsible for the total volume and were evaluated in regards to that criteria. In the end this setup was seen to positively affect suppliers' performance and delivering favorable results for the end customer. The setup of the sourcing strategy was created to maintain a high level of competition since the focal company created a playing field that was very supportive towards the weaker supplier.

2.2.4 Supplier Selection

Van Weele (2010) summarized the main steps associated with purchasing into a six step process (see *figure 4*); define specification, select supplier, contract agreement, ordering, expediting and evaluation. In the context of this thesis, the supplier selection step is the only step of interest regardless of the type of purchase situation (new-task situation, modified rebuy or straight rebuy), hence it was also the only step being elaborated further. For NPD firms, the supplier selection phase of the purchasing process is crucial. Finding

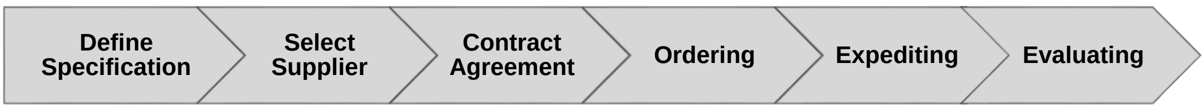


Figure 4 - The purchasing process (Van Weele, 2010:p.29)

a supplier or suppliers that match the specifications while still being flexible to the firm's technological uncertainty is important. In the supplier selection phase, a various number of criteria can be used to evaluate suppliers; technological, relational, cultural, and operational as well as the cost of the technology (Melander, 2014). Van Weele (2010) explains that the supplier selection phase consist out of four steps: (1) Determining the method of subcontracting (turnkey or partial subcontracting), (2) preliminary qualification of suppliers and drawing up a bidders list, (3) preparation of the RFQ and analysis of the bids received and (4) selection of the supplier. If a critical or strategic supplier is about to be chosen a comprehensive risk assessment should be carried out, for example, by evaluating technical, quality and financial risk. (Van Weele, 2010). For a NPD firm that deals with a high level of technological uncertainty the second step of the supplier selection phase becomes tricky. Melander (2014) states that since supplier selection is associated with technology selection and a particular technology is sometimes provided by only a few suppliers, it can be difficult to assess the supplier in a proper way. The reason for this is that technology uncertainty creates a situation where the buying firm does not know which technology that will be most suitable. Based on this, firms are required to be flexible and not commit to one specific supplier in order to cope with the technological uncertainty (Melander, 2014). Due to this, firm's need to be competent when it comes to knowledge about the technology they are buying in order to assess the suppliers in a proper way. As mentioned, one technology might only have a few suppliers but it can also have many competing suppliers. It could also be that the technology of which the supplier is providing is proprietary to that supplier, making the supplier selection process affected (Melander, 2014). Also, the level of criticality of which a certain technology contributes to the end product will affect the supplier selection process. Having said this, there are some important aspects that NPD firms should consider when moving forward with supplier selection which is covered in the following discussion.

Aspects of collecting information about suppliers

To limit the uncertainty of suppliers' capabilities and reduce the technology uncertainty the buying NPD firm should collect information about suppliers. When doing so, the buying firm is exposed to two types of risks; (1) information asymmetry and (2) adverse selection (Melander, 2014). Information asymmetry implies that it is difficult for the buying firm to access supplier information since it may be sensitive, resulting in suppliers being reluctant to share it. Also, the buying firm might not have the same amount of knowledge as the supplier has regarding the technology of which the buying firm is trying to purchase from the supplier. Adverse selection implies that when the buying firm reaches out to suppliers in order to get information about them, suppliers can provide inaccurate information, misleading the buying firm (Melander, 2014). In that sense it is important for the buying firm to gather information related to the nature and actions of the supplier in addition to its technical capabilities (Holmström, 1979). This specific task can be difficult but a few ways of doing so is to use database and technical information, visit the suppliers and examine previous collaboration projects (Melander, 2014).

Supplier assessment and evaluation

When firms evaluate suppliers, they use two categories: (1) technological capabilities and (2) relational capabilities. In addition, cost is also considered to be a criteria in the evaluation although it becomes less important in NPD firms with high technological uncertainty compared to firms with low technological uncertainty (Melander, 2014). Research shows that relational capabilities are more important in situations of high technological uncertainty while technological capabilities are more important in situations with low technological uncertainty (Hoetker, 2005). Nevertheless, it is important to remember that technological and relational capabilities complement each other and that there have been cases of supplier selection, based only on technological capabilities, which have failed. The reason for this being that the buying firm failed to identify that the supplier was not suitable as a NPD collaborative partner (Melander, 2014). When it comes to actually evaluating suppliers, firms have two approaches of doing so. At first, they evaluate suppliers through information about the current situation of the supplier and secondly they evaluate the suppliers through previous collaborations (see *figure 5*) (Melander, 2014).

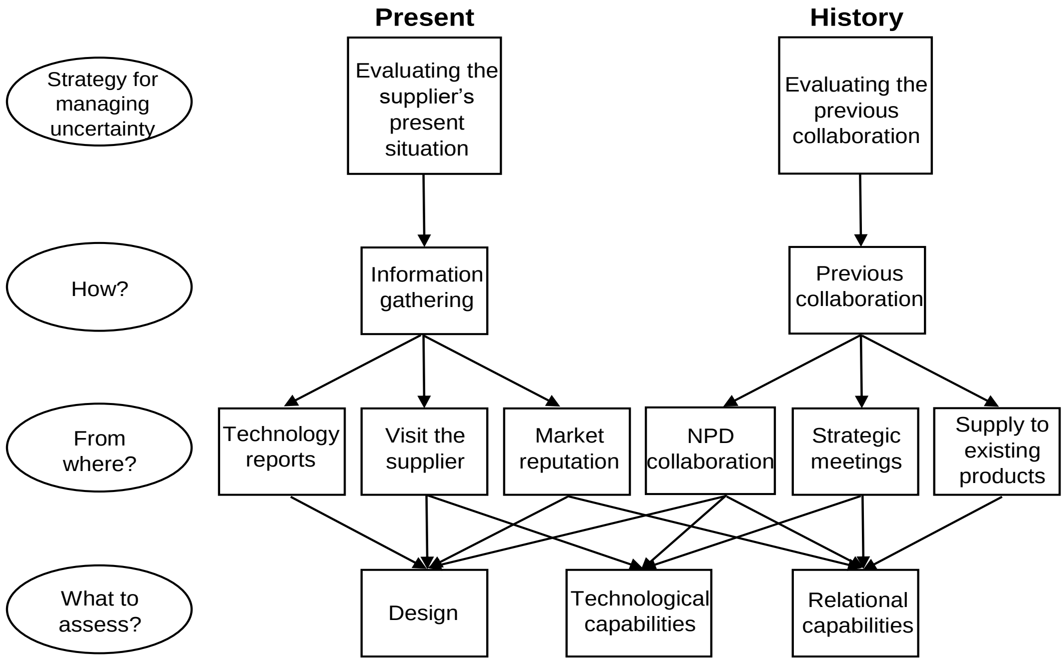


Figure 5 - Managing technological uncertainty through evaluation of supplier's present situation and history (Melander, 2014:p.79)

When evaluating the current situation, the buying firm collects information from technical reports, from visiting them and investigating the reputation of the suppliers. The outcome of this approach is an assessment of the supplier's design of the product/component, technological capabilities and relational capabilities. When evaluating previous collaboration and the history of the supplier, the buying firm examines old collaborations with the supplier, not only in terms of NPD projects but also in terms of previous strategic meetings and the supply of existing products. The outcome of this approach is an assessment of the supplier's design, technological capabilities and relational capabilities. The two strategies complement each other. (Melander, 2014)

<u>Selection of new or existing supplier(s)</u>

In order to maximize the benefits of a close NPD collaboration with a supplier the relationship should be developed over a long time (Schiele, 2006). At the same time, firms cannot use this approach with all suppliers because close relationships take time and are costly. Instead, firms have to create a balance between long-term relationships with selected suppliers while inviting others to participate in NPD. Firms tend to select suppliers of which they are familiar with because it is easier for them to evaluate the capabilities of that suppliers (Melander, 2014). However there are some disadvantages in doing so. Firstly, suppliers of which the buying firm has already worked with might be redundant as new technologies are required at the buying firm (Johnsen, 2009). In that way firms reduce their access to valuable external technologies. Secondly, old long-term collaborations with former suppliers might have certain influences from previous collaborations which hampers creativity and limits innovation for the buying firm (Johnsen, 2009; Melander, 2014). Lastly, the buying firm might miss out on chances of broadening its network, meaning that it misses out in establishing new relationships with innovative suppliers and expanding the business network (Melander, 2014).

Risk Assessment

When involving suppliers, whether it is in a turnkey or partial subcontracting, it is important for the buying firm to make a risk assessment. Especially if the buying firm is getting involved in a new buyer-supplier relationship. Van Weele (2010) demonstrates three types of risks that a buying firm can be exposed to: (1) Technical risk, (2) commercial risk and (3) performance risk. Technical risk relates to whether the supplier has the skills, tools, equipment, and suitable management and production skills to deliver within agreed terms. Commercial risk relates to uncertainty in price and cost that will incur during the collaboration with the supplier. Performance risk relates to the risk of the supplier not being capable to perform the job which was agreed upon. To evaluate risks, the risk matrix can be used in order to determine the magnitude of the risk related to a supplier (see *figure 6*).

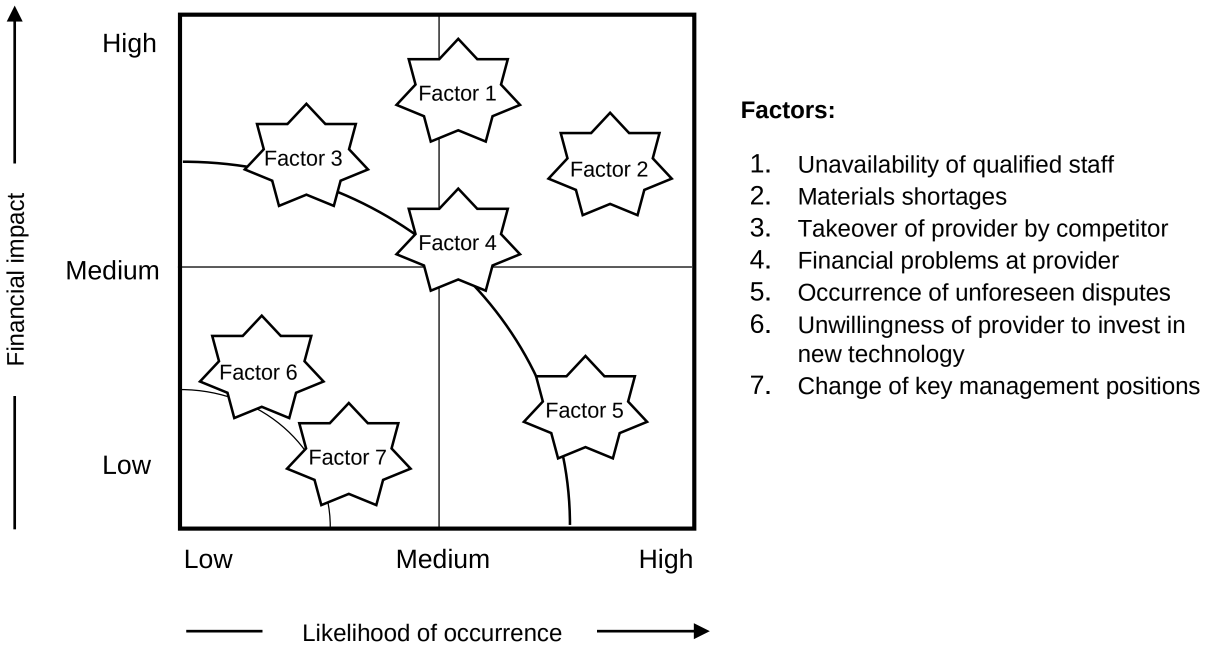


Figure 6 - The risk matrix (Van Weele, 2010:p.175)

By analyzing each risk factor according to the y-axis i.e. its negative impact on the firm's financial performance or operations and the x-axis i.e. the likelihood of risk factors to occur (Van Weele, 2010), the buying firm can get a good overview of the overall risk and manage it.

2.2.5 Supplier Involvement

In this section, theory related to how suppliers should be involved in NPD and how to manage such involvements is presented. Firstly by describing the supplier relationship distance and secondly a relationship distinction is made depending on the characteristics of the product. Lastly, the actual characteristics of the supplier involvement and its benefit is discussed.

Relationships distance

Various relationships are developed over the lifetime of a company each of which is managed differently and with different expectation towards the output. Establishing a supporting network is beneficial but each relationship comes at a cost which is why suppliers are considered carefully and a continuous evaluation of the supplier base should be in place to guarantee an efficient use of resources. Although most basic buyer-supplier relationship can be seen as a buyer purchasing standardized products from a selected supplier, suppliers can also be an important source of valuable knowledge (Gadde et al., 2001). Depending on mutual interests and expectation towards the relationship it will develop differently. The most common way is to distinguish between them by assessing the magnitude of involvement. Below, a comprehensive description, including discussions on the characteristics for both ends of the spectrum, will be provided. However, it should be mentioned that relationships can also be defined as somewhere in between the two extremes.

High involvement relationships are expensive since they are resource intensive and therefore not suitable in all situations. They are often characterized by mutual adaptation and close collaboration when it comes to R&D which requires mutual investments. Establishing a high involvement relationship takes time since a certain level of trust has to be in place before it becomes feasible to make necessary investments and adaptations. If actors expect benefits from close relationship and a mutual interest is in place they will gradually increase investments, communication and adaptations towards the relationship. If everything goes well the benefits will most likely appear in the shape of lower procurement cost, improved transparency which positively affects the impact of hidden costs, increased flexibility, higher service level and opportunities to take advantages of supplier knowledge into R&D processes. Although, possible outcomes from high involvement relationship might be seen to be favourable in many situations, the high cost is a strong barrier for many companies which is why they have to carefully consider with whom they should aim for that kind of establishment. Generally this is most suitable in cases when non standardized solutions are needed. (Gadde et al., 2001)

On the other end of the spectrum, low involvement relationships appear and obviously they have different characteristics. Mutual adaptations are rare in this setting and more commonly the buying firm has to make adaptation in order to utilize standard offerings. This offers more flexibility in negotiation of unit prices while at the same time uncertainty related to hidden cost generally becomes higher. Furthermore, those kind of relationships are usually not expected to contribute to improvements in product developments at the buying firm. Little or no adaptations are needed in this setting which makes it most favorable for standardized solutions which are not critical for the buying firm. These relationships can be applicable for single transactions as well as for longer lasting relationships. (Gadde et al., 2001)

Standardized versus customer-adapted product

Another perspective when looking at relationships between a buying firm and a supplier is to consider the resource interface between them, as Araujo et al. (1999) do in their article. They elaborate about four categories of interfaces that depend on the degree of customer-adaptation or standardization in the exchanged product. The categories are known as; standardized, specified, translation and interactive. Standardized interface, the first category, is defined as a situation where the knowledge of the buying firm and the knowledge of the supplier are unrelated. The standardized interface represents an arm's length relationship where only a simple sales-to-purchasing function is required. The cost in a standardized interface is low since no investments are needed and transaction costs are low. The specified interface, is the first interface dealing with some kind of customer adaptations regarding the exchanged product hence the resources need to be adapted to each other based on the buying firm’s directives. These are typically directives on characteristics of the product and how it is produced. This means that the supplier becomes an extension of the buying firm’s production structure. Good examples of the specified interface are subcontracting or outsourcing and these arrangements can work very efficiently. Moreover, the translation interface implies that the buying firm’s directives are based on the functionality of the product, hence the supplier needs to translate the functionality into the exchanged product. Compared to the specified interface the supplier takes on more responsibility than the buying firm in the translation interface. Although the directives still come from the buying firm, the directives have a higher degree of freedom compared to the specified interface. Lastly, the interactive interface meaning that an open dialogue is ongoing between the supplier and the buying firm based on how to combine knowledge between the two. In this interface the supplier and the buying firm can develop benefits and productivity increase for both sides. Costs associated with an interactive interface are high and require time but on the contrary it will open possibilities for innovation gains.

The four interface categories differ in terms of two aspects: (1) cost associated with the use of the interface and (2) benefits provided in terms of (a) productivity and (b) innovation. Furthermore, the interactive interface requires the most investments in the relationship. At the same time it has the highest contribution to innovation while standardization allows for economies of scale and scope from the supplier perspective without contributing extensively to further developments.

Supplier involvement in NPD

Fast pace in industries has demanded businesses to find ways to keep up with the external speed in order to maintain their business. A frequently mentioned dimension in literature to keep up with external speed is increased supplier involvement in NPD (Petersen et al., 2003; Van Echtelt et al., 2008). Here the context of the relationship plays a critical role and so does the companies' characteristics. Before involving suppliers, the buying firm should have a clear vision about what they want to achieve and which goals they are aiming at. Technological roadmaps are therefore frequently mentioned as a tool for the management team to align internal strategies (Schiele, 2010; Petersen et al., 2003; Van Echtelt et al., 2008). Strategies are aligned by coordination of activities within different criteria such as innovation, sourcing and supplier selection. A technological roadmap is useful for that coordination. Then the output from the roadmap functions as an established timeline with defined steps in order to reach a set goals. Bear in mind that one or more roadmaps can be in place at the same time, all with different goals. When an internal roadmap has been created it can be used as a guidance in supplier selection by evaluating suppliers in regards to their capabilities of contributing to the roadmap targets.

Main findings of benefits from involving suppliers into NPD were; increased innovation through taking advantages of supplier’s know-how, improved quality, shorter time to market and particularly reduced cost. At the same time criteria such as ownership of potential findings, mutual investments and responsibility have to be addressed and stated in a contract (Petersen et al., 2003; Schiele, 2010; Van Echtelt et al., 2008; Johnsen, 2009).

A couple of different contract mechanisms can be applied as a risk mitigation activity, for instance confidential agreements, non-disclosure agreements (NDA), exclusivity contracts and purchasing agreements (Melander, 2014). The most suitable ones are picked each time in order to protect both parties when proprietary information is shared outside of company's boundaries. The challenging part is to cover all areas since in NPD with high level of technical uncertainty all possible future scenarios cannot be included. Therefore, defining a level of flexibility is needed in the contract. Due to this reasoning, the trust dimension becomes a big part of relationships, although establishing a relationship which is rich of trust takes time. In the end, trust is contributing to performance while contracts are in place to prevent both parties from opportunistic behavior on the behalf of the other party (Melander, 2014).

Expectations from a particular supplier relationship can sometimes differ depending on the development characteristics. Incremental developments tend to benefit more from high involvement relationship with critical supplies while playing around with many business partners is more likely to contribute to discontinuous innovations since new perspectives are frequently brought in (Schiele, 2010; Johnsen, 2009). Furthermore, differences in power should be managed to prevent conflicts. This is usually not a problem when the power is on the supplier side but in the opposite situation there is a risk of the buying firm taking advantages of their power resulting in potential abilities of monitoring the supplier. In a preferred situation, mutual gains often appears from supplier involvement through shared knowledge and by working towards the same goals. Cost targets can further be established as suggested by Petersen et al. (2003). To reach such targets companies need a high level of trust since it often requires the supplier to give away information about their cost structure, enabling both parties to spot potential areas for cost savings. Thinking outside the box and explore alternative technological solutions is mentioned as part of this effort.

2.2.6 Design Questions

In this section, design questions are presented which have been used as a guide for data collection. The second research question has been broken down into the following, more specific design questions:

- *Make or buy lithium foil*
    - *What is the strategic importance of the studied component?*
    - *What is the existing level of competitiveness at GSB/GBC?*
- *What is the level of customization/standardization?*
    - *What requirements does GSB have?*
- *What are the suppliers' capabilities?*
- *What are the characteristics of GSB's existing supply chain?*
- *What are the lithium sources for selected suppliers?*

2.3 Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) is a method that was used in this thesis for supporting the supplier selection. The method is known for being used a lot in environmental applications but the structure of the method works in other contexts too. The basis of the method is that it allows for preferences and performance from different management alternatives to be compared in a clear formal way (Linkov et al., 2011). The basic outline of a MCDA is described by Linkov et al. (2011) as:

Problem identification
The first step is to identify the problem meaning that relevant stakeholders and an overall structure is determined without any quantitative descriptions. In this thesis the only stakeholder is GSB/GBC hence only one matrix is used for the analysis.

Problem structuring
The second step is to define the criteria and alternatives used for the analysis. Criteria meaning the set of properties that describe the performance of a supply strategy while alternatives meaning the different suppliers to be compared.

Model assessment and building
In the third step the criteria are weighted according to the importance they have to the supplier selection where the sum of all weights was decided to end up at 100 in this thesis. The alternatives are then to be scored against the criteria ranging from 1-5. The outcome being information about how well each supplier perform on each criterion.

Model application
The fourth step of the MCDA is to use the information in order to make a decision on the most suitable supplier(s).

Planning and extension
The last step of the MCDA is to plan how to establish connections with the selected supplier(s) and take other alternatives into consideration. In this thesis the emphasis is put more on selecting the suppliers hence the last step of the MCDA was handle as a discussion.

3. RESEARCH METHODOLOGY

This chapter goes into the essence of the methodology and ethics applied throughout the process of this thesis.

3.1 Research Strategy

There are several strategies available when writing a thesis. What is common to these strategies is that the context plays a critical role when matching the aim of the thesis with the right strategy. Bryman (2008) stated quantitative and qualitative research as two strategies while also mentioning a third one that has emerged from the other two. This one is defined as mixed methods research.

Quantitative research emphasizes on having quantified information as the base of the research, both when collecting and analyzing data. Mathematical models are applied for evaluating the data which is compared to theory by using natural science models (Bryman 2008). There are two ways of collecting quantitative data; experiments and surveys (Creswell, 2013). Experiments are used to find out if a treatment has effects on an outcome from a sample. Surveys on the other hand seeks to observe information through questionnaires or structured interviews. Surveys are conducted to provide a reflection on trends, attitudes or opinions observed from a group of participants with the aim of generalizing through statistical analysis. In this thesis, qualitative data has been collected in terms of RFQ surveys which was distributed to selected suppliers. These surveys were produced by GBC Corporate Research and modified in cooperation with the authors of this thesis. Qualitative research is based on words which can be both written and spoken. By using words as the source of data, individual interpretation becomes an increasingly important factor when analyzing that same data (Bryman, 2008). In this thesis qualitative data has been collected in terms of arranged meetings at GSB, conference calls with GBC Corporate Purchasing in Europe, emails, spontaneous meetings and discussion which is very common setting for companies in the San Francisco Bay Area. The last research strategy is the mixed methods research which is the most recent approach. This strategy has gotten an increased focus lately as it offers more possibilities to take advantages of different approaches and therefore make use of positivism as well as written and spoken reference points (Bryman, 2008). The mixed methods research strategy was applied in this thesis by combining surveys from the quantitative approach and the different qualitative settings mentioned in the qualitative approach. Furthermore, the two approaches were combined using concurrent procedure which implies that data gathering and analysis were applied both from qualitative and quantitative strategies in a parallel way. According to interpretation of qualitative data provided by Bryman (2008) and Creswell (2013), this procedure was seen as having the best fit with the context of this thesis.

Bryman (2008) suggested two strategies for qualitative data analysis; analytic induction and grounded theory. The process of analytic induction consists of a couple of steps including roughly defining a research question and hypothetical reasoning of the problem before going into data collection. Bryman suggested that throughout the process of a thesis, a hypothesis might need to be redefined or reformulated depending on where the analysis directs the researcher. This strategy was thus applied for the data analysis as it is a good support when trying to solve a problem for a specific company, which is the approach for this thesis.

3.2 Research Design

Creswell (2013) combined and elaborated more on existing literature in the research design area which resulted in a few defined groups. These groups are; ethnographies, grounded theory, case studies, phenomenological research and narrative research. The authors of this thesis could not find a specific match among these groups regarding the thesis design, hence the thesis was explained to be conducted in a way that it deals specifically with GSB as a company and aims to help this company with a specific issue. The difference between this explanation and for example, a case study, is that the former aims to address a question specific for a company (in this case GSB) while the latter is focusing on addressing a general question, where a case is studied to support answering that question.

3.3 Research Method

In this thesis a distinction has been made between secondary and primary data. Secondary data is the already existing literature, studies and information. What characterizes that data is the fact that it was not created with an aim to contribute to the thesis work, but is still applicable since it covers topics which are relevant to the thesis. Examples of secondary data used in this thesis are digital studies of lithium market segments, supplier information sheets, literature about supply strategies, etc. On the other hand primary data is created specifically to relate to the purpose of this report and to answer formulated research questions (Glass, 1976). Examples of primary data used in this thesis was internal quantitative data received from GSB in terms of technical specifications and, as proposed by Bryman (2008), interactive qualitative data for example, statements about market analysis requirements and supply strategy aspects. See *figure 7* for a detailed structure of the research strategy and methodology of the thesis.

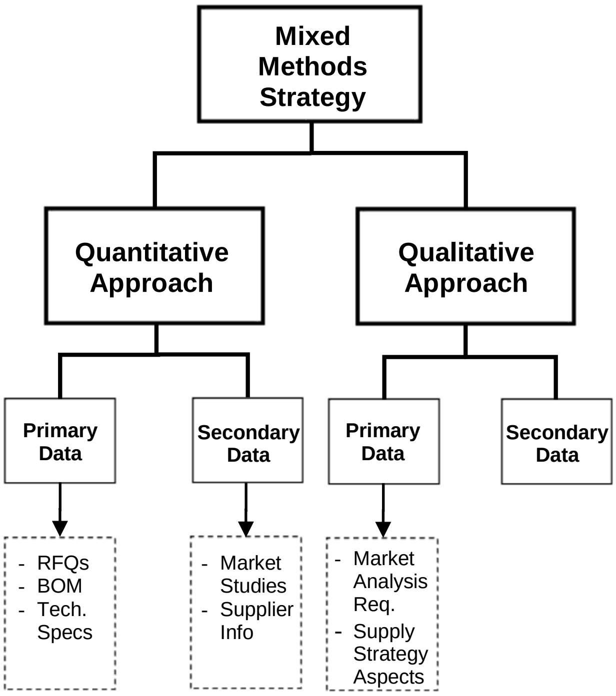


Figure 7 - The thesis research method structure

Section 3.3.1 through *section 3.4.4* reviews the different types of ways data was collected in this thesis.

3.3.1 Literature Review

An academic literature review was conducted in order to create the frame of reference (see *chapter 2*) for the topic of this thesis. This was done in order to understand the situation of which GSB is facing but also in order to make use of what has already been studied in similar contexts. The literature study started off by mapping up areas of concerns and thus defining relevant keywords. Initially, literature related to the author's' past educational background within the field of Supply Chain Management was collected and its content reviewed. To access certain topics in further details the Chalmers Library online platform with Summon search function was used as first choice in the literature search while Google Scholar had a role as a secondary platforms if sufficient results were not reached through the initial search. Another platform used was Google Patents, not for the purpose of searching literature, but for the purpose of screening relevant lithium patents. Books in physical form available through the Chalmers Library were collected and rented, while articles and electronic books were mostly attained in digitalized form. Internet based search was also applied to find the most relevant literature each time. By using that approach it was possible to cover a large database in an efficient way. Information about the company as well as limited amount of other information was reached through web pages, considered to be sources of trustworthiness. Furthermore, through meetings with different people at the division of Industrial Marketing at Chalmers University of Technology, suggestions were received regarding relevant books related to the thesis topic. The relevance of those suggestions were evaluated and the relevant books were collected in physical form. In the end, only literature and information that was evaluated as coming from reliable and trustworthy sources was used as a base to support further discussions in this thesis.

3.4 Data Collection

To answer the research questions created in *section 1.4* a lot of information was needed in addition to what was already published. It mostly related to information directly connected to GSB, GBC and relevant suppliers. To access that information different approaches were applied which is described in this section.

3.4.1 Internal Documents

Internal documents and historical data are sources of information which can be best described as secondary data, supported by Bryman's (2008) definition. These documents relate to GSB/GBC and the day to day business which takes place there. The internal documents used for the purpose of this thesis were most often categorized as secondary data although some were especially created as supporting documents for this thesis work. In those cases the main implication were to clarify or simplify certain relevant areas which turned out to be useful throughout the research process.

3.4.2 Interviews and Arranged Meetings

The aim of having interviews during the process of this thesis was to collect qualitative primary data which would later became an important source of information for the analysis and outcome of the thesis. Interviews were conducted regularly throughout the process of this thesis, most often not in the shape of formal interviews. For the entire period of which the authors of this thesis were present at GSB, regular meetings were scheduled which functioned as a way of talking to people in a real work context, replacing the traditional interview setting. Before reviewing the different meetings and the persons involved, the organizational structure of GSB and GBC is presented in order to get a better understanding for how communication and responsibilities are divided within the organization.

Until the acquisition R&D engineers at GSB were responsible for the purchasing tasks due to its start-up characteristics. Two of these engineers worked especially with lithium foil. After the acquisition, when GBC entered the picture, the purchasing operations were directed more towards GBC and GSB’s engineers would remain in contact with suppliers mainly for the purpose of technical discussions. As can be seen in *figure 8*, GBC has a centralized purchasing department, called corporate purchasing (CP), which supports all divisions. GSB is part of GBC Battery Division which is part of the Gasoline Divisions. Project X is another battery project which GBC had ongoing. CP’s responsibilities regarding the lithium foil was to scout for foil suppliers, analyze the cost structure of GSB’s batteries, identify where costs are created in the supply chain, sending out requests for quotation (RFQ) and conducting technical supply discussions (TSD). Hence GBC would focus more on the cost structure of the lithium foil while GSB would focus more on the technical aspects of the foil component, functioning as a pure R&D company.

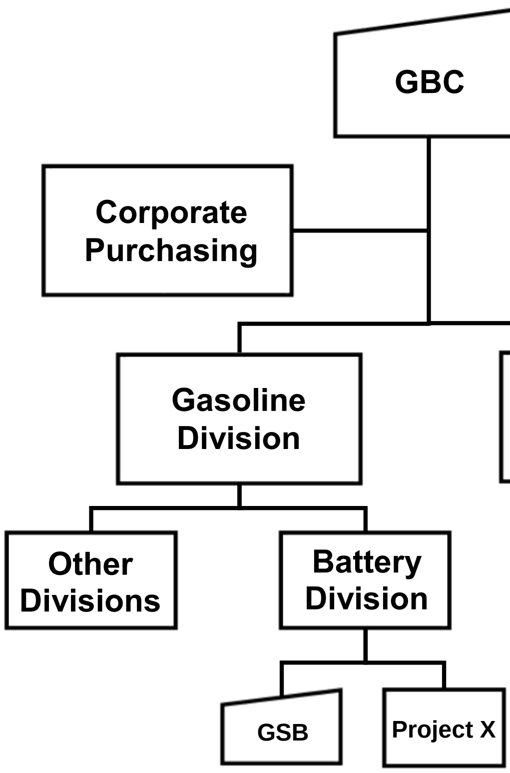


Figure 8 - Organizational structure of GSB/GBC

The three types of meetings that took place during the time the authors of this thesis were present at GSB is presented below:

Lithium anode supply meeting
The meeting took place frequently, where the authors of this thesis had the chance to present the current work progress of the lithium foil supply, while discussing the topic and asking questions in order to obtain required information. In this setting, only people from GSB were involved. The following people were present in those meetings:

The CEO of GSB
The VP of Cell Development and Pilot Line Production at GSB
R&D Engineer 1 at GSB
R&D Engineer 2 at GSB

Total number of meetings: 8

Cost estimation meeting
The meeting took place a couple of times where the corporate purchasing department of GBC was responsible for the meeting agenda. One of many topics discussed during those meetings was the lithium foil supply. The authors of the thesis had the chance to obtain information about lithium foil suppliers since corporate purchasing were responsible for communicating with suppliers. The following people were present in those meetings:

The CEO of GSB
The Director of Project Management at GSB
Corporate Purchaser 1 at GBC
Corporate Purchaser 2 at GBC
Corporate Researcher in Ceramics at GBC

Total number of meetings: 3

Master thesis meeting
The meeting took place frequently during the last half of the thesis period where the authors of this thesis had the chance obtain information and explain what information was needed from GBC. Also the work progress was presented for GBC. The only people involved in this meeting were the authors of this thesis and *Corporate Purchaser 1* who had the responsibility of being the thesis contact at GBC.

Total number of meetings: 6

Something that all the three sessions of meetings had in common was that they were conducted in a semi-structured way. This meant that agendas and PowerPoint slides had been created as to keep the meetings on track and towards a preferred direction. Moreover, the semi-structured meetings can be segmented into three categories based on level of presence, the categories of the meetings are as follows; face to face, video call and phone call. For the lithium anode supply meeting, face to face was applied, while for cost estimation meeting a mix between face to face and phone call in terms of conference call through WebEx was used. Lastly, the master thesis meeting was only conducted as a phone call in terms of a conference call through WebEx.

3.4.3 Informal Meetings

Being present at GSB almost every weekday for three months contributed significant knowledge that were indirectly taken into consideration while writing the report. The start-up environment and the company culture allowed for very casual conversations and quick access to information as it was needed. In that sense, rather than collecting questions over certain period of time and schedule interviews, an approach of just dropping by and ask for answers from a relevant person was used. In addition to that, information was received through very informal conversations such as general discussions over lunch, during coffee breaks or other occasions.

3.4.4 E-mail Communication

Conversations via email should not been overlooked although it was not the most critical way of accessing information. It was rather used for clarification and to verify that observation of qualitative data did not include any bias. Furthermore, email conversation became vital to access external information and to get in contact with GBC about suppliers and their RFQ answers. Some of that information became very valuable throughout the process and could not have been accessed more easily through other communication forms.

3.5 Research Ethics

When studying the focal company the researches had to sign an agreement regarding confidentiality, more specifically a one way confidentiality agreement. The purpose of that agreement from the company perspective is to mitigate risks related to leakage of proprietary information which is highly relevant considering the company's characteristics and its effort in discovering previously unknown areas. The one way agreement implies that the researchers are not allowed to give any information away that might be sensitive to non-contracted actors. Furthermore, if proprietary data was in need to be discussed with contracted actors, an approval from the CEO was required beforehand. Moreover, the agreement implies that the researchers are not under any circumstances allowed to receive confidential information from third parties.

To avoid causing any type of harm, all confidential information was excluded from this report. To make sure that this criterion was fulfilled, the company's CEO reserved the right to read through the report before it was made available through publication. Furthermore, numbers on the company's specification and other technical aspects have been modified.

Bryman et al. (2015) provided comprehensive discussions about research ethics in their book. As they suggested all interviewees were informed about the purpose of this thesis and they informed that their names will not be stated in the thesis in order to maintain privacy. This strategy was applied on company names as well, hence they were disguised when needed. Furthermore, the interviewees could choose not to answer questions without giving any explanation to avoid harm. After the thesis work ended, GSB received ownership of all gathered information and data for internal purposes.

The set of ethical rules were used throughout the entire process of this thesis. Moreover, ideas that can possibly be conceived as inventions, created from knowledge observed during the process of this thesis and within eighteen months from the completion of this thesis will be disclosed to GSB's CEO.

3.6 Research Quality

Assessments on research quality, often referred to as trustworthiness, were discussed by Bryman (2008) as it gives the reader insights into what has been done in order to prevent biased or misleading information. If a research is to be helpful then it needs to be trustworthy. Several tools and discussions on how research quality can be improved were provided by Bryman (2008). Two categories, reliability and validity, were of highest importance in that sense. As this research is carried out as a mixed methods research, the discussion below will be divided accordingly.

3.6.1 Reliability

Reliability relates to evaluation of areas concerning standardization and the ability to conduct the research again without the results differing too much. In that sense, a research that can be conducted over and over again by different researchers while always deliver the same results can therefore be classified more towards the reliable end of the reliability spectrum. The general rule when it comes to reliability is that quantitative research tend to be more repeatable than qualitative research and therefore has a higher degree of reliability. Furthermore, Bryman (2008) distinguished between external and internal reliability. External reliability is dependent on factors such as social settings which differs and implies that the repeatability of this research would be challenging. If the process had been performed by other researchers different topics could have gotten attention and therefore the conclusion would have had a different focus. Therefore external reliability is generally higher when same researchers undertake the research again rather than substituting them (Bryman, 2008). By having the same researchers again it is more likely that what is seen, heard and read will be observed in a similar manner as when the original research took place. Even with a well-defined interview guidance high external reliability would be challenging to reach. Practises attempting to increase external reliability were carried out such as documentation of interview questions, participants and notes. Notes were written down separately during meetings and then combined immediately after to ensure the quality of the data. Furthermore, internal reliability is described as the consistency among researchers when interpreting and evaluating data. High internal reliability is reached if researchers interpret information in a same manner regardless of if they are doing it the first or the second time. In this particular research, bias related to internal reliability were counteracted by working closely together. Sharing a desk resulted in significant communication throughout the process and if any uncertainty regarding how to interpret certain data occurred, discussions took place right away and lasted until a mutual understanding were reached. Overall, it is believed that decisions made towards a higher level of internal reliability had positive effects.

3.6.1 Validity

Assessment of validity aims at finding out if the researchers are really observing, describing, documenting and collecting data which is consistent with the initial aim of the project (Bryman, 2008). Also, it describes how well the authors follow up on their research by cross checking the validity of the external information and its reliability. Validity can further be divided into two groups; internal and external validity. Internal validity takes into account the fit between the research findings and the theoretical findings within that area. To secure a high internal validity the authors asked for feedback from a supervisor on some of the key concepts and applied triangulations as suggested by Bryman (2008).

When the triangulation approach is used, two or more data sources are used each time to compare findings from different authors as it acts as a risk mitigation to block out damaged or poor quality information. It is believed that using this approach resulted in more holistic and correct view upon each concept. This approach was applied as much as possible. To secure validity of company specific data weekly meetings took place where preliminary data was presented and discussed as well as certain aspects were clarified. This gave opportunities for critical comments if collected data were not seen to be supporting the aim of the study. External validity on the other hand considers the possibility to apply the findings in different settings. As this particularly research was limited to only one component within one company, external validity is limited. However, to increase the external validity, efforts were made in generalizing some parts in order to apply them for other purchased components within GSB. Furthermore, companies within the same industry are believed to benefit from the findings to some extents although external validity would be higher if confidentiality concerns would have been ignored.

4. LITHIUM SUPPLY MARKET ANALYSIS

This chapter aims at answering research question one. In order to do so GSB/GBC requirements on that analysis are presented followed by the actual market analysis. The analysis consists of the value added steps to produce lithium foil, an in depth study on lithium as a resource and discussions on the current lithium market.

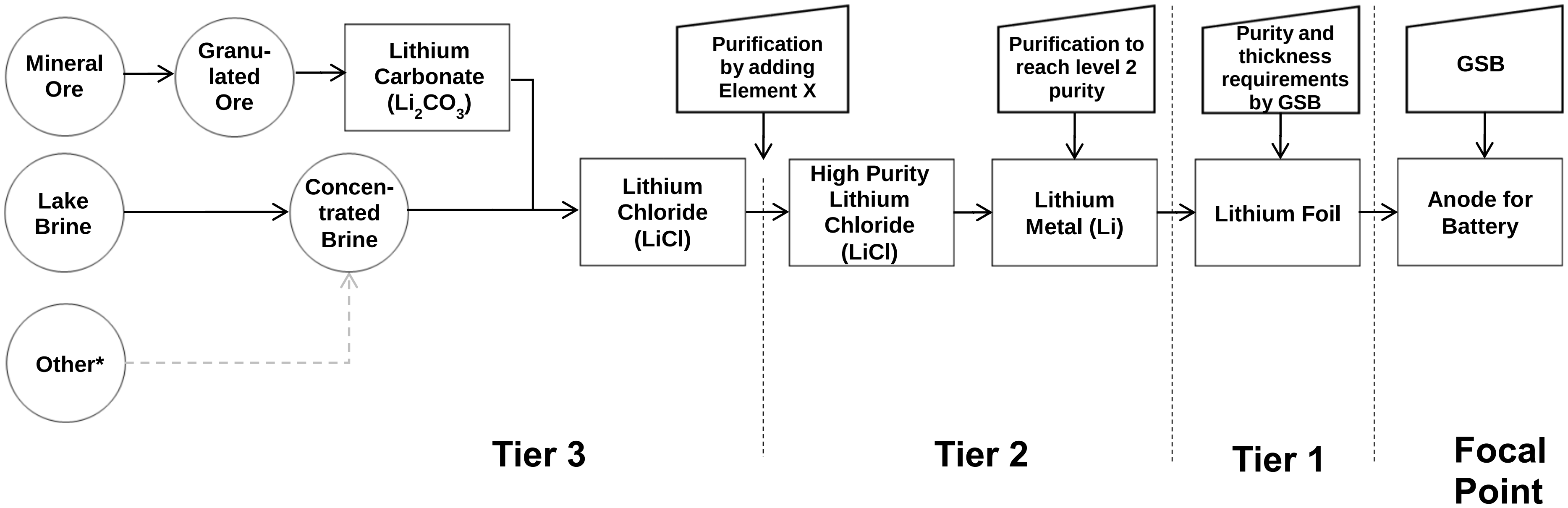
4.1 GSB/GBC Requirements on the Supply Market Analysis

In order to structure the supply market analysis, GSB had some requirements about what aspects to cover in the analysis. During a meeting with relevant stakeholders at GSB it was stated that the company wanted to start focusing on the first stages of the supply chain. This implied looking into sources and global resources of lithium, split by country. When investigating origins, GSB wanted the supply market analysis to not only focus on existing sources, such as lake brine and mineral ore, but also on future origins like seawater and hydrothermal sources. In relation to that, GSB was also interested in knowing the largest actors on the market and the market shares each of these actors possessed. Moreover, GSB wanted the supply market analysis to focus on the demand side too, implying that the end use split of lithium between different industries was to be investigated based on consumer volume. Lastly, GSB was interested in prices and costs at different stages of the lithium foil supply chain implying that they wanted a cost distribution calculation analysis of where the value was created in the supply chain. The goal was to better understand the market and have information to support a make or buy decision of producing foil for the batteries.

In another meeting with two people from GBC corporate purchasing and one from GBC corporate research, it was stated that in addition to GSB's requirements, GBC was interested in how much lithium carbonate goes into lithium metal (see *section 4.2* for different stages in the supply chain). Furthermore they also wanted to know more about recycling of lithium and which actors in the supply chain that had proprietary information e.g. patents on important technology that were crucial to lithium foil production.

4.2 The Lithium Market Process Chain

The supply chain structure for lithium foil is divided into three tiers (see *figure 9*) based on input and output from the different suppliers found in this supply chain (see *section 4.6* for these suppliers). It should be mentioned that in each stage, the materials can have different purity levels which affects quality, cost etc. This will be further elaborated on.

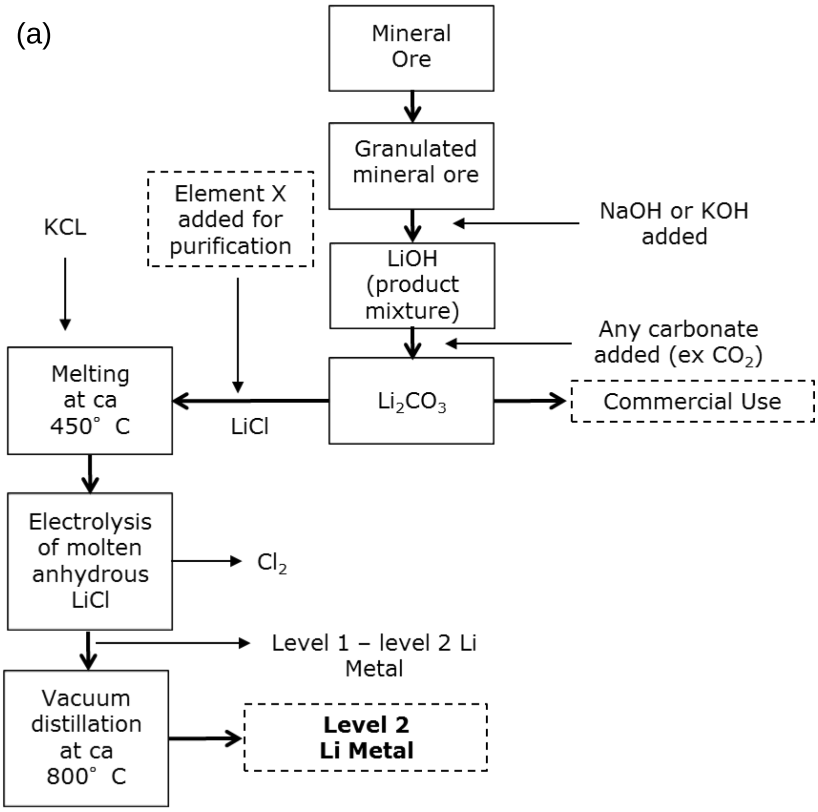


** Hydrothermal brine and seawater extraction*

Figure 9 - The lithium foil supply chain (Adapted from Palmer et al., 2008; Dunn et al., 2015)

Tier 3 and Tier 2

Lithium comes from various different sources; mineral ore, lake brine and others (see *section 4.3* for a more details). Depending on source, the production process to produce lithium foil takes different routes. When using lake brine, which is the most common source, the brine is turned into concentrated brine before going into lithium chloride (LiCl). In the next step LiCl is purified in order to reach higher quality e.g. purity which enables LiCl to be used for producing lithium metal. When using mineral ore as the source of lithium to make lithium metal, the ore has to go through a lithium carbonate (Li_2CO_3) step before going into LiCl. After that the process steps up to lithium metal are the same for both sources. A detailed description of the process steps when going from lake brine or mineral ore to lithium metal is presented in *figure 10*.



(b)

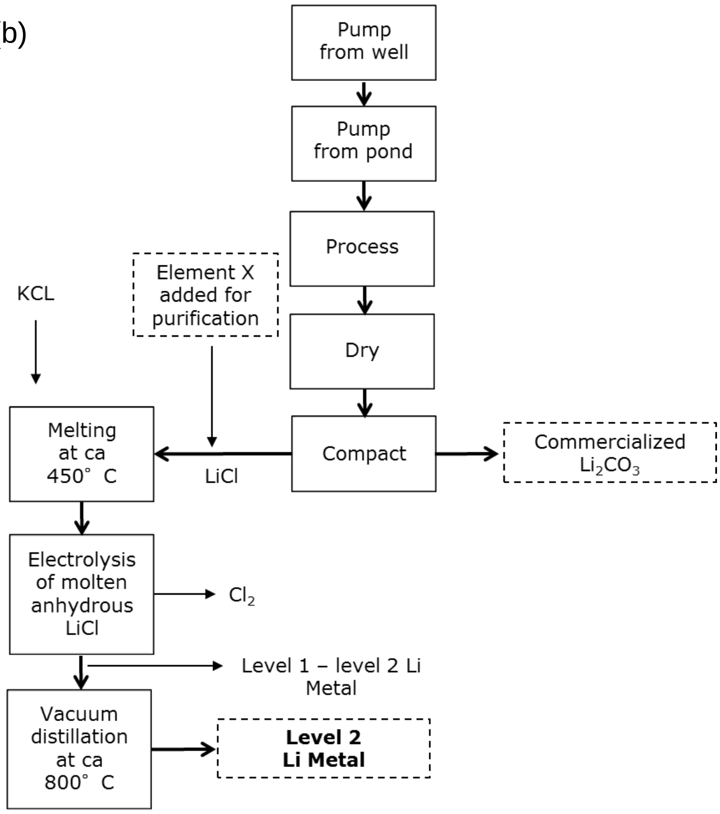


Figure 10 - Detailed process step of tier 3 and 2 for minerals ore (a) versus lake brine (b) (Adapted from Dunn et al., 2015 and Anovitz et al., 2006)

Note that in the case of lake brine, water is evaporated from the concentrated salts in the "process" stage where one can extract LiCl, a process that takes 18 to 24 months per batch (Martin, 2015). Both production chains can produce Li_2CO_3 but in the case of mineral ore this step is necessary while in the lake brine case this step is optional when producing Li_2CO_3 for commercial use. The extracted LiCl in both the lake brine and mineral ore process flow is sometimes commercialized and sold, but mostly further produced. The commercialized LiCl is used in applications like: dip brazing, soldering, desiccant in air conditioning and as electrolyte material in Li-ion batteries. It should also be noted that Li_2CO_3 can be used directly in battery cathodes. The difference between LiCl and high purity LiCl is the purification process where unwanted materials are removed from the lithium compound. It is also in this step where element X is added to remove sulfate from LiCl (Amouzegar et al., 2000; Ekberg et al., 2015) and where excessive amounts of element X is added to the lithium which creates impurities GSB does not want. Sulfuric acids are added afterwards to remove added element X (Garrett, 2004) although some of it still remains in the lithium after that treatment.

As can be seen in *figure 10* an electric current is passed through melted anhydrous high purity LiCl in order to make it into lithium metal. The current separates the compound into lithium metal and chlorine gas, thus lithium metal is extracted. The lithium metal is casted into ingot which is later on sold or used in further production for lithium products.

<u>Tier 1</u>

In tier 1, lithium metal is processed into lithium foil shaped by technological requirements which GSB provides. The most important requirements are thickness (aiming for ≤ 4,000

ADU) and purity requirements (aiming for at least level 3). The process of making lithium foil out of lithium metal has two steps: (1) extruding and (2) rolling (see *figure 11*). The rolling stage can be ignored if the foil thickness is greater than 20,000 ADU.

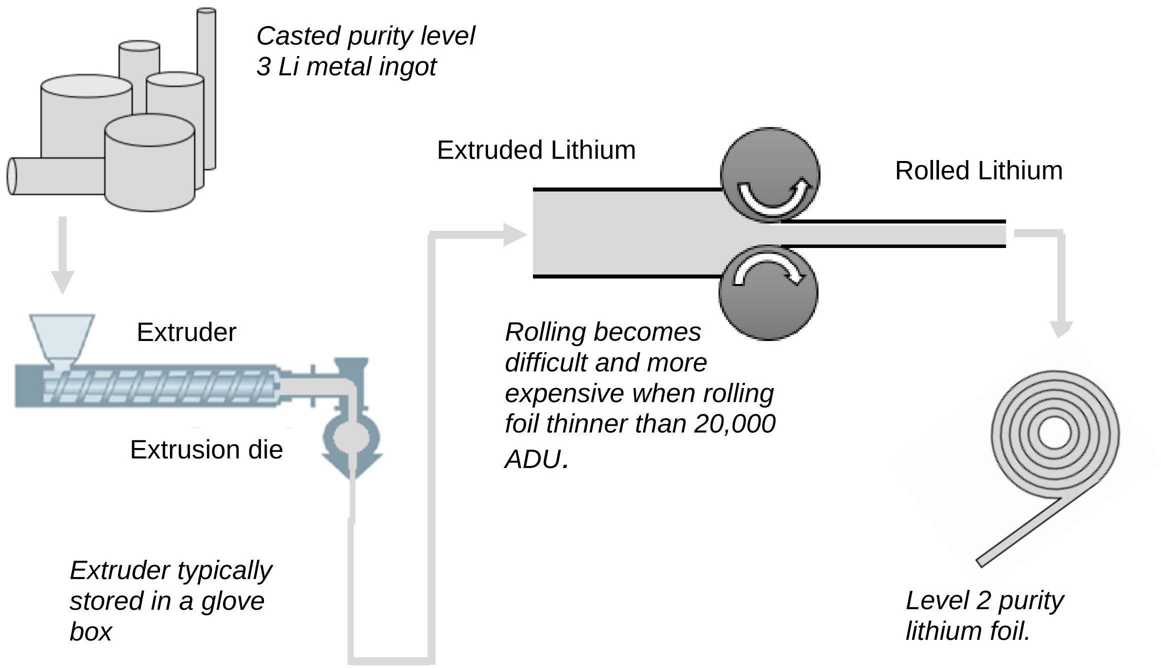


Figure 11 - Tier 1 general process flow

As mentioned in the beginning of this section, the purity levels in each stage are important in order to make sure that a lithium foil with purity of level 2 will be reached (GSB's required purity level). The purity levels related to Li_2CO_3 are typically level 1 or level 2 and for lithium metal purity levels are typically level 1, level 2 or level 3.

4.3 Lithium as Raw Material

This section focuses on the different sources of which lithium can be produced from, including global volumes and a geographical split for raw lithium.

<u>Lake Brine</u>

This is the most common source for lithium as approximately 60% of the global lithium production comes from lake brines. Lake brine is extracted from salt lakes (salars) which are most common in South America. Lake brines are mostly extracted in Chile, Argentina, China and the US, where the most favorable location is Chile for two reasons; (1) low production cost due to cheap labor and (2) high lithium concentration due to dynamics from ancient drainage. Lake brine is also easier to explore as the lithium is closer to the surface compared to mineral ores and they occur in salt flats which generally makes them easy to access logistic wise. The results is considerably lower investments needed for starting up lake brine production as well as the production cost itself is much lower (Loewen, 2015). There are different groups of lake brines; alkaline, sulfate-rich and calcium-rich but it is currently unknown how these affect the process of manufacturing lithium foil.

Mineral Ore

Mineral ore accounts for approximately 40% of the global lithium production and is mined from hard rock. The rock which is extracted contains spodumene ($LiAl(SiO_3)_2$) which is a pyroxene mineral consisting of lithium aluminum inosilicate. Other minerals that are used are petalite ($LiAlSi_4O_{10}$) or lepidolite ($K(Li,Al)_3(Al,Si,Rb)_4O_{10}(F,OH)_2$) (Garrett, 2004). It is from these minerals that lithium is produced and the process is very energy intense and more costly than processing lake brine (see *section 4.2*). Mineral ore is mostly extracted in Australia, China and the US (see *section 4.4*).

Hydrothermal Brine

Hydrothermal brine is a source for lithium that has not yet been commercialized. One company that has focused on developing this technique is Supplier 23. The company is currently operating in Imperial Valley, CA, where they are extracting lithium through hydrothermal brine which is a by-product from geothermal power plants. Commercialization of Supplier 23 technology began with a demonstration facility in 2010 and was followed by the opening of what is claimed to be the world's highest purity lithium carbonate (purity level 5) plant in September 2011. At the beginning of year 2016, the company said it was preparing to break ground on its first commercial lithium plant, which at full capacity, was expected to produce enough lithium for about 1.6 million plug-in hybrid electric vehicles per year (Reitenbach, 2015). The cost of extracting lithium from hydrothermal brine is considered to be at the same low cost level as lake brine from Chile. However reports have highlighted that Supplier 23 has some investments issues resulting in layoffs, delaying the development of this process technology (Roth, 2015).

Seawater Extraction

Lithium is present in seawater and there are ways of extracting it. This process is not commercialized, but Hoshino (2014) has developed and showed a dialysis process for lithium recovery from seawater without electrical supply. This type of dialysis has good energy efficiency and is easily scalable which makes it suitable for industrialized mass production. It should be noted that the dialysis was performed with briny waters from South America which, according to Hoshino, is the most suitable water for this type of process. It is also a good approach for recycling used lithium ion batteries. *Table 3* shows the mass percentage of lithium in different geographical lake brines compared to seawater.

Table 3 - Mass percentage Li in lake brine compared to seawater

Lake Brine Origin	**Mass % Lithium**
Chile	0.160
Argentina	0.052
USA	0.020
China	0.068
Seawater	0.000017

Seemingly, the extraction process of seawater requires approximately ten thousands (10^4) times more input than lake brine (in Chile) in order to generate the same amount of lithium. Although this might be viewed as quite a distinctive difference, extracting brine is a slower process than the process of extracting seawater, hence seawater extraction has the possibility to be more beneficial. On the other hand, some sources say that extracting lithium from seawater would be more expensive than extracting brine and would not become feasible unless demand exceeds production capacity from other sources first (see *figure 12*). It is projected that prices for seawater extraction can be as much as ten times larger compared to brine extraction (Bache, 2014). In relation to these prices, the estimated recoverable lithium from seawater is 44.8 billion tonnes (Bache, 2014).

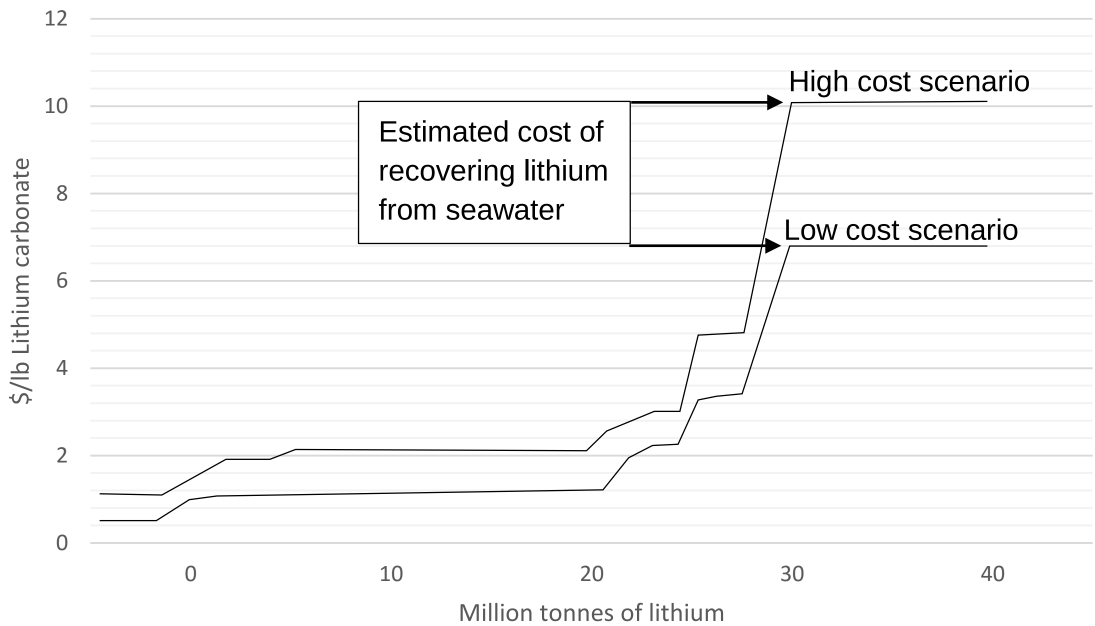


Figure 12 - Cost estimations for seawater extraction (Adapted from Yaksic et al., 2009)

4.4 Global Volumes and Current Production

Most of the world's lithium resources are present in South America in what is known to be the lithium triangle (Bolivia, Chile and Argentina). All regional volumes can be seen in *table 4* where the distinction is made between resources and reserves. A resource is the actual amount of lithium in the ground while the reserve is the economically and technologically mineable amount that has been allocated for extraction. Note that Bolivia, even though they have the highest amount of resources, does not have any reserves (Jaskula, 2016). The reason for this is that the Bolivian government established restrictions (potentially to be removed in near future (Revette, 2016)) for lithium extraction.

Table 4 - Global lithium resources, reserves, production and end split between resources in 2015 (Jaskula, 2015 and 2016; Center of Energy Economics, 2015)

Country	**Resources (metric tonnes)**	**Reserves (metric tonnes)**	**Production in 2015 (metric tonnes)**	**Resources % Lake Brine**	**Resources % Mineral Ore**
Bolivia	9 000 000	-	-	100%	0%
Chile	7 500 000	7 500 000	11 700	100%	0%
USA	6 700 000	38 000	870*	53%	47%
Argentina	6 500 000	2 000 000	3 800	100%	0%
China	5 100 000	3 200 000	2 200	77%	23%
Australia	1 700 000	1 500 000	13 400	0%	100%
Canada	1 000 000	N/A	N/A	0%	100%
Congo	1 000 000	N/A	N/A	0%	100%
Russia	1 000 000	N/A	N/A	0%	100%
Serbia	1 000 000	N/A	N/A	0%	100%
Brazil	180 000	N/A	160	0%	100%
Mexico	130 000	N/A	N/A	N/A	N/A
Austria	130 000	N/A	N/A	N/A	N/A
Portugal	N/A	60 000	300	N/A	N/A
Zimbabwe	N/A	23 000	900	N/A	N/A
Total	**40 940 000**	**14 369 000**	**34 000****	**-**	**-**

*Data from 2013, recent numbers not posted to avoid disclosure of proprietary data.
**Rounded number for included countries

Market Shares

Historically the global lithium market has pretty much consisted of three major actors (FMC, Albemarle and SQM) which have dominated the market (Global LLC, 2015a). However recently, as will be further explained in *section 4.9*, Chinese actors have emerged and obtained larger market share where actors like Tianqi and Ganfeng are in the forefront. *Table 5* shows the market shares of the different actors.

Table 5 - Maximum capacity and distribution of market shares (Hykawy et al., 2015; Matich, 2015; U.S. Geological Survey, 2013)

Producer	Maximum Capacity 2014 (tonnes/year)	Global Lithium Market Share 2014
Tianqi	20 679	36%
SQM	9 008	26%
Albemarle	7 365	12%
FMC	4 306	7%
Ganfeng	-	12%
Other Chinese Ore Miners (collectively)	2 832	1%
Others	-	6%
Total	**44 190**	**100%**

4.4.1 Recycling

Recycling of lithium has historically not been carried out to any extents although the material itself has a good potential for being recycled. In 2012 about one fourth of lithium batteries were recycled in EU and is expected to increase up to 45% by the end of 2016 (Speirs et al., 2013). However, recycling of batteries is not conducted with the aim to reuse lithium but the current purpose is to recycle the cobalt and nickel hydroxide (Speirs et al., 2013). As lithium prices have been considerably low throughout the years, recycling of lithium has not been economical. To trigger increased recycling of lithium prices need to go up, regulations have to become stricter or economic incentives need to be provided. Peiró et al. (2013) claims that in 2011 only three percent of lithium was recycled within the battery manufacturing industry which falls short when considering the total lithium volumes. If recycling becomes economically feasible, researches have pointed out that the amount of reused lithium could increase significantly. However, not all agree on to what extents the recycling process can be carried out which results in numbers from 40.000 tonnes of contained lithium to be recycled in US only and up to half of the global lithium demand by 2050 (Speirs et al., 2013). The only thing certain now is the existence of technological knowledge for lithium recycling which can increasingly be put into action as it becomes more economically beneficial.

4.4.2 Countries and Politics

Six countries (Argentina, Australia, Bolivia, Chile, China and the U.S.) holds the majority of the global lithium reserves, all of which are currently producing except for Bolivia which is more in a testing phase. Political instability is believed to be part of the reason why Bolivia has not started any mass production yet (Missouri university of science and Technology, 2012) although the existence of the resources has been known for a couple of decades. This might though change in the coming years as the government there has an intention to boost the local extractions. One should bear in mind that such a process might take years and regulations with an aim of encouraging industrialization within the country are likely to be implemented in association with that process (Revette, 2016). Despite limited geographical spread of the lithium resources factors such as political, regulatory and social factors are not seen to have any large impacts on the current lithium production (Chu, 2011) mainly because the six countries are rather diversified and independent on each other. As the countries are different, one can evaluate them from the perspective of attractiveness of mineral exploration policies and amount of potential resources after current laws and regulations have been applied (Maxwell, 2013). Countries considered in the assessment were combined on a list where information on lithium containing countries were retrieved. Here, numbers from the list are presented in an order starting with the most attractive areas and ending with the least favorable. The numbers in parenthesis represent the actual position on the list: USA such as Nevada (4/96), Western Australia (9/96), Chile (11/96), Argentina's Salta province (54/96), China (72/96), Argentina's Jujuy province (84/96) and Bolivia (96/96). Furthermore, Dolbear (2014) ranked 25 countries according to economic system, policy system, social issues affecting mining, bureaucratic delays, corruption, currency stability and competitiveness of tax policy. His conclusions were as follows: Australia (2/25), USA (3/25), Chile (4/25), China (16/25), Argentina (20/25) and Bolivia (24/25) (latest assessments on Bolivia were made in 2012 and are not included in Dolbear's most recent list). Comparison of these two studies show similar trends although there are some minor differences in where certain countries are placed on the lists.

Due to the fact that these countries are diversified and show very different results in mining attractiveness, it becomes interesting to look further into how these countries differ in terms of fiscal regimes. To give a brief overview, taxation can either be profit based (taxes based on corporate income, profit or tax flow) or production based (generate revenue for the government regardless of company's profits) (Perotti et al., 2015). Furthermore, the main tax types are categorized according to these two categories and shown in *table 6*.

Table 6 - Main tax types (Perotti et al., 2015)

Profit-based taxes	**Production-based taxes**
- Corporate income tax - Profit tax on dividends - Royalty based on profit / income measure - Withholding tax on remitted dividends - Resource rent tax - Excess profit tax / Windfall tax	- Royalty, unit based (flat-rate) and value based (ad valorem) - Sales and excise tax - Payroll tax - Export duty - Import duty - Value added tax (VAT) - Application / issuing / registration fees and stamp duty - Land rents - Withholding tax on loan interests and services - Property tax

As all the main lithium reserves countries are independent they have chosen different routes for taxation of lithium. Regulations can either be applied on a regional level or be dependent on domestic territories. Chile, Argentina and USA are examples of countries who apply different taxations based on territories. This becomes highly visible for Chile (see *appendix I*) where current taxations related to mineral extraction for different countries are compared. Although taxations are framed in a certain way today there is no guarantee for continuity of the regulations in an unaltered form in the years to come as it is dependent on political interest. It is clear that fiscal regimes highly differ from country to country which partly explains why some countries are more favorable than others both in terms of attractiveness and supply security. Also what is worth noticing is the volume limitation that the two major actors in Chile are facing. If those numbers are further studied one can see that one of the major producer reaches its production quota in 2038 if production continues at the current rate or in 2028 if they get permission to extract at full capacity. On the other hand, another major producer has a quota covering the period until 2030 and if they want to produce until the contract expires they will have to reduce the production rate or they will reach their limits in 2023 (Desormeaux, 2015). At this point no one can tell what happens when the quota is reached or when contracts expires but what is known is that there is some level of uncertainty involved.

4.5 End Use of Lithium

As can be seen in *figure 13* and in *section 4.3* the commercially used lithium is mainly extracted from two origins, lake brines and mineral ores. From the point of origin the chemical takes different paths through the value-chain until it ends up in stock or as waste. Different applications use lithium in their end products, each of which has different volume requirements. Batteries and ceramics & glass are sectors with the highest demand on lithium, accounting for 31% and 35% respectively while other sectors are accountable for 8% or less (see *figure 13*). The battery sector can be divided into four subgroups; 3C (computer, cell phones and electronic appliances) (79%), transport (10%), power & motive (10%) and heavy duty (1%) (Hykawy et al., 2014). GSB's focus is on batteries for transportation which is the category expected to grow the most in the upcoming years and account for 65% of the battery subgroup, while increasing the share of the total battery sector up to 58% by 2025 (Center of Energy Economics, 2015). The battery category is the most suitable group for recycling lithium, mainly because of shorter life cycle of batteries compared to other end usages. Lithium recycled from batteries is also most suited for reuse in batteries which explains why the recycled lithium is returned into the battery group in *figure 13*.

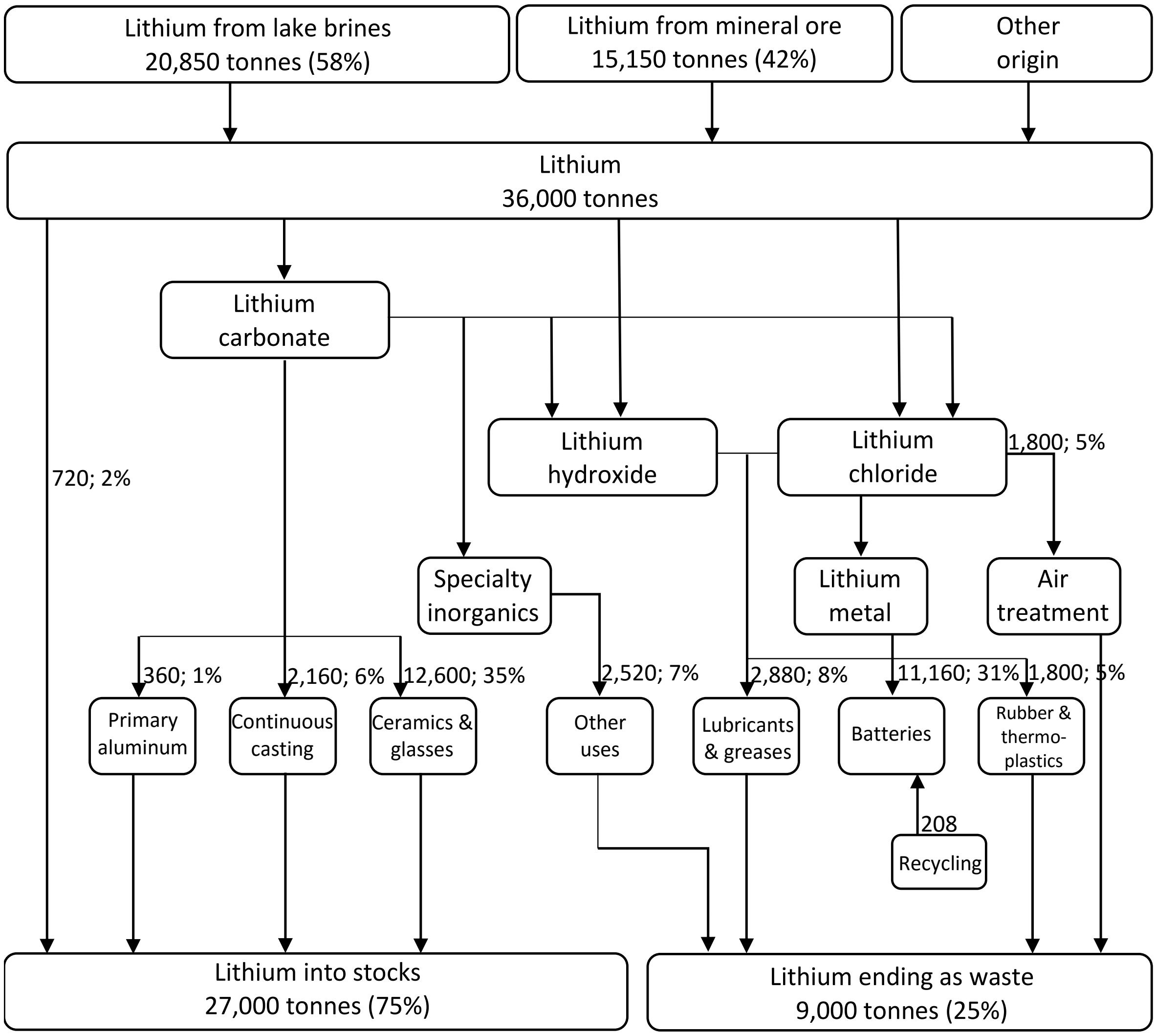


Figure 13 - Lithium volumes and split between applications. (Adapted from Center of Energy Economics, 2015 and Peiró et al., 2013)

4.6 Upstream Lithium Foil and Lithium Compound Suppliers

The list of suppliers known to supply lithium foil are listed in *table 7* and will be further discussed later in the report. Note that only suppliers of relevance are listed e.g. suppliers contacted by GBC through RFQs and suppliers who GSB has been in contact with before. There were other lithium foil suppliers that were not taken into consideration for a variety of reasons.

Table 7 - Lithium Foil Suppliers

Foil Suppliers	Geographical Source of Lithium
Supplier 1	USA, Chile and Australia
Supplier 2	USA, Mexico and China
Supplier 3	No possession of lithium sources
Supplier 4	China
Supplier 5	USA and Argentina
Supplier 6	Argentina and Australia
Supplier 7	No possession of lithium sources
Supplier 8	No possession of lithium sources

Table 8 shows the upstream suppliers relevant to GSB/GBC that are not producing foil but producing other lithium compounds, all of which have operations in the 2nd tier and the 3rd tier.

Table 8 - Upstream suppliers producing other lithium compounds then foil

Supplier	Geographical Source of Lithium	Comment
Supplier 15	Mexico	Develops hectorite deposits that can be mined using low-cost bulk-mining techniques. Plans to manufacture carbonate soon. Collaborations with Tesla to provide hydroxide.
Supplier 16	USA and Argentina	Brine exploration company with many locations
Supplier 17	Argentina and Australia	Supply carbonate
Supplier 18	N/A	Supply level 2 lithium metal
Supplier 19	Australia, Czech Republic and Mexico	Supply carbonate
Supplier 20	N/A	Supply level 2 lithium metal
Supplier 21	Canada	Supply carbonate
Supplier 22	Australia	Supply carbonate

Supplier 23	USA	Supply carbonate from hydrothermal brine
Supplier 13	Chile	Supply carbonate and chloride. One of the big actors on the lithium market
Supplier 9	Chile, Australia and China	Supply carbonate, chloride and level 2 metal
Supplier 24	Argentina and USA	Recent merger. Supply carbonate.

4.7 Prices and Cost Split

Table 9 shows prices at different stages of the lithium foil supply chain. The prices are presented as APU/kg Li metal where 1kg Li metal corresponds to 5.3kg lithium carbonate equivalent (LCE) which is normally used as the common measure for lithium compounds in order to compare prices.

Table 9 - Lithium prices at different stages of the supply chain, for further details see appendix II (Bacanora, 2016; Epstein, 2016; Fox-Davies, 2013; Hagopian, 2011; Hykawy et al., 2014; Li3Energy, 2014; SignumBox, 2014; The Economist, 2016; Jaskula, 2013; internal sources)

Compound	Region	Price range (APU/kg Li metal)
Raw Li - Lake Brine	Argentina, Chile, China	63.8 - 153.3
Raw Li - Mineral ore	Australia, Canada, China, Mexico	127.8 - 213.0
Chloride	Argentina, Chile	142.2 - 198.9
Carbonate	Argentina, Chile, China	154.2 - 766.8
Metal	N/A	560.0 - 640.0
Foil (x ≥ 20 000 ADU)	N/A	8,000 - 8,760
Foil (20 000 ADU ≥ x ≥ 10 000 ADU)	N/A	8,000 - 17,184
Foil (x ≤ 10 000 ADU)	N/A	21,840

GSB put emphasis on finding out the cost structure of the lithium foil supply chain e.g. where the value is generated in the supply chain. Creating that kind of investigation was complex due to the difficulty of getting hold of supplier's costs related to each stage in the supply chain. Hence the cost distribution was based mostly on prices in each stages which still show the value creation although profit margins are included. *Figure 14* shows the cost distribution for 12,000 ADU level 2 lithium foil, produced from South American lake brine according to Supplier 1's supply network (see *section 5.2.5*).

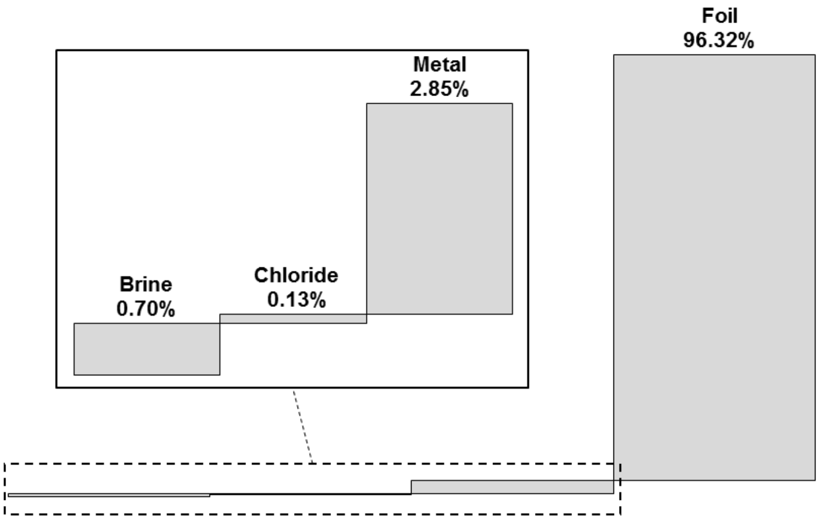


Figure 14 - Cost distribution in the supply chain for 12,000 ADU level 2 lithium foil originated from a South American brine (Supplier 1's supply chain)

As can be seen, the first tier represent the biggest share of the final price which GSB currently pays. *Figure 14* is a bit misleading though. When GSB and GBC reach the point where they want to start producing batteries in full scale manufacturing, GSB estimates that a reasonable target price for lithium foil in order to stay competitive is 1600 APU/kg Li metal. Based on that target price the cost distribution would be as shown in *figure 15*.

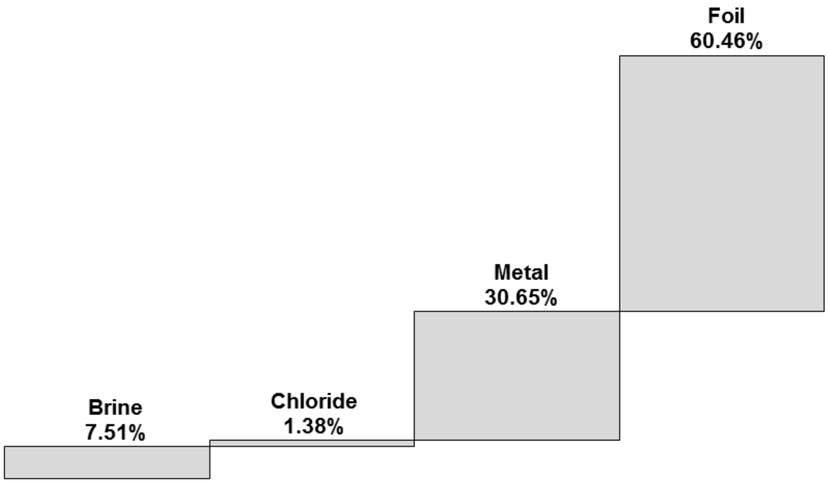


Figure 15 - Cost distribution in the supply chain based on the target cost for 12,000 ADU level 2 lithium foil originated from a South American brine (Supplier 1's supply chain)

Even though the lithium foil target price would be reached, the greatest share of value creation is still in the first tier (assuming that the target cost is reached while other costs remain fixed) hence it is interesting for GSB to know the details of this tier. As mentioned in *section 4.2*, producing foil out of lithium metal consist out of two steps; (1) extruding and (2) rolling. Extrusion costs for Li metal is 1600 APU/kg while rolling costs is 9600 APU/kg Li metal, thus the rolling process is the most costly one when making lithium foil. This is valuable information for GSB and GBC when making strategic decisions.

4.8 Patents

In the existing lithium foil supply chain, patents are present at every tier. By using the database mentioned in *section 3.3.1*, it was identified that Supplier 1 and Supplier 14 (a laboratory with know-how which a competitor to GSB/GBC is basing their product on) were owning patents related to lithium foil. Supplier 1 has six relevant patents that could be divided into three categories which they obtained through acquisitions:

1) Two patents about producing carbonate and purifying it in order to remove magnesium
2) Two patents for producing high purity lithium carbonate and chloride
3) Two patents for purification of high purity lithium chloride to be used in lithium metal production

Furthermore, Supplier 14 has four patents which all relate to rolling a very thin lithium foil, i.e. the foil which GSB is pursuing. Moreover there are other patents that relate to lithium foil but are owned by companies with less connection to the studied lithium foil supply chain, hence these are not included. Further details on those patents as well as the ones discussed earlier can be found in *appendix III*.

4.9 The Lithium Market and Market Trends

While the battery sector is growing rapidly because of the increased demand for electrical vehicles, the lithium supply market itself is slow in terms of upscaling because of political boundaries. Due to this, a rapid increase in demand can be expected to occur, meaning that a lot of companies from different industry sectors, which are depending on lithium, have noticed the steeper increase in demand than supply and are therefore concerned about securing their future supplies of lithium.

Market Structure

Many sources talk about "the big three" when it comes to the actors on the lithium supply market namely; Albemarle, SQM and FMC. These actors used to dominate the market in 2004 and earlier by holding around 85 percentages of the lithium carbonate market share (Global LLC, 2015a). Since then Chinese companies have become more visible. In result, "the big five" has emerged from the old big three together with Tianqi and Ganfeng. Combined production from these companies accounts for approximately 75 percent of the today's lithium market (see *table 5*). Since these five companies possess most of the lithium supply market share, the market can be considered an oligopoly (Forbes, 2015). Even though "the big five" are controlling the lithium supply market the market trends point towards even greater impacts from Chinese actors in the near future (Global LLC, 2015a).

Supply

So far, lithium producers have done a good job coping with the global lithium demand despite of almost steady demand increase in the past. For the upcoming years (up to 2025), the projected increase in capacity of lithium supply is still going to be enough to meet the demand (see *figure 16*) (FMC, 2012). As seen in *figure 16* the capacity is expected to double between 2011 and 2025 while the demand almost triples. According to those estimations producers are reaching full capacity utilization around 2025. This implies a need of new mining projects to take place in order to meet the demand beyond 2025. Those projects from existing actors which are already in the pipelines are not seen to bring enough capacity which implies opportunities for new mining firms to enter the lithium market. Building up a production site and negotiating mining permission takes time.

Furthermore, as mentioned in *section 4.2*, turning brine to one batch of lithium chloride (LiCl) takes 18 to 24 months, hence the production processes are considerably slow which implies difficulties in meeting high unpredicted demand increases. Another concern is that so far the "big five" have somewhat been able to scale their production according to their own interest (opportunistic behavior), mainly due to the oligopoly situation (Forbes, 2015). This affects the supply and demand balance and the prices accordingly which is one of the reasons for why large end users of lithium are looking for more control in their lithium supply chains in order to secure lithium supply. To give some insights into what potential future volumes to expect the discussions below will focus on the future demand.

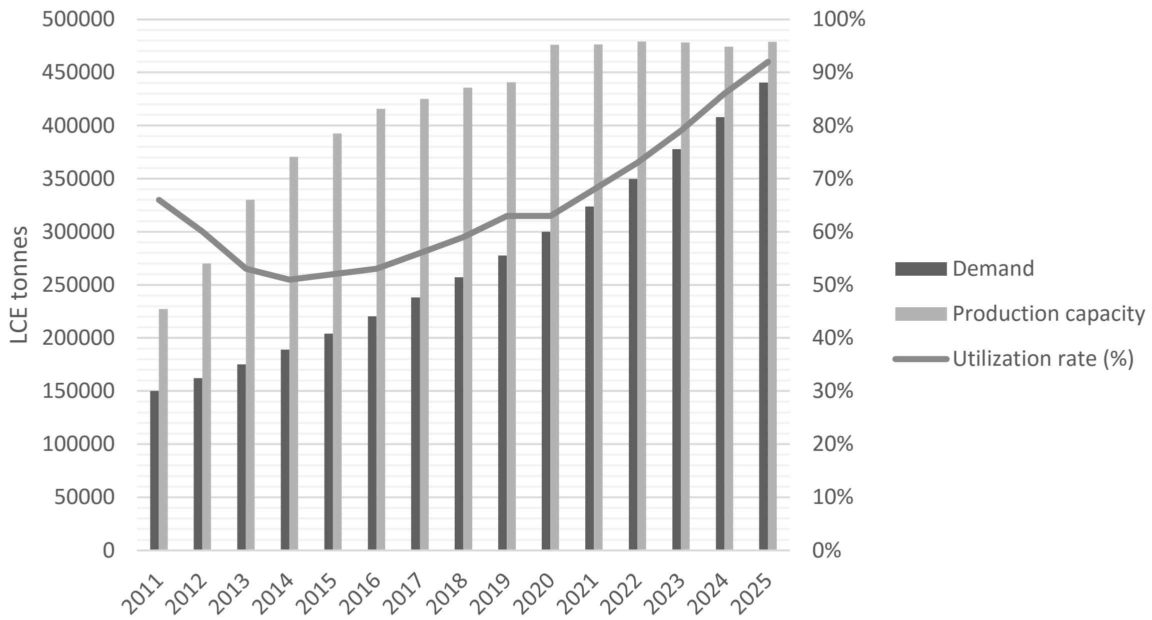


Figure 16 - Production capacity balance (Adapted from: Li3Energy, 2013)

<u>Demand</u>

From early 2000 global lithium producers have been facing steady demand growth (Fox-Davies, 2013). This increase can mostly be explained through increase in batteries demanded from the consumer market as new technology has emerged resulting in wide spread of commercial electronics such as mobile phones, laptops, tablets and other devices with rechargeable batteries (SignumBox, 2012). Alongside with increase in commercial electronics, the transportation sector has increasingly been exploring opportunities for electrification. A tipping point in that development dates back to early 1990's when the California Air Resources Board triggered the market with new regulations.

However, as the commercial electronics sector is getting balanced regarding annual lithium demand, it is believed that electric vehicles (EV) sector is catching up. Furthermore, they are believed to be the dominating sector with regards to lithium usage for the years to come or until at least 2020-2025 (FMC, 2012; Strachan Corporate, 2015; Li3Energy, 2013; Hykawy et al., 2013). Although sold EV's will not reach the same numbers as sold units of commercial electronics, the amount of LCE needed for each application is an interesting comparison (see table 10).

Table 10 - Need for lithium in different consumer products (FMC 2015; SignumBox, 2012; Strachan Corporate, 2015)

Application	**Lithium consumption (LCE)**	**Application**	**Lithium consumption (LCE)**
Smartphones	2-3 g	PHEV	~9 kg
Tablets	20-30 g	EV	15-75 kg
Laptop	30-40 g	Chevy Volt	~15 kg
Power tools	40-60 g	Nissan Leaf	~21 kg
E-bikes	~0.3 kg	Tesla Model S P85	~75 kg
E-motorcycle	~0.5 kg	Hybrid bus	~20 kg
HEV	~2 kg	E-bus	~200 kg

As seen in *table 10* different end products require different volumes of lithium. Only looking at the transport sector, the step from HEV to EV requires significant increase in lithium consumption and so does going from smaller EV's to heavier EV's with longer range or E-buses. Due to high volumes of lithium in EV's the global lithium demand will increase remarkably in the upcoming years if predictions on the EV's market becomes a reality. For instance, the Chinese government is promoting lithium-ion batteries and electric vehicles, with the biggest emphasis on buses. Sales of green energy vehicles in China almost tripled in the first ten months of 2015 compared with the same period in 2014 (The Economist, 2016). Tesla Motors, is also on the prowl. Tesla is starting a gigafactory which is expected to supply lithium-ion batteries for 500,000 cars in the near future. Other major carmakers also have a growing interest for lithium. Toyota has begun offering lithium-ion batteries instead of heavier nickel-metal hydride batteries, the ones in its Prius hybrid. Also, tougher emissions standards in Europe and America are likely to boost carmakers' need for lithium. As can be seen in *figure 17*, an exponential growth in lithium demand can be expected which is different and higher compared to the growth in supply, hence an unbalance in demand and supply can be expected around or after 2025 if no new mining projects are starting in the near future.

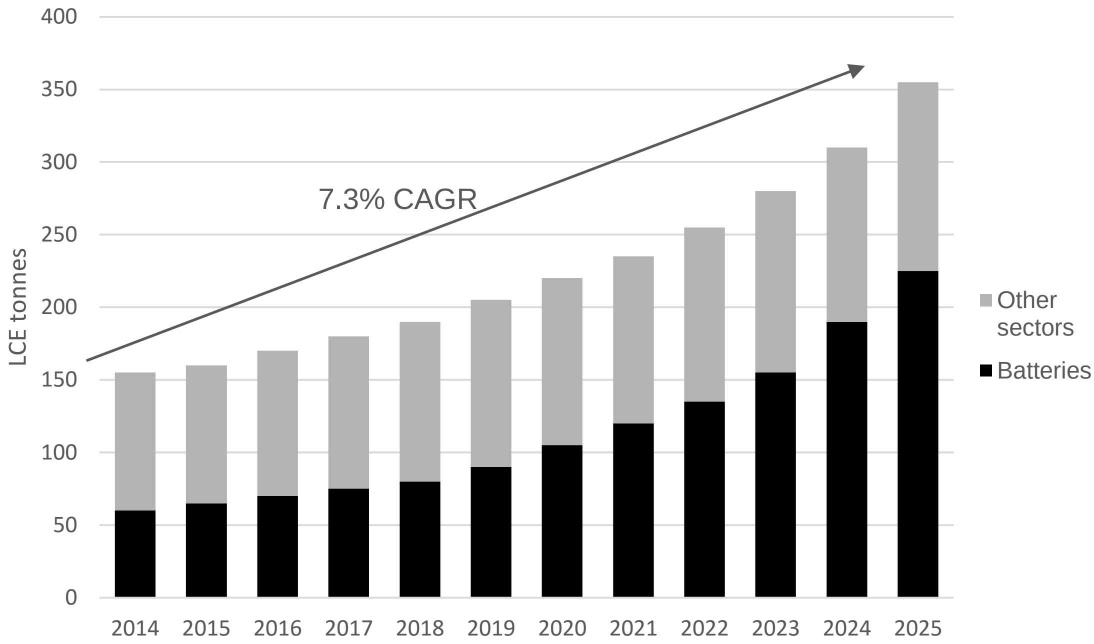


Figure 17 - Future growth in lithium demand (2014-2025) (Adapted from Li3Energy, 2014)

Different studies on future demand show different results but what they all agree on is that the lithium demand will not go down in the upcoming years. *Figure 16* shows the demand in 2025 to be 440.000 tonnes while *figure 17* expects the demand to be 350,000 tonnes in 2025. Other comparable studies posts numbers around 100,000 tonnes in 2025 (Center for Energy Economics, 2015) and between 90,000 and 290,000 tonnes in 2030 for EV's only (Els, 2014).

As the lithium demand is expected to increase quite rapidly the next coming years mainly due to increase in battery use, as seen in *figure 17*. However, according to a 2011 study conducted at Lawrence Berkeley National Laboratory and the University of California, Berkeley, the estimated reserve base of lithium is not going to limit the large-scale production for electrical vehicles although the production needs to be scaled up. The estimation is that the current reserves can supply enough lithium, both short-term (10-20 years) and long-term (40-50 years), to meet demand for the EV applications (Green Car Congress, 2011). The question is whether lithium producers will get permissions in time and reach capacity levels fast enough to prevent lithium shortage.

<u>Prices</u>
Looking at historical prices for lithium carbonate one can see that the average price has approximately tripled between 2000 and 2015 (see *figure 18*).

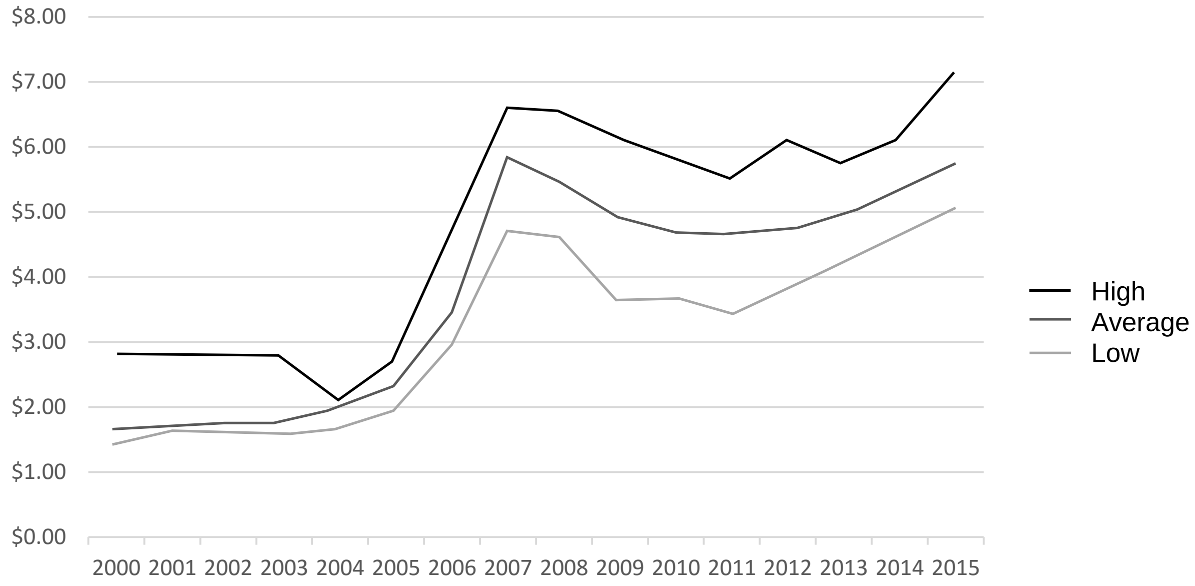


Figure 18 - Global lithium carbonate prices 2000 - 2015 (Adapted from Global LLC, 2015b)

The prices rapidly increased from 2005 until the world was struck by an economic crisis in 2008 to 2009 and the prices went down. As the global market recovered, the prices have gone up again quite steadily (Global LLC, 2015b). Whatever the underlying reason for the price increase is will not be asserted here but its impacts on the studied company is of high concerns. Even more recent data on spot prices for lithium carbonate from China shows that the prices more than doubled in the last two months of 2015 and reached numbers that had not been seen before (The Economist, 2016). However, most major buyers of carbonate have long term contracts in place and are therefore not as affected by spot prices as smaller buyers. This sudden increase is believed not to give an accurate image on how prices will develop in the long run, i.e. double within two months. Even though the prices go up it might not be enough to automatically stimulate a surge in supply (The Economist, 2016). Nevertheless, companies dependent on lithium for their products should prepare for higher lithium prices in the coming years although accurate numbers on how much to expect cannot be provided here.

5. LITHIUM FOIL SUPPLY STRATEGY

This chapter aims at answering research question two by introducing GSB/GBC requirements on the supply strategy followed by reviewing the current state of the lithium foil. Lastly a walkthrough of the suggested supply strategy is presented.

5.1 GSB/GBC Requirements on the Supply Strategy

GSB wanted the supply strategy to take risk mitigation into consideration. Risk mitigation in the sense that the strategy takes large actors with a vast access to lithium reserves and the effects of that into consideration. Furthermore, corporate purchasing at GBC stated that in a supply strategy, make or buy and supplier selection are important aspects to consider when evaluating different supply strategies. Moreover, corporate purchasing at GBC also stated that in the process of screening suppliers and selecting which ones to collaborate with, not too many of them should be involved since GSB/GBC do not want to reveal too much of their proprietary information.

5.2 Current State on Lithium Foil

This section contains information about lithium foil supply networks, in-house/supplier capabilities and the importance of lithium foil, all of which relate to answering the second research question in *section 2.2* i.e. suggesting a supply strategy for GSB/GBC.

5.2.1 GSB's Current Lithium Foil Supply Network

GSB's current lithium foil supply network consist out of two suppliers; Supplier 1 and Supplier 7. The reason for why those suppliers were initially selected mainly relates to previous results from test samples of which capabilities of producing foil with the most appropriate thickness and purity were decisive. As can be seen in *figure 19*, Supplier 1 covers all tiers of the supply chain and gets lithium from three regions; USA, Chile and Australia. GSB has had the closest collaboration in the past with Supplier 1 where 6,000 ADU foil has been supplied as the thinnest with 11,000-13,000 ADU width. It should also be noted that no one is currently ordering foils thinner than 12,000 ADU from Supplier 1, hence any foil thinner than that is made to GSB's specifications, which explains the high foil prices GSB has paid in the past. Supplier 7 is sourcing from Supplier 1 and in addition to using Supplier 1 as a supplier, Supplier 7 has been sourcing from a supplier from China. In that case Supplier 7 is sourcing lithium metal which they turn into purity level 2 lithium metal themselves. Supplier 7 can supply 12,000 ADU thick foil to a width of 11,000 ADU but claim to be capable of making 6,000 ADU or 4,000 ADU thick foil.

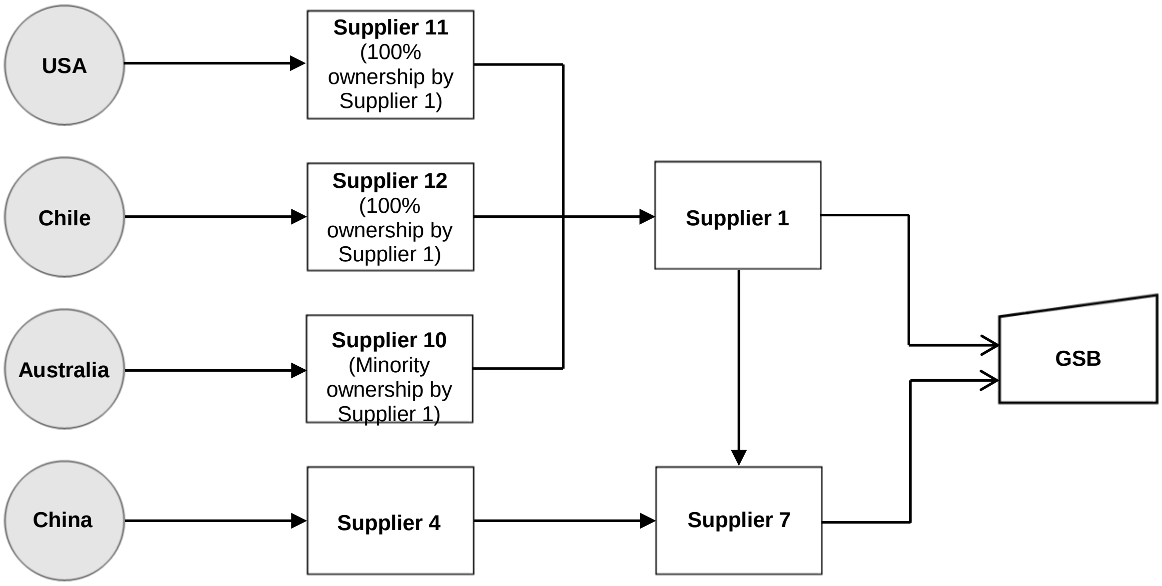


Figure 19 - GSB's current supply chain

Currently, the R&D engineers at GSB works very closely with Supplier 1 in order to develop lithium foil with a thickness of 4,000 ADU or thinner with a high purity. This has been going on for a couple of years, thus GSB has a close relationship with Supplier 1. From the GBC side, one employee of the corporate purchasing department explained that due to the close relationship with Supplier 1, they should continue working close with them to improve the technical understanding rather than ordering a lot of different foil samples from various suppliers. Moreover, two employees at GSB have established a close relationships with Supplier 7 due to their Japanese backgrounds which has resulted in lower purchase price for the lithium foil. GSB has also had some involvement with Supplier 5, another lithium foil supplier, which they abandoned due to poor purities.

5.2.2 GSB's Lithium Foil Specification

The lithium foil (see *figure 20*) is, as mentioned, the material used for the anode in GSB's lithium ion batteries. The purity and thickness of the lithium foil is part of what determines the performance of the battery. Hence those are two important parameters when purchasing lithium foil. Moreover, lithium foil is currently purchased with a width of 13,000 ADU. GSB is currently purchasing foil in thicknesses of 6,000 ADU and 12,000 ADU, where 6,000 ADU has shown some quality issues. The aim is to use 4,000 ADU or thinner, but no supplier has yet to show capabilities of supplying such foil. The reason is that making foil thinner than 6,000 ADU requires expensive development in new processes. The purity target is set to level 3 purity or higher but the same applies here, only one supplier has shown capabilities of supplying level 3 purity. According to GSB's bill of material (BOM) lithium foil is currently the biggest cost driver for the battery cell. The current prices from Supplier 1 and Supplier 7 range from 8,000 APU/kg Li foil up to 21,840 APU/kg Li foil depending on thickness and supplier. That price is way too high and valid for development only. A reasonable target price in order to stay competitive in an upscaling situation with full scale production would be 1,600 APU/kg Li foil for a thickness of 4,000 ADU or thinner.

Figure 20 - Lithium Foil (MTI Corporation, 2016)

5.2.3 The Strategic Importance of Lithium Foil

The corporate purchasing at GBC claim that the core component in the cell is the solid polymer electrolyte technology even though the foil is currently of high importance due to the technological uncertainties related to it. It is the solid polymer electrolyte that differentiates the battery cell from competing batteries which other companies make, rather than the lithium foil in the anode. Another argument for why the lithium foil is not a core component is that the lithium foil supply market has several suppliers (see *section 4.6*) that can provide foil with high efficiency and effectiveness, hence the strategic importance is not high. Also, if a new supplier was to enter the market, the entry barriers are quite low due to the characteristics of the production process (extrusion and rolling) which are not considered to be of the highest complexity to put in place. Even though the lithium foil is not core for GSB and GBC, the interactions with suppliers should be performed with caution. The reason for this is that the quality of the foil affects the performance of the battery and the technical specifications for getting the right quality is considered to be proprietary information for GSB which has to be unrevealed.

5.2.4 The Level of Competitiveness of Lithium Foil

When looking at GSB/GBC's own capabilities, good rolling equipment is available in-house at GBC, if they were to go with the option of producing foil themselves. Extrusion is on the other hand missing including knowledge about rolling thin foil which is required. This is something that corporate purchasing at GBC headquarters sees as obtainable in some years. At the same time no resources are allocated towards the extrusion/rolling topic due to capacity constraints at GBC. As mentioned before, there are also many suppliers producing foil and at the same time many actors using it, hence GSB/GBC is behind lithium foil suppliers and the level of competitiveness relative to suppliers low. Even though the foil suppliers might not be able to meet all the technical requirements yet, corporate purchasing at GBC state that there is a great chance for suppliers to meet the requirements once the upscaling phase is initiated at GSB/GBC. The reason for this is that producing lithium foil to the requirements will be of more interest for the suppliers once GSB's battery cells are in full scale production. In that case the suppliers will have a great head start compared to GSB/GBC.

5.2.5 Supply Network and Supplier Capabilities

By reviewing the lithium foil suppliers through the use of the industrial network approach, the relevant supply network for lithium foil could be identified (see *figure 21*). Relevant meaning that corporate purchasing had those suppliers on the RFQ list or that previous interactions had occurred before. The marks for LiCl and Li_2CO_3 in tier 3 represent whether that specific supplier uses the lake brine process flow (LiCl) or whether the supplier use the mineral ore process flow (Li_2CO_3). Worth pointing out is that while all the actors in tier 1 are simply foil suppliers, Supplier 3 is producing electric cars where they use battery technology with similarities to GSB's, hence they are in a position of being a competitor to GSB/GBC. As can be seen in *figure 21*, Supplier 8 is sourcing from Supplier 6. Supplier 8 claim that the purpose of that is to make foil with higher purity level. *Table 11* shows an overview of the foil suppliers mentioned in *figure 21*, stating their capabilities as a support to the supply strategy and the supplier selection.

In *figure 22*, other lithium actors found when screening the market for suppliers are shown. The actors in tier 1 are suppliers which provide foil but are not of relevance to GSB and GBC at the moment due to insufficient purity levels or thickness capabilities. Two actors in this network worth keeping an eye on in the future are Supplier 13 and Supplier 9, both because they have large market shares on the lithium market.

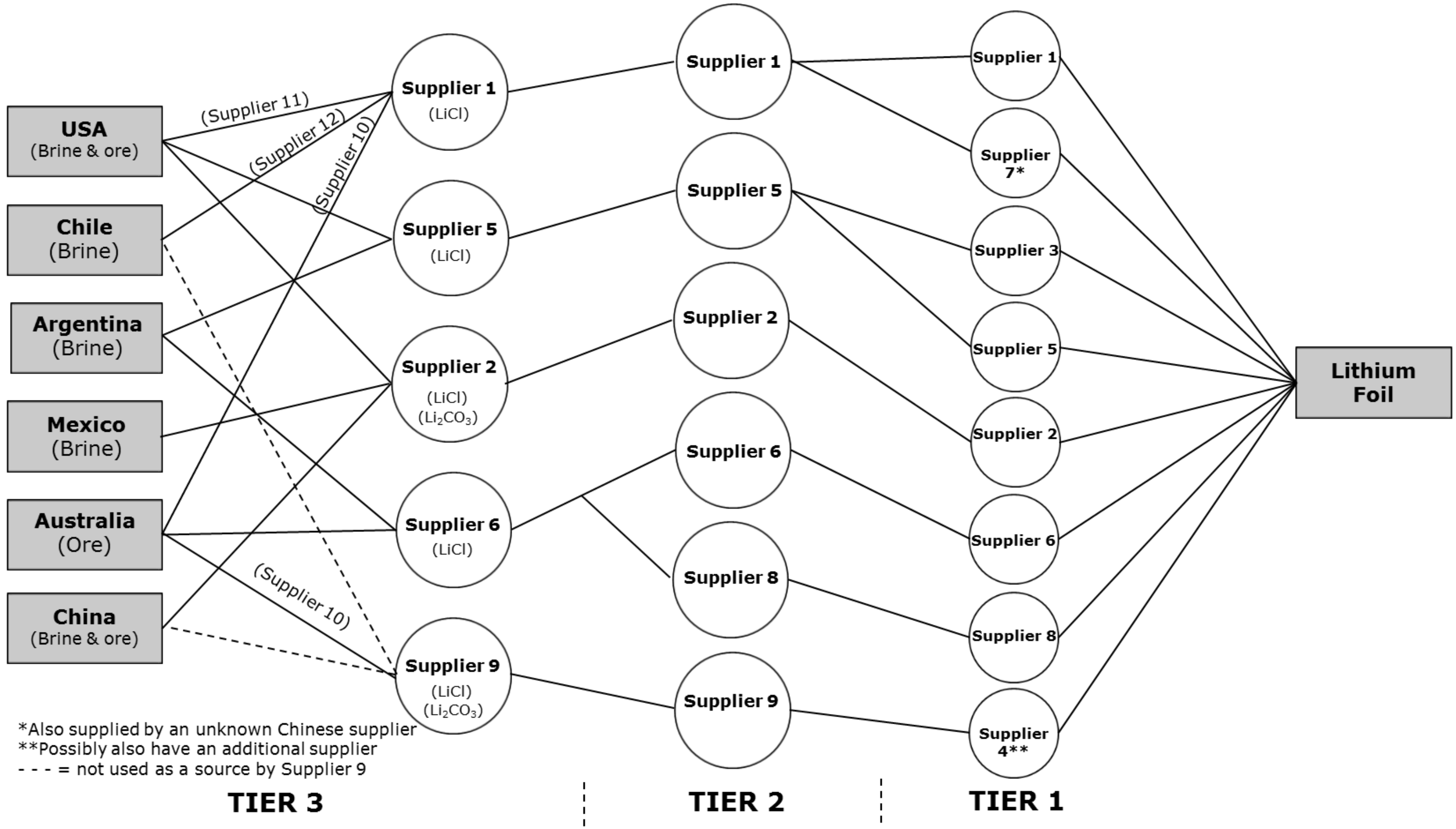


Figure 21 - Supply network for relevant suppliers

Table 11 - Supplier capabilities

Supplier	Thickness (ADU)	Tolerance (+/- ADU)	Width (ADU)	Purity	Quality System	Liquidity (*see appendix IV*)	Solvency (see *appendix IV*)	Revenue (M$)	Capacity (tonnes/year)	Comment
Supplier 1	6,000	N/A	11,000-13,000	Level 3	ISO 9001 & ISO 14001	0.52	35.38%	3651	N/A	Has good access to resources and is working on foil improvements but is resistant to cooperate and share information about production processes. Is an existing relationship and samples have been tested with good results.
Supplier 2	5,000	N/A	< 3,540	Level 5	ISO 9001, Six Sigma & Lean Sigma	N/A	N/A	3-25	N/A	Has good thickness capabilities but is providing statements that they cannot live up to what they promise on their webpage. Not an existing relationship and samples have not been tested.
Supplier 3	5,600	N/A	200-1,000	Level 4	ISO 9001 & ISO 14001	4.00	51.33%	13754	Low	Has access to patents for rolling thin foil but is a direct competitor to GBC which makes a potential relationship complex. Not an existing relationship and no samples have been tested.
Supplier 4	6,000	800	5,080	Level 3	ISO 9001 & ISO 14001	N/A	N/A	5-10	Medium	Has excellent purification capabilities and sell production equipment for producing foil but has low capacity. Newly established relationship and samples have been tested with good results.
Supplier 5	20,000	N/A	800-2,000	Level 3	ISO 9001 & ISO 14001	1.04	39.31%	3276	N/A	Has good access to resources but is far behind other suppliers when it comes to thickness capabilities. Not an existing relationship but samples have been tested with poor results.
Supplier 6	28,000	N/A	6,000-11,000	Level 3	ISO 9001	1.65	69.90%	869	High	Has good access to resources but is behind on capabilities. Not an existing relationship and no samples have been tested.
Supplier 7	4,000	1,000	24,000	Level 3	ISO 14001	N/A	N/A	N/A	Low	Has good manufacturing capabilities but the production capacity is very low. Is an existing relationship and samples have been tested with good results.
Supplier 8	10,000	600	2,000-8,000	Level 4	ISO 9001	N/A	N/A	N/A	Low	Believed to have high purity level lithium foil but has no direct access to resources. Not an existing relationship and no samples have been tested.

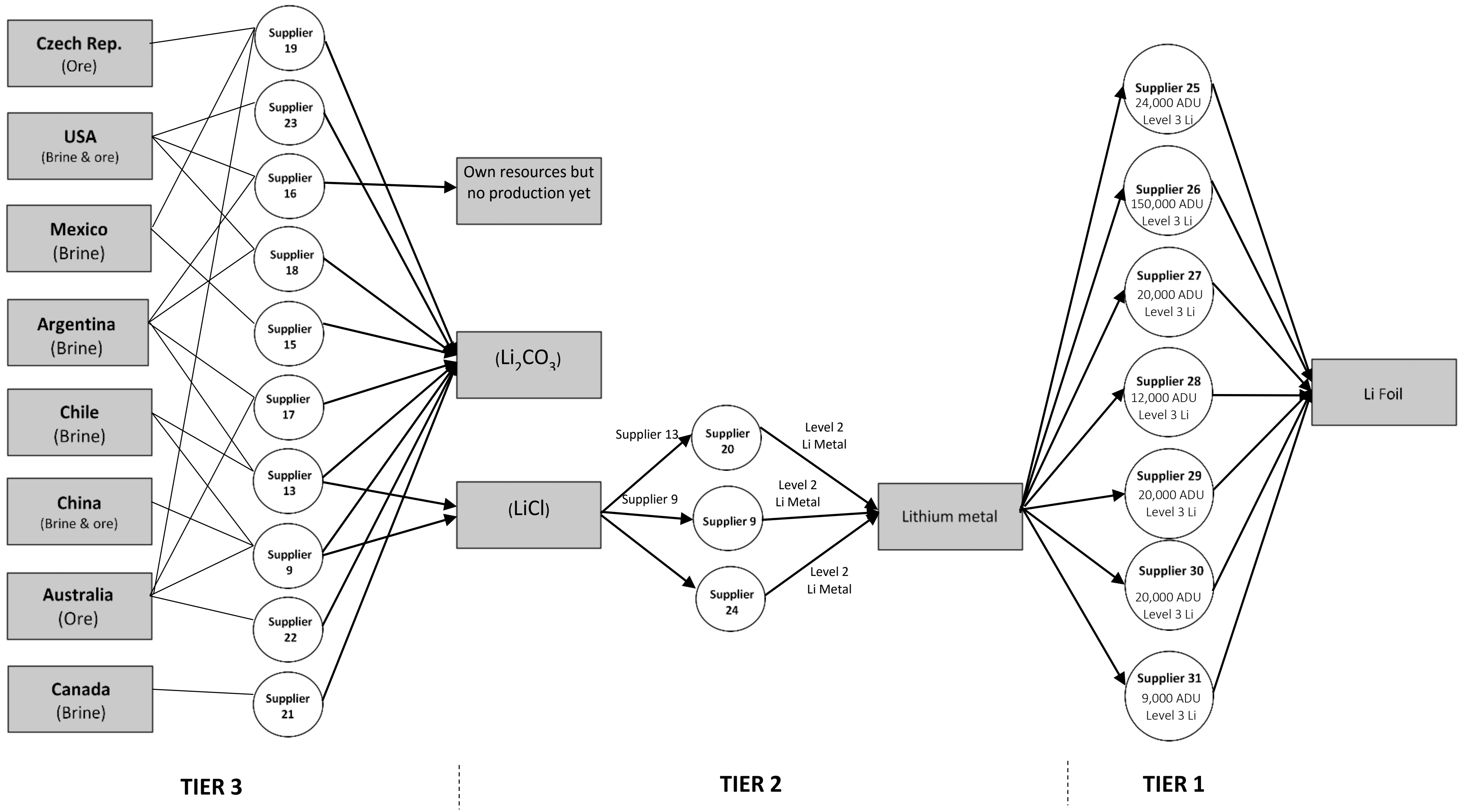


Figure 22 - Other lithium related producers

5.3 The Suggested Supply Strategy

In this section the suggested supply strategy is presented. This includes decisions on make or buy, single or multiple sourcing, supplier selection including risk assessment for proposed suppliers and supplier involvement.

5.3.1 Make or Buy

The first step in creating the supply strategy for GSB/GBC is to determine whether they should make or buy the lithium foil. The make option would imply producing the foil and sourcing lithium metal while the buy option would imply buying the lithium foil from one or several lithium foil suppliers. As stated by Gadde et al. (2001), a make or buy decision is a matter of determining whether a company is in need of control shaped as ownership or in need of flexibility to prevent lock-in-effects and making it possible to follow technology trends. In the case of GSB/GBC they are very much in need of flexibility. This is due to one aspect which was brought up during one of the weekly meetings; GSB/GBC are looking into one alternative to the foil namely lithium film. The lithium film could potentially be made thinner than 4,000 ADU but there are currently no suppliers out there who can do this. Due to the fact that lithium film might be an option to replace lithium foil in the future, GSB/GBC need flexibility to be able to switch over to lithium film. In the situation of GSB/GBC, where one sourcing component (foil) might be switched to another one (film) depending on the development of that technology, the buy option is preferable rather than starting producing foil in-house and then having to invest in new machines and knowledge in a future scenario. Another advantage with choosing the buy option is that suppliers can contribute with unique knowledge which GSB does not have, hence the technology uncertainties can be solved. By involving suppliers early in the development of the anode material (foil or film) GSB/GBC can reach higher performance of the battery cell in the end.

Furthermore, one advantage for GSB/GBC when it comes to making the foil in-house, is that there is more potential to reach the cost target since GSB/GBC are in control of the production chain. At the moment, the demand for lithium foil is not high enough for the supplier to take greater advantage of economies of scale i.e. pushing down production costs through fewer intermediaries, more efficient transports, etc. Hence costs are better controlled in-house. Moreover, proprietary information about the anode can be kept within the company. The main advantages related to make and buy options are presented in *table 12*.

Table 12 - Advantages related to make and buy options

Make	**Buy**
Proprietary information related to the anode can be kept within the company	GSB/GBC will maintain the flexibility towards changing from foil to film
Cost and price targets can be more easily reached through production efficiency, fewer intermediaries, more efficient transports, etc.	The probability of solving the technology uncertainties will increase

To determine what option to choose, the outsourcing matrix presented by van Weele (2010) was used (see *figure 23*). As mentioned in *section 5.2.3* the lithium foil is not seen as a core component but still has some proprietary information related to it, hence the strategic importance of competence is medium. Also, as stated in *section 5.2.4*, the level of competitiveness relative to suppliers is quite low due to equipment and knowledge limitations at GSB/GBC. The position of the lithium foil in the outsourcing matrix is marked with a cross in *figure 23*.

Figure 23 - The lithium foil positioned in the outsourcing matrix (Adapted from van Weele, 2010)

As the outsourcing matrix show, GSB/GBC should keep buying (outsourcing) the lithium foil but try to create some kind of collaboration with the supplier or suppliers such as partnership, alliance, joint-venture, licensing, etc. (see further discussion in *section 5.3.5*). This will help GSB/GBC to protect the proprietary information related to the anode material while still being able to solve the technology uncertainties they face. The outcome of the make or buy decision will function as a basis for further analysis of how GSB/GBC should structure their supply strategy.

5.3.2 Single or Multiple Sourcing

The second step in creating the supply strategy is to make a decision of whether GSB/GBC should use single or multiple sourcing. This is based on the make or buy decision in *section 5.3.1*, where it was concluded that GSB/GBC should buy the lithium foil rather than making it themselves. To decide whether to go with single or multiple sourcing, it is important to look at the advantages and disadvantages with the two options.

On one hand, single sourcing is generally favoured when the main goal is cost reduction as it increases economies of scale and contributes to high level of efficiency in relation to transaction and relationship costs. On the other hand, multiple sourcing is most often used in relation to mitigation of a variety of risks. As there is still a high degree of uncertainty related to lithium as a raw material as well as to whether foil or a film should be used in the anode of the battery cell, multiple sourcing from two selected suppliers is suggested. By adopting to this strategy, not only risks related to the supply of lithium as raw material is mitigated but GSB/GBC also get two sources where new knowledge can be generated.

The market analysis brought to light some important characteristics of the lithium market used for deciding upon single or multiple sourcing. First of all, lithium demand is expected to increase in the near future and exceed supply which is likely to affect prices. Secondly, lithium is a limited resource of which the majority is found in only a few countries. Thirdly, political instability and regional policies within countries that hold a big share of the resources imply the need for large lithium consumers to take actions in order to decrease volatility towards those regional specific actions. It is therefore important to secure access to resources from geographically diversified area to ensure continuity of supply. Multiple sourcing from two different suppliers that compensate each other is an action towards that direction. Furthermore, by using multiple sourcing the dependency on a single supplier is reduced in situations where unexpected events occur or where managerial decisions are made which are not in favour of the focal company.

Current lithium foil prices for R&D purposes are not completely transparent and the first tier in the supply chain accounts for the majority of the created value. A part of the reason is the lack of economies of scale, hence companies are passing the R&D cost on to the customers. Suppliers are struggling to meet GSB's thickness and purity requirements on the lithium foil which has opened up opportunities for other lithium based products to become part of the battery cell, given that the required performance is reached e.g. lithium film. In both situations GSB/GBC benefit from having multiple sourcing in order to be able to compare processing efficiency at different suppliers as well as having two sources of new ideas/innovations for the anode material. The market of the lithium production for anode material is considered as a heterogeneous oligopoly as the existing suppliers try to differentiate their products through dimensions, purity, offerings, etc. Having two independent suppliers working on improvements on their products at the same time can result in time reductions for solving the technological uncertainty that GSB is facing which might take more time if only one supplier is used.

Going for multiple sourcing makes the company miss out on some of the benefits related to single sourcing but as uncertainty is high, both related to the lithium as raw material and the lithium foil, the benefits gained from multiple sourcing were evaluated by the authors to be greater. As the purchasing unit at GBC is well functioning and believed to be capable of dealing with suppliers efficiently, multiple sourcing is not expected to create any internal problems related to purchasing. Since multiple sourcing is the best option for GSB/GBC the next step is to decide how many suppliers to work with. Because of the technology uncertainty related to the foil, two suppliers should be chosen in order to focus technical collaborations and maximize the outcome.

5.3.3 Supplier Selection

This section goes into the essence of the use of the MCDA supplier assessment matrix which was created in order to have a standardized way of evaluating potential suppliers and later on selecting what suppliers to use in the supply strategy i.e. as dual sourcing. The matrix assesses suppliers by analyzing four different categories, each of which is broken down into criteria. All criteria are answered on a scale with five potential answers where strongly agree (5) and strongly disagree (1) delimits the ends of the grading. Different approaches were used when gathering information as some information is hard to access due to sensitivity but also because internal knowledge about processes used by the suppliers tend to be lacking in some cases. Therefore, some criteria were evaluated by considering previous experience with suppliers, gathering current information which included looking into patents databases and analyzing supplier's business relationships/connections to other actors, etc. Adjustments to correct for adverse selection was also required as some information obtained from suppliers was misleading regarding technical capabilities. A close cooperation with engineers at GSB was established in order to find a way past those challenges.

Three areas were of highest concern when deciding criteria as input into the matrix (1) technological capabilities, (2) relational capabilities and (3) cost concerns. These areas are consistent with what was presented in *section 2.2.5*. As technological uncertainty is still present, relational capabilities were not underestimated as future collaboration was needed in order reach the targeted performance of the anode material. Furthermore, the MCDA matrix which was used for the supplier selection did take information asymmetry and adverse selection into consideration by letting these risks being reflected on the matrix scores. Information asymmetry related a lot to the purity level since it is affected by the process of which the foil supplier uses, hence it is information that the supplier does not want to reveal and the purity level the supplier claim to have can therefore be misleading. In order to deal with the information asymmetry issue suppliers that had proven performance generally got a better score in the MCDA matrix. Adverse selection also relates to purity level as well as to foil dimensions and capacity. Purity levels were in some cases stated on the supplier webpage, but when questioned about it some would claim the purity level to be lower. Foil dimensions and capacity would be stated by the supplier, in most cases without any proof, hence the adverse selection risk was present in that sense. In order to deal with the adverse selection issue, suppliers of which GSB had previously received foil from (with the right dimensions), were generally given a better score.

5.3.3.1 Distribution of Weights

Four categories were decided upon which were believed by the authors to cover the main aspects needed in order to support supplier selection. The categories were quality; cost & financials, technological uncertainty & collaboration and risks. Each category was further broken down into criteria which were answered by attaching relevant scoring. To make sure that all criteria got the attention they deserved, categories were firstly weighted against each other with a total sum of 100. After those weights were distributed the scores were allocated to each criterion according to the importance for the supplier selection where the weight increased with importance for the strategy, all weights and scoring were decided upon by the authors.

5.3.3.2 Categories and Criteria

This section is reserved for discussions on decided groups mentioned in *section 5.3.3.1*. Each group is firstly defined in general terms followed by discussions on each sub criteria and a scoring guidance accordingly. The rationale behind the scoring of each criteria is discussed by stating what qualities that needed to be fulfilled to get the highest score as well as what characteristics that contributed to lower scores. Current information on suppliers were applied whenever available while more subjective discussions where conducted in cases when potential future scenarios were assessed.

<u>Category 1 - Quality (weight 28/100)</u>

As GBC is a supplier for the automotive industry the quality standards that applies for that industry are pushed down to subsidiaries and suppliers, hence quality is weighted as one of the most important aspect when choosing a supplier. If quality issues are discovered after commercialization it becomes very expensive to recall cars which can be located all over the world in order to repair a defective part. Therefore a high quality material that delivers high class performance is required together with standardized processes to ensure asymmetry. All this should also be documented in a standardized way to guarantee transparency and ensure tracking abilities.

Criterion 1a - The supplier provides high purity lithium foil (weight 11/28). As the anode in the battery cell consists of lithium foil the purity of the material becomes vital. Today, level 2 lithium represents the highest purity level. The highest level still includes some impurities which are affecting the performance of the battery cell. Thus the purer the lithium is the better, which is why purity becomes important for the company in order to design a battery cell with a high performance.

For this criterion high score is given to suppliers that have been tested and proved their purity capabilities. Purity is measured from the proportion of lithium out of the total weight. The challenging part here is that not all elements are measured when those numbers are defined by suppliers. Thus quality defects caused by impurities that are not accounted for when purity level is measured are showing up in internal tests. For that reason, both stated measures as well as in-house results were accounted for. Thus suppliers with stated purity level of at least level 4 and good results on internal tests got maximum score while suppliers claiming to have level 3 got between two and four depending on internal tests. Others got minimum score.

Criterion 1b - All relevant quality standards are adopted (ISO9001 / ISO14001 / TS16949) (weight 9/28). All suppliers to the automotive industry must meet requirements on the ISO9001 quality management system and TS16949 which is an automotive sector-specific quality management standard certification. If those standards are not already in place the focal company has to initiate that transformation before their components can be used in manufactured automobiles. Furthermore, it is highly appreciated if suppliers have adopted ISO14001 environmental management system.

Minimum score was given to those suppliers with no certified standards in place. One point is added for having standards in place other than the ones mentioned within the parenthesis above. Suppliers having one or two of the mentioned standards got the score of three or four respectively while in order to get maximum points all three standards needed to be adapted.

Criterion 1c - Dimensions and tolerance are favorable (weight 8/28). As the thickness of the foil is of high concern this category evaluates abilities to meet thickness requirements. Tolerance is also an important aspect since small deviations have a great impact on the final functionality.

Scores were given in relation to capabilities in providing thin lithium foils. All foils over 20,000 ADU got minimum score, those who met the target of 4,000 ADU got maximum and others were rated based on milestones determined at 6,000, 10,000 and 20,000 ADU. Tolerance was also considered in this context with possibility of lowering score in cases when abnormal. This was to ensure asymmetry in order to prevent future quality issue scenarios.

<u>Category 2 - Cost and financials (weight 25/100)</u>
In order to be competitive GSB/GBC have to be able to provide prices that customers are willing to pay compared to what they are getting. Finding ways to lower the cost of the lithium foil is of interest as it is the largest single cost driver in the battery cell which explains why this category gets a high weight. Furthermore, suppliers' financials were evaluated in terms of their revenue and their potential to pay off their short and long term commitments.

Criterion 2a - The supplier has potential to meet cost targets (weight 20/25). Considering the currently consumed volumes of lithium foil for R&D purposes it becomes obvious that ambitious cost targets are hard to reach. Thus, this question/statement was evaluated with volumes in mind that matches future upscale plans. Supply chain efficiency was evaluated with the aim of spotting potential for cost savings when economies of scale increases.

The evaluation here was based on purchasing volumes according to the upscale scenario. Economies of scale up to a certain level was therefore assumed to be reached at all suppliers and the main criteria is therefore supply chain efficiency. Current production processes were excluded from this evaluation as that information is hard to access as it relates to core competencies. High supply chain efficiency can be reached if the following criteria are reached: (a) the lithium comes from brines as that production process is less expensive than extracting lithium from ores. (b) The lithium is sourced from low cost countries. (c) There is a limited number of intermediaries in the supply chain. Suppliers that fulfilled all those areas in a good manner received the highest score. Others would receive score depending on their level of fulfillment.

Criterion 2b - The supplier is financially stable (weight 5/25). With this question/statement the suppliers were evaluated on their capabilities of paying off expenses in terms of liquidity and solvency. The revenue was also taken into consideration.

The numbers calculated for liquidity and solvency were compared to what is typical for a financially stable manufacturing company i.e. liquidity ≥ 1 and solvency ≥ 35%. Financial reports and statements were used as a source in evaluation of that criteria. This could only be applied for public companies as information on private companies were lacking. In those cases revenue was generally the only financial statement available and therefore used to give hints. Hence scoring on those companies included higher uncertainty than public companies.

Category 3 - Technological uncertainty (weight 24/100)
Technological uncertainty is another category to pay attention to as it provides information on where the supplier's interest areas are as well as what level of development and collaboration willingness they have. Assessment is made on parameters such as suppliers' capabilities to keep up with newest trends, level of innovation within the company and willingness to collaborate in order to solve technological uncertainties. As available solutions on the market does not fully meet GSB's requirements on the lithium foil, this category is of high concern. Different suppliers generally have different agendas which implies that there is not always a fit for collaboration or willingness to solve the right problems related to the focal company's context.

Criterion 3a - The supplier has a potential to keep up with the newest trends (weight 12/24). This relates to the degree of innovation. Is the supplier constantly improving and coming up with innovative solutions or is the supplier likely to stagnate? This is important to evaluate in order for GSB to constantly have the best known solution in their battery cell and therefore remain competitive.

Following trends and showing innovative performance is seen as an advantage as the focal company wants to have access to the best technology every time to stay in the forefront. Lithium films on a substrate has a good potential as anode material because manufacturing processes and costs are in favor of thin films. Due to uncertainty in regards to the foil, suppliers' ability to provide both solutions are favored. Hence this criterion related to suppliers abilities in film production. Those who are not offering it nor showing other innovative solutions for anode material got minimum score while those in the forefront considering this aspect got the highest score. Others got scored according to their current performance in that field.

Criterion 3b - The supplier has potential to solve technological uncertainty and do joint developments (weight 12/24). As collaboration to a certain degree is believed to be needed it is an important factor to evaluate in the MCDA matrix. The evaluation was based on prior experience with suppliers and by looking into their history of collaboration. To maximize the benefits of a collaboration both actors need to be committed to the relationship and willing to share valuable information.

Based on discussions with relevant people at GSB, suppliers have been ranked on their willingness to do joint developments and potential for solving technological uncertainty, including solving impurity problems caused by element X. Suppliers which have historically been showing interest in solving problems brought up by GSB got high score while those which had been resistant to collaboration got a lower score. Suppliers with no earlier interaction were evaluated upon relevant characteristics and stated goals/vision, thus those scores remain more uncertain.

Category 4 - Risks (weight 23/100)
The aim of this category is to cover risks that can potentially have negative impacts on GSB/GBC. A robust supplier strategy has to consider such factors and cover plans on how to mitigate risks.

Criterion 4a - The supplier has secured access to resources (weight 13/23). This question/statement deals with the likelihood of being in a situation where the supplier is unable to fulfil orders due to restricted access to resources. Here, supplier capabilities are evaluated with regards to their connections to lithium as a raw material, available reserves in those locations and the potential share allocated to that specific supplier. This risk is believed to have the highest impact on the focal company in case of occurrence and hence this criterion has the highest weight considering all criteria in this category.

This relates to control of resources and actions the supplier has taken in order to secure access to lithium. Preferred situation: Supplier is holding long term contracts for extraction in geographically spread areas where the reserves are high. Undesirable situation: Supplier is sourcing lithium from a single actor which extracts lithium on a short term contract in an area with low reserves. Scores are given considering where on this spectrum the supplier is located.

Criterion 4b - Political risk related to the supplier is minor (weight 8/23). Political risk becomes relevant to consider due to differences in governance depending on countries. Here the political characteristics are studied for the location each supplier's lithium is originated from. Political decisions can affect the focal company through prices due to taxation, volumes through production permits, availability through export laws, etc.

In *section 4.4.2* political risk is discussed and countries with high reserves ranked in terms of attractiveness of mineral exploration policies. On one hand, suppliers receiving lithium from two or more countries all of which with low political instability are assumed to be facing low political risk. On the other hand, suppliers supplying from a single location where political instability is high are at greater risk of being affected by politics thus get a lower score in the evaluation matrix.

Criterion 4c - Supplier takeover risk is minor (weight 2/23). As recent market trends show that the lithium market is rapidly changing due to acquisitions, mergers and establishments of new actors these movements became a risk factor when evaluating potential suppliers. A slightly changed business focus is often associated with acquisitions and mergers in regards to what products to provide, etc. As different industries require different lithium products a changed focus can result in less innovation on products of interest for GSB/GBC or in the worst case the company might remove important products from their assortments. This can be tricky to predict but certain characteristics and behaviors can provide clues.

To evaluate this criteria two aspects were considered; the size of the company and technological capabilities. It is therefore assumed that considerably small suppliers holding valuable technological knowledge are more likely to be affected by merger or acquisition than large companies which requires higher investments. However, in cases where the company focus and operation remains the same, even after a merger or acquisition, the score can still by high.

5.3.3.3 Alternatives - Relevant Suppliers

Although there is only a limited number of suppliers capable of providing thin lithium foil it was not considered to add any value to evaluate all of them since they were not capable of meeting basic requirements and therefore excluded. This evaluation is therefore limited to the eight suppliers which are believed to have the best potential for supplying the right product (see *section 5.2.5*), those are Supplier 1 through Supplier 8. For those suppliers, the focal company has earlier experience with three of them, one is currently being tested and the remaining ones have no transaction history with the company.

5.3.3.4 The MCDA Matrix Outcome

According to weights and scoring guidance presented in *section 5.3.3.2* the eight alternatives were given scores accordingly. Each supplier was able to score somewhere between 100 and 500 depending on fulfilments of the categories where higher scoring implied better fulfilments and vice versa. The final scores of the MCDA matrix are posted in *table 13* while more details on individual scoring on each criterion can be retrieved from *appendix V*.

Table 13 - Calculated final score for each of the evaluated supplier in the MCDA matrix

Supplier	**Final score**
Supplier 1	413
Supplier 5	403
Supplier 7	395
Supplier 4	375
Supplier 2	371
Supplier 8	334
Supplier 6	324
Supplier 3	298

The purpose of the MCDA matrix was to give an input into the supplier selection process. Although this matrix aims at covering a comprehensive area of aspects for each supplier it is not capable of suggesting the two suppliers that are most suitable in a combined solution. Hence a subjective assessment was needed in order to evaluate the feasibility of establishing a relationships with the suppliers. Thus the outcome of the MCDA matrix was used as a guidance and further analysis was conducted in order to suggest a robust strategy. The potential suppliers were investigated further, in addition to the matrix scores, in order to find the optimal combination of suppliers that could outweigh the capabilities of a single supplier. In that sense a pair of suppliers with different characteristics and abilities to compensate each other is preferred. That discussion is presented in *section 5.3.4.*

5.3.4 The Lithium Foil Supply Strategy

Based on the make or buy decision (see *section 5.3.1*) where it was suggested that GSB/GBC should buy the lithium foil, the single versus multiple sourcing discussion (see *section 5.3.2*), the MCDA supplier selection matrix (see *section 5.3.3)* and the outcomes of the market analysis (see *chapter 4*) a supply strategy was created.

When the lithium supply strategy was suggested the main objectives were to:

1. Get a strategy robust enough to function on the lithium market while still being able to solve the technological uncertainties related to GSB's battery technology. As the market analysis showed, the lithium market is a market with expected imbalance

in future supply and demand implying high risks of lithium shortages. Also, due to the oligopoly structure it is vital to be an important customer to at least one of the big actors.
2. Follow the market trends given from the market analysis where China is a merging market for lithium.
3. Get secure access to as much lithium resources/reserves as needed in the future scenario.
4. Keep the option to insource the extrusion and rolling of lithium foil production since that process is the biggest cost driver.
5. To be able to make a future transition from lithium foil to lithium film as effective as possible.

The strategy means that GSB/GBC should do a dual sourcing consisting of Supplier 1 and Supplier 4 where Supplier 4 source its lithium from Supplier 9 (see *figure 24*). This section will elaborate why this specific strategy was suggested and explain the advantages and challenges related to it.

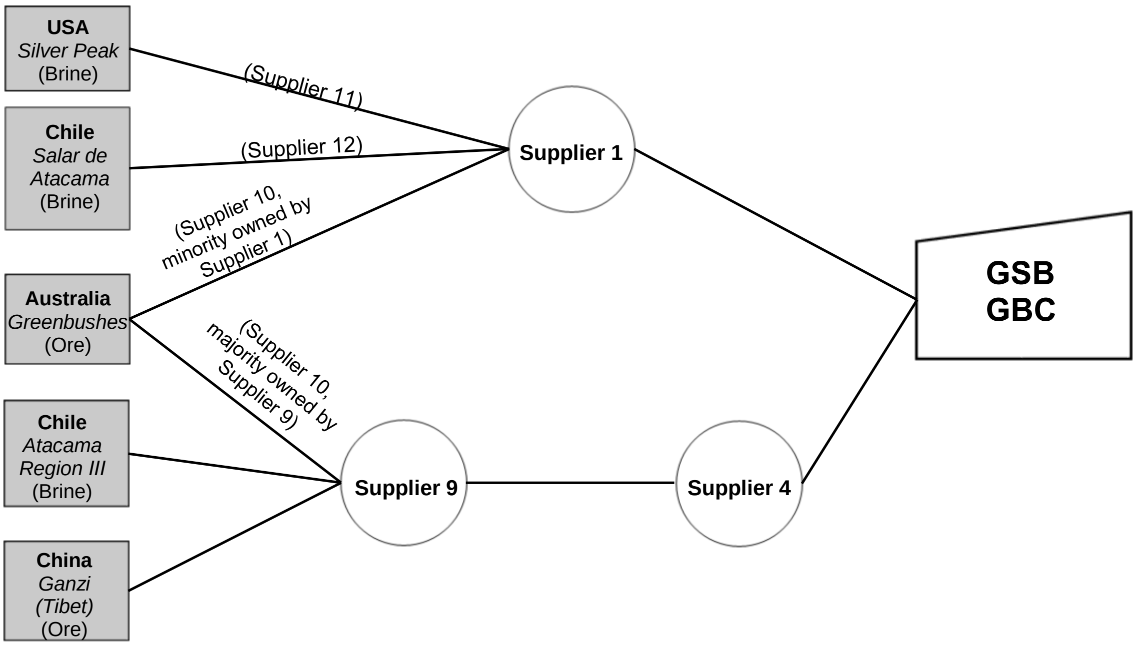


Figure 24 - The supply network behind the suggested strategy

The reasons for why the other suppliers in the MCDA matrix were not chosen are supplier specific. In the case of Supplier 7 it was mainly due to their business model which focuses on manufacturing for R&D companies hence Supplier 7 has way to low capacity. Also, since Supplier 7 is partly sourcing their lithium from Supplier 1, having it as the second supplier did not increase the access to lithium enough and would make GSB/GBC too dependent on Supplier 1. In the case of Supplier 5, it had less access to lithium resources than the other big suppliers like Supplier 1 and Supplier 6. Also, it had shown poor results in previous foil samples which did not look to promising for solving the technological uncertainties. Supplier 5 was not considered to be a good second supplier due to the scope of its business along with its many similarities to Supplier 1. Supplier 3 is a direct competitor to GBC and sourcing from it would be difficult since both companies are producing batteries for the same market. Supplier 3 also got the lowest score from the MCDA matrix meaning that it is the least promising one when sourcing lithium foil for full scale production. The reason for why both Supplier 6 and Supplier 8 were disregarded was because neither of them were producing lithium film or showing efforts to get into that business, hence they were not able to follow the newest technological trends. Also, they did not get a satisfying scores in the MCDA matrix. Lastly, Supplier 2 had some issues were it promised certain purity levels and when GSB was confronting it about whether those levels were correct, it claimed they were not, thus trusting that supplier was difficult. In addition to this, Supplier 2 offers products made from all elements in the periodic table, hence it was uncertain whether they could provide enough focus to be a good supplier.

<u>Advantages with the proposed strategy</u>
By using Supplier 1 and Supplier 4 (supplied by Supplier 9), GSB/GBC can access lithium (from both lake brine and mineral ore) from USA, Chile (two locations), Australia and China. This makes it possible for GSB/GBC to get access to the growing lithium market in China and at the same time increase the chance of solving the technological uncertainties since different lithium sources can be tried out. Also, the countries of which this supply strategy covers are all seemed to be politically stable at the moment except for Chile where there is a small risk of regulations of future production being introduced, although it is not likely. Moreover, the strategy with a combination of Supplier 1 and Supplier 4, suggests that the Supplier 1 relationship is focused on the largest portion of GSB/GBC's lithium foil demand once the battery cells are in full scale production while the Supplier 4 relationship is used for the smaller portion. The use of Supplier 4 for the smaller portion of the demand together with their willingness to cooperate makes this relationship optimal for R&D purposes where GSB can try different origins of lithium and investigate the processes in order to increase the lithium foil purity.

Other advantages related to the supply strategy relate to the mix between new and existing suppliers, which was suggested by Melander (2014). By having this mix, GSB/GBC can benefit from new technologies such as techniques for rolling thinner foil which Supplier 4 is currently investigating and other lithium processes which will help solve the technology uncertainty and increase purity. Also the former collaborations with Supplier 1 will not dictate the future meaning that the previous interactions, which have shown some reluctance from Supplier 1, will not prevent the development and innovation of the anode in GSB's battery cell. Furthermore, the supplier dependency will be low due to the use of two suppliers hence supply risks will be mitigated. Another advantage with using Supplier 1 and Supplier 4 (supplied by Supplier 9) is that GSB/GBC will have access to more than more than half of the lithium production capacity. Also, both Supplier 1 and Supplier 4 state that they are trying to develop lithium film which is promising for the future hence they are also worth working with in order to get access to that new type of technology.

When looking more into why Supplier 4 was recommended as a supplier a lot of the advantages of which Supplier 4 could provide was related to solving the technology uncertainty. First of all Supplier 4 showed a high level of willingness to cooperate on purity issues, although they already had good purity levels in the foil sample provided to GSB. Supplier 4 would be a supplier who would be easy to influence when it comes to finding the source of element X in the lithium foil. Moreover, Supplier 4 sells extrusion and rolling equipment for lithium foil, so building a relationship with Supplier 4 will still keep the in-house option open since extrusion and rolling knowledge can be obtained through them. As mentioned, the lithium metal used by Supplier 4 to produce foil for GSB/GBC is sourced from Supplier 9.

Looking more into why Supplier 1 was chosen as a supplier, the advantages related to the reliability in lithium supply. With Supplier 1, GSB/GBC can be sure of having a low risk of lithium shortage since Supplier 1 has access to a lot of resources and capacity. For example, Supplier 1 has a production contract in Chile which secures access until late 2028 at full capacity or until 2038 at current production rate. The fact that Supplier 1 is an already existing relationship does save GSB/GBC both time and cost when using Supplier 1 as the supplier for the larger portion of the demand. The time and cost gained in this existing relationship can be used in developing the relationship with Supplier 4 and solving the technological uncertainties.

<u>Challenges with the proposed strategy</u>

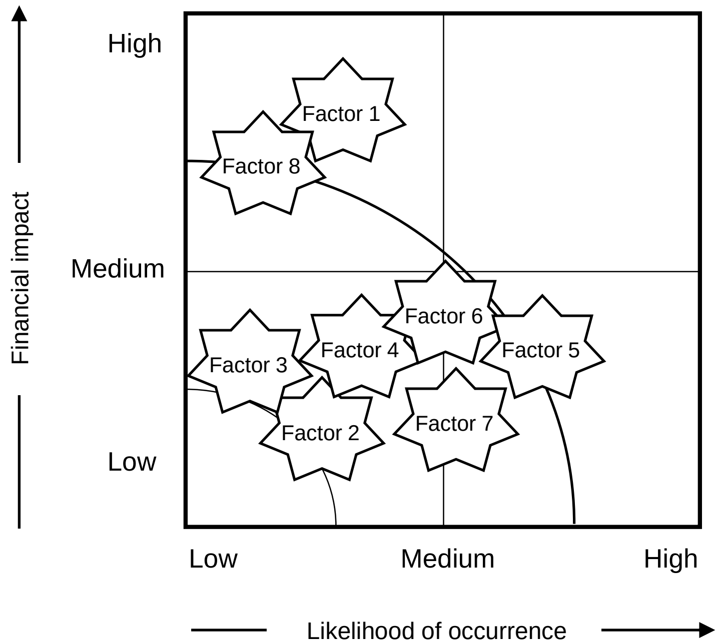
Challenges related to using Supplier 4 as one of the suppliers in the supply strategy very much relate to their capacity. At the moment their upscaling and capacity capabilities are too low to cover all of GSB/GBC's demand if they were to source all of it from Supplier 4. If Supplier 4 is going to be used to supply a greater demand of lithium foil in the future, investments in their capacity might be needed from GSB/GBC. When it comes to using Supplier 9 as the lithium metal supplier to Supplier 4, GSB/GBC face the challenge of establishing a new relationship, since it is important to have contact with the lithium metal supplier in order to control the quality of the lithium foil. Establishing a new relationship is something that will require time and costs and there will always be bumps along the road. As mentioned in the discussion about the supply strategy advantages that time and cost is saved in using Supplier 1. Moreover, there is also a risk of using Supplier 9 as a lithium metal supplier for Supplier 4, indirectly sourcing from Supplier 9, since Supplier 1 and Supplier 9 are close competitors. The race for Supplier 10 is a big part of that competition. The acquisition of Supplier 10 which Supplier 1 now owns the smaller share in while Supplier 9 own the remaining share, had many turns where Supplier 1 (at that time a different name) was about to acquire the mine when Supplier 9 got into the game and managed to obtain the largest share. Because of this it is important for GSB/GBC to understand that the relationship between them and Supplier 4 will affect the one between them and Supplier 1 and the other way around. Furthermore, when it comes to Supplier 1, it have been a bit reluctant to cooperate with GSB and have not been really interesting in solving the technology uncertainties. This is a challenge that GSB/GBC have to work hard with. Even though the relationship with Supplier 1 is not going to be the R&D relationship it is still vital that the relationship is embraced by both actors. Since Supplier 1 is a big actor on the oligopoly market the power balance between them and GSB has been "in favor" of Supplier 1 in the past, but with GBC in the picture it is going to be easier to balance the relationship and make it more cooperative in the future, if done in the right way. This will be further explained in *section 5.3.5.*

5.2.4.1 Supply Strategy Risk Assessment

To assess risks associated with the proposed supply strategy the risk matrix presented in *section 2.2.5* is applied on both suppliers separately. As they have different characteristics, different risk factors are not equally likely to occur in both relationships. The same applies for the financial impact on GSB/GBC. Risk factors remain the same for both suppliers and the same evaluation procedure was applied in both cases. As the evaluation was carried out separately the discussions in this sections will take the same form in the beginning of this section followed by a brief discussions on how the dual sourcing strategy reduced the impacts of certain factors. The eight factors which were decided upon can be obtained from *figure 25* and *figure 26*. Those were chosen by the authors due to high relevance to the sourcing strategy and the context of GSB/GBC. Furthermore, the positioning of factors within the matrixes were decided by the authors and include a subjective assessment based on all information obtained through the process of this thesis.

Supplier 1

The risk factors have been located in the risk matrix according to the characteristics of Supplier 1. Positioning can be viewed in *figure 25*.



Factors:

1. Material shortage
2. Unfavorable political decisions are taken
3. Financial problems at supplier
4. Takeover of supplier
5. Major material cost increase
6. Unwillingness to provide lithium foil
7. Unwillingness to invest in solving technological uncertainties
8. Damaged reputation through supplier

Figure 25 - The risk matrix applied on Supplier 1

Factor 1: Material shortage is not very likely as the company controls their own resources but the financial impact would be high in case of occurrence. Their mines are located in areas with high reserves and current contracts provide access in Chile until late 2028 at full capacity or until 2038 at current production rate (SignumBox, 2015). Of all contracts, this is the contract with the highest degree of uncertainty. An eye should be kept on Supplier 1's contract statuses and if things are turning against them, a new source of lithium should be explored. This is however not expected to happen in the near future.

Factor 2: Australia, Chile and U.S.A. are all favorable locations for mining companies as political stability is ranked high for each country. Furthermore, having access to all of them also reduces dependency on a single country which mitigates risks. Due to the setup of Supplier 1's supply chain this factor is not expected to have significant financial impacts in case of occurrence and a minimum effort should be put in following up on this factor.

Factor 3: Supplier 1 has shown good results on chosen financial parameters which evaluate their capabilities of paying off their expenses. Thus the likelihood of them running into financial problems is minor.

Factor 4: Supplier 1 is a big actor with established presence in different markets, all of which are contributing to substantial assets. Therefore, in order to be taken over high investments are needed. For that reason the takeover risk is not believed to be significant.

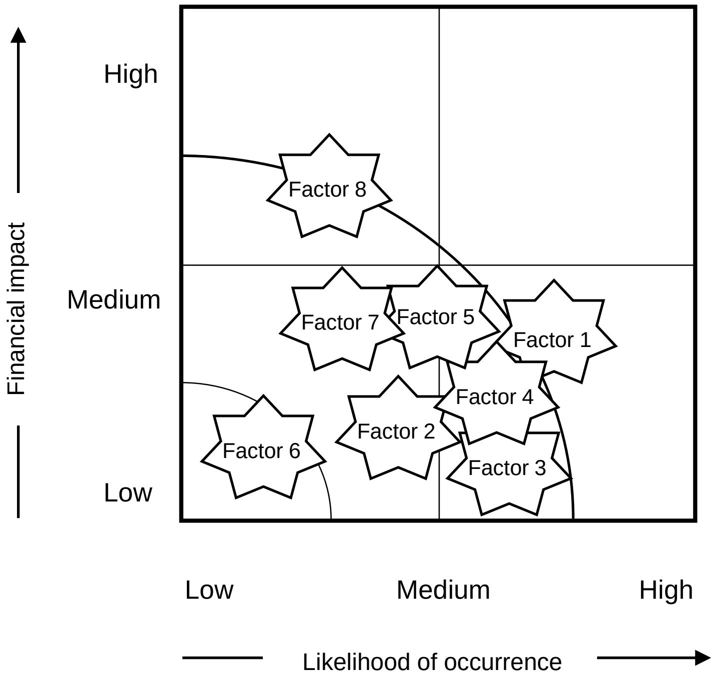
Factor 5: Many future predictions agree on increased lithium demand in the years to come which is expected to result in higher prices. To mitigate impacts due to that situation, contracts should be established were those aspects are negotiated. Furthermore, increased process efficiency in future scenarios is expected to be reached because of increased economies of scale which could reduce the risk related to lithium foil cost fluctuations.

Factor 6: Supplier 1 has a wide lithium assortment and provides different products for a variety of purposes. Therefore Supplier 1 is not too dependent on the foil business which means that the foil needs to have a satisfying margin in order to be attractive for Supplier 1. This can be mitigated through contracts where GSB/GBC commit themselves to purchase a defined volume that Supplier 1 agrees on supplying.

Factor 7: As the foil is not delivering the ideal performance there is still a high degree of technological uncertainty. Some of those problems require efforts from the supplier as the know-how on the processes mainly exists at the supplier. To mitigate that risk GSB/GBC should develop a better understanding on processes to decrease dependencies on the supplier.

Factor 8: GSB/GBC should require certain standards from suppliers which relate to the environment as well as to social criteria. Those activities need to be followed up on to prevent unexpected events to occur. Moreover, GSB/GBC should try to push these standards further upstream the supply chain, e.g. to sub-suppliers in cases where it is applicable.

<u>Supplier 4</u>
The same matrix was applied on Supplier 4 and the results can be seen in *figure 26*.



Factors:

1. Material shortage
2. Unfavorable political decisions are taken
3. Financial problems at supplier
4. Takeover of supplier
5. Major material cost increase
6. Unwillingness to provide lithium foil
7. Unwillingness to invest in solving technological uncertainties
8. Damaged reputation through supplier

Figure 26 - The risk matrix applied on Supplier 4

Factor 1: Supplier 4 does not hold any control over lithium resources and is therefore dependent on external supply. This can be mitigated through selection of a well-established supplier with a good access to resources in a geographically spread area.

Factor 2: Again, by having a supplier which is presented in a geographically spread area the dependency on a single country in terms of politics is reduced.

Factor 3: As Supplier 4 is a considerably new establishment, established in 2006, there is a greater risk of them running into financial problems. This can be mitigated through allocating certain production volumes to the supplier in order to establish a steady income for them.

Factor 4: As Supplier 4 is seen to have good technology and is a considerably small business, around 60 employees, they can be seen as an attractive opportunity for investors. This risk can hardly be mitigated. Thus GSB/GBC should be aware of that risk and have a plan in place that deals with such situation.

Factor 5: Supplier 4 might face cost increase from their supplier in case of an imbalance in supply and demand on the lithium market. That cost increase is likely to be covered by higher prices. That scenario can be hard to mitigate but GSB/GBC should be prepared to take on price increases for the lithium foil.

Factor 6: As the company is considerably new and not presented in many areas it is assumed to be unlikely that the company loses interest in the lithium foil. Thus that situation need minor attention.

Factor 7: Supplier 4 has so far been very cooperative when it comes to solving problems which is why problems related to technological uncertainty are expected to be solved through that relationship. A joint development contract should be in place with them to get commitment on cooperation.

Factor 8: Same as for Supplier 1.

Implication on risk factors for the suggested strategy
As seen in the discussions above the risks related to each supplier differs. By having two sources of lithium foil, risks related to all factors except for factor 8 are better mitigated compared to single sourcing. This is due to lower dependencies on a single supplier. Also the fact that the characteristics of the actors are very different, they are believed to compensate for each other's weaknesses and generate a good and secure source of supply.

5.3.5 Supplier Involvement

The suggested strategy has two relationships, each of which managed in a different way due to expected outcomes. One will be focused on efficiency through high volume production while the other will be more R&D oriented with a smaller supplier and therefore lower volumes. Considering the power position between the actors in the relationships, the relationship with Supplier 1 is expected to be well balanced while GSB/GBC would be the more powerful actor in the relationship with Supplier 4, despite the significant lower volumes going through that connection. This power imbalance needs to be coped with in order to get the best out of the weaker actor.

How to manage the relationship and what to expect from the partners is another point to consider, especially as technology uncertainty is still presented in the field. Before bringing up the discussion with external partners, an internal technology roadmap should be created which defines goals and milestones along the way in order to reach the targets. Aspects from those roadmaps needs to be discussed further with suppliers in order to find out if they are willing to work towards the specified goals. If there is a willingness for collaboration, a relationship type should be chosen according to the suggested strategy i.e. a R&D relationship with Supplier 4 and a mass production oriented relationship with Supplier 1.

As mentioned, the relationship with Supplier 1 will focus on efficiency and high volumes. The outputs are specified by GSB/GBC which implies some customer adaptation for Supplier 1. Therefore the relationship can have characteristics slightly closer to distant relations on the relationship heaviness spectrum (see *section 2.2.5*). Disclosure of sensitive information between actors in the relationship is minor and appropriate contracts should be in place to protect both actors from opportunistic behavior on behalf of the other party. As high volumes are going through the relationship, it requires a certain amount of interaction and problem solving both related to the purchased product as well as other supply chain related tasks. This explains why the relationship with Supplier 1 is classified somewhat between close and distant.

Differently from the relationship with Supplier 1, the relationship with Supplier 4 will have a greater focus on R&D while a certain amount of the total capacity is still allocated to that supplier in order to build trust and secure cash flow for them. The supplier is currently showing a good performance, is cooperative and is built up around purification and rolling which is a good base for cooperation. In order to increase the performance of the lithium foil in that relationship, appropriated contracts need to be in place which allow for sharing information between GSB/GBC and the supplier. However, as contracts cannot cover everything, a high level of trust between GSB/GBC and Supplier 4 needs to be in place as well. Building trust takes time and the existing relationship with the supplier should therefore be used as a starting point for further cooperation. The relationship will handle specified orders from GSB/GBC as well as allow for interactive discussions on improvements and innovative solutions. A close relationship is thus needed with an interactive interface with the target of jointly creating a high performing anode material.

6. CONCLUDING DISCUSSION

This chapter aims at concluding the thesis by summarizing the main results and discussing the next steps for GSB/GBC. Furthermore it is discussed what GSB/GBC should do if parts of the suggested strategy do not work as anticipated. Lastly, a discussion on how GSB/GBC should act if significant market changes occur.

The lithium market analysis revealed a potential future imbalance in demand and supply. This risk has created a turbulence on the lithium market and companies are increasingly coming up with plans to mitigate that risk. Part of the reason is the uneven distribution of the raw material resources and political policies within the countries that control the resources. Due to this imbalance, industries dependent on lithium should prepare for lithium price increase and be aware of how other industries are utilizing lithium and how they are affected by each other.

The market analysis was used as a base for suggesting the supply strategy and in addition to that, further data collection was needed that focused more on the lithium foil. The recommended strategy consists of buying the lithium foil from Supplier 1 and Supplier 4 which gives good access to resources in a geographically spread area while maintaining flexibility to follow the newest trends and abilities to obtain new technology as it evolves. Furthermore, the chosen suppliers have shown good performance and proven their manufacturing capabilities. By using the suggested strategy the relationships with those suppliers are expected to be exploited even further.

Both Supplier 1 and Supplier 4 are known to the company and some weaknesses in the relationships have already been spotted. This is not unusual but nevertheless something that needs attention and should be taken care of in order to develop successful long lasting relationships. Investments in the relationships have already started and can be used as a starting point for further developments. Technological improvements and collaboration in problem solving, e.g. element X defects, should be directed towards the R&D relationship while focus on other already existing suppliers should gradually be reduced.

The supply network which was identified in this thesis is believed to be useful in many aspects as proven through the process of this thesis. But bear in mind that the market has been changing rapidly the last couple of years which implies that connections need to be updated as time passes by. The MCDA evaluation matrix is also valid for other components other than the lithium foil, if slightly modified to each context.

In case the negotiation with one or both of the suggested suppliers does not work, Supplier 5 could fill the gap for Supplier 1 and a supplier with similar characteristics as Supplier 4 should be chosen for smaller volumes and R&D purposes. Furthermore, Supplier 3 was seriously considered by the authors as a supplier to team up with as their battery pack has similar characteristics and their goals towards the anode material is likely to be very much aligned to the goals at GSB/GBC. Combined effort between those companies has therefore a great potential to solve some of the existing challenges and increase the gap between other potential competitors. Although it sounds promising the complexity in establishing an efficient communication between GBC and Supplier 3 is expected to have high impacts on the feasibility of that establishment.

The authors believe that the reliability of the thesis could be improved if the authors were allowed to contact suppliers themselves. In that case data would come from primary sources instead of secondary sources. Furthermore, a closer investigation in regards to extrusion and rolling cost structures would improve the robustness of the make or buy decision.

This thesis has given an in depth analysis on the lithium foil while other potential anode materials have mostly been excluded from the discussions. Lithium film has a good potential to become the final anode material as well. This has somewhat been included in the strategy, as chosen suppliers have the ability to provide film as well. Further studies on lithium film will however be needed in terms of performance, production capabilities and cost feasibility before suggestions can be made in that direction.

If predictions on future demand and supply on the lithium market become a reality, accessing resources might become more challenging compared to how it is today. This opens up new opportunities to access lithium through methods that have not been exploited so far because of lack in feasibility e.g. recycling and seawater extraction. Bolivia could also be a game changer in that context. The country holds the largest part of the global lithium resources which means that there is not going to be any lack of interest from the lithium producers. The Bolivian government has a key role and discussions implies that the country might change their policies towards lithium mining in the years to come. If that becomes a reality, lithium prices might not be as much affected and the supply side could be boosted considerably. The highest concern at the moment is whether the market will run out of time or not when it comes to building up capacity. In addition to that, getting permission takes time and so does preparing for production.

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APPENDIX

Appendix I

Overview of fiscal regime in Argentina, Australia, Bolivia, Chile and China (Perotti and Coviello, 2015)

Categories

1. *Lithium royalty*
2. *Corporate income tax (CIT)*
3. *Level of which CIT is applied*
4. *Ownership of lithium*
5. *(1) Tax on exports (2) Land taxes*
6. *National concession status*
7. *Fixed rental obligation in (USD/year)*
8. *Expiration of exploitation*
9. *CIT deduction allowed for*

Argentina

1. 3% - Provincial mining royalty (deductible in CIT calculation)
2. 35% - Any royalty paid at the province level is deducted as an expense from income at the federal level
3. Federal
4. Nation / provinces
5. (1) Ore extracted: 5%, Processed ore: 5%, Refined metal: 5-10%
6. Lithium is concessible, however, lithium is considered to be strategic resource in several provinces, in those cases the projects have to be approved by experts

9. Depreciation of ores, buildings and machinery; applicable to tax paid for first five years. Import taxes

Australia

1. 5% - Any royalty paid at the state level is deducted as an expense from income at the federal level
2. 30% - flat rate
3. Federal
4. The states of Western Australia for the lithium sources used here
5. (2) All states/territories impose land taxes as an annual tax on the unimproved value of land held in the state/territory. The rates vary from state/territory, but are in all cases progressive. The government of Western Australia has a list of all land tax rates.

Bolivia

1. 12.5%
2. 25%
4. The Plurinational State of Bolivia
6. Lithium is not concessible. All mining concessions have become transitory, since 2010 June 12, by presidential Decree. All lithium belongs to the state which also manages it

Chile

1. 6.8% or Royalty free depending on companies
2. 20%   Federal
3. Chilean state (regulated by Nuclear Energy Commission)
4. Lithium has been non-concessible after Mining Code of 1983: Oaw 18.097. Lithium in Chile is a strategic mineral of national interest
7. 15.000 or Free of payment depending on companies
8. Until 2030 or until exploited 960 kMT LCE for one company / Initially 30 years but renewable for 5 successive years until it has fulfilled its exploitation goals which are 1065 kMT LCE for another company   Depreciation of ores, buildings and machinery allowed over the lifetime of the mine, with no limit of tax %.
9. Import taxes

China

1. 25%
2. Federal

Appendix II

Lithium Prices

	Price (APU/kg Li metal)	Source	Region
Source	63.84*	Lake Brine	Chile
	106.48*	Lake Brine	Argentina
	127.76*	Lake Brine	China
	120.08	Lake Brine	Chile
	153.28	Lake Brine	Chile
	85.2 - 127.76*	Lake Brine/Clay	Mexico
	127.76*	Mineral Ore	Australia
	180.96*	Mineral Ore	Canada
	191.6*	Mineral Ore	China
	127.76 - 212.96*	Mineral Ore	Mexico
	* Production cost		

	Price (APU/kg Li metal)	Source	Region
Chloride	142.16	Lake Brine	Chile
	198.88	Lake Brine	Argentina

	Price (APU/kg Li metal)	Source	Region	Purity
Carbonate	247.2	-	-	Level 1
	554	-	-	Level 1
	766.8	Mineral Ore	China	Level 1
	276.8	-	-	Level 2
	287.76	-	-	Level 2
	298.4	-	-	Level 3
	198.52	Lake Brine	Argentina	-
	200.96	Lake Brine	Chile	-
	206.56	Lake Brine	Chile	-
	154.16	Seawater	South America	

	Price (APU/kg Li metal)
Metal	588.4*
	632.48*
	560-640
	*Average price

	Price (APU/kg Li metal)	Dimensions (thickness · width)	Purity
Foil	8,000	20,000 ADU · 5,080 ADU	
	8,760	20,000 ADU · 12,700 ADU	-
	8,000	12,000 ADU · N/A	Level 2
	12,760	12,000 ADU · 12,700 ADU	-
	17,184	12,000 ADU · 12,700 ADU	-
	8,000	20,000 ADU · N/A	Level 2
	21,840	6,000 ADU · 12,700 ADU	-

Appendix III

Patents

Between Brines and Carbonate

Name: Process for producing high purity lithium carbonate Year: 1980	Name: Production of lithium carbonate from brines Year: 1999
Name: Method for removing magnesium from brine to yield lithium carbonate Year: 2000	Name: Process for the purification of lithium carbonate Year: 2003
Name: Production of lithium compounds directly from lithium containing brines Year: 2011	Name: Production of lithium and potassium compounds Year: 2013
Name: Method for the production of battery grade lithium carbonate from natural and industrial brines Year: 2014	Name: Production of high purity lithium compounds directly from lithium containing brines Year: 2015
Name: Preparation of lithium carbonate from lithium chloride containing brines Year: 2015	Name: Method for producing high-purity lithium carbonate Year: 2015

Between Carbonate and Metal

Name: Process for purification of lithium chloride Year: 1981	Name: Production of lithium metal grade lithium chloride from lithium-containing brine Year: 1990
Name: Production of lithium by direct electrolysis of lithium carbonate Year: 1991	Name: Process of separation of calcium and nitrogen from lithium Year: 1991
Name: Process for the purification of lithium carbonate Year: 2000	

Between Metal and Foil

Name: Rolling of lithium Year: Mar 20, 1973	Name: Additives for lubricants used in rolling lithium films strips into thin foils Year: 1996
Name: Process for rolling lithium into thin films using controlled Year: 1996	Name: Process for laminating a thin film of lithium by controlled detachment Year: 1996
Name: Process and apparatus for manufacturing lithium or lithium alloy thin sheets for electrochemical cells Year: 2007	Name: Lithium sheet die with adjustable profile Year: 2014
Name: Polymers and the use thereof as lubricating agents in the production of alkali metal films Year: 2015	

Appendix IV

Liquidity and Solvency Calculations

$$Liquidity = \frac{Current\ Assets}{Current\ Liabilities}$$

$$Solvency = \frac{Equity}{Total\ Assets}$$

Supplier	Currency	Current Assets	Current Liabilities	Equity	Total Assets	Liquidity (ratio)	Solvency (%)
Supplier 1	M$	846.4	1,616.7	3,401.3	9,615.0	0,524	35,38%
Supplier 2	-	N/A	N/A	N/A	N/A	N/A	N/A
Supplier 3	M€	17.4	4.3	12.1	23.5	4,00	51,33%
Supplier 4	-	N/A	N/A	N/A	N/A	N/A	N/A
Supplier 5	M$	2,438.6	2,343.3	2,530.9	6,437.9	1,041	39,31%
Supplier 6	M¥	1,146.8	694.4	1,816.2	2,598.1	1,65	69,90%
Supplier 7	-	N/A	N/A	N/A	N/A	N/A	N/A
Supplier 8	-	N/A	N/A	N/A	N/A	N/A	N/A

A good level of liquidity is higher than 1.
A good level of solvency is higher or equal to 35% for a manufacturing company.

Appendix V

MCDA Matrix Scores

	Weights	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6	Supplier 7	Supplier 8
Quality (28/100)									
Dimensions and tolerance	*8,0*	4,0	4,0	4,0	4,0	2,0	1,0	5,0	3,0
The supplier provides high purity foils	*11,0*	3,0	4,0	3,0	5,0	3,0	3,0	4,0	4,0
All relevant quality standards are adopted	*9,0*	4,0	3,0	4,0	4,0	4,0	4,0	4,0	3,0
Cost and financials (25/100)									
The supplier has potential to meet financial targets	*20,0*	5,0	4,0	4,0	3,0	5,0	5,0	4,0	4,0
The supplier has favorable financials	*5,0*	5,0	3,0	2,0	3,0	5,0	3,0	3,0	3,0
Technological uncertainty (24/100)									
The supplier has a potential to keep up with newest trends	*12,0*	3,0	4,0	2,0	4,0	5,0	1,0	4,0	1,0
The supplier has potential to solve technological uncertainty and do joint developments	*12,0*	3,0	4,0	3,0	5,0	3,0	3,0	5,0	4,0
Risks (23/100)									
Political risk related to the supplier is minor	*8,0*	5,0	4,0	3,0	3,0	3,0	3,0	5,0	3,0
The supplier has secured access to resources	*13,0*	5,0	3,0	1,0	3,0	5,0	4,0	2,0	4,0
Supplier takeover risk is minor	*2,0*	5,0	3,0	5,0	3,0	4,0	4,0	3,0	4,0
Total	*100,0*	*413,0*	*371,0*	*298,0*	*375,0*	*403,0*	*324,0*	*395,0*	*334,0*