

Opportunities for new metal value chains in Sweden

Growth Analysis
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Preface

In October 2016, Growth Analysis received an assignment from the Swedish Government to map the future need of materials for green-tech innovations in Sweden and Europe, to analyse necessary policies and actions for Sweden to host the associated new metal value chains and finally to analyse the barriers and opportunities for a rare earth elements (REE) cluster in Sweden.

Growth Analysis commissioned Copenhagen Economics to perform this analysis from 1st of November 2016 to 1st of March 2017.

A reference group consisting of representatives from Geological Survey of Sweden, Vinova, Teknikföretagen¹, and the University of Luleå has followed the work and provided helpful comments over the course of the project.

In this report, we present our main findings, conclusions and recommendations for future policies. Background material can be found in the associated appendix (In English).

¹ The Association of Swedish Engineering Industries

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Executive summary

For the past many years, Swedish manufacturing jobs has declined significantly. As in other western economies bearing witness to the same trend, Swedish policy makers are developing strategies and looking for opportunities to reverse it. This has resulted in the launch of Nyindustrialiseringsstrategin *Smart industry* from the government.² The current report seeks to unlock hidden potentials for high value manufacturing jobs within classic Swedish strongholds with future growth potential.

We find that Sweden has a *potential* for developing thousands of new, high paying jobs driven by the expected strong growth in demand for energy storage and renewable energy technologies. In particular, we find that production of lithium-ion batteries used in e.g. electric vehicles and special alloys and permanent magnets used in e.g. windmills requires a long value chain starting with mining of critical metals, chemical industry and deep materials knowledge, all of which Sweden already possess. We find that if Swedish companies are able to exploit current strongholds to foster 5,000 new jobs and reap productivity synergies, Swedish GDP would increase by 1/2 billion SEK a year permanently.

However, we find that building on strongholds is only a necessary, not a sufficient characteristic for reaping the potential and fulfilling part of the Smart industry strategy. The reason is that while on the one hand the batteries and alloys/magnets markets are attractive because of the high-expected growth rates, they are on the other hand extraordinarily risky because of their immaturity. Compared to more mature markets, uncertainty as to which technology will eventually prevail, who will emerge as credible buyers and suppliers, and how governments around the world will support and regulate the markets, come on top. For companies seeking to invest, this implies a premium on top of the required return, which reduces their incentive to invest. The consequence may be that, despite obvious business opportunities, investments are never made and the potential never reaped. This would have a negative impact on the Swedish economy.

However, targeted non-distortive government interventions can address the market failures that create this extraordinary risk. If done diligently, the result may be that investors and companies alike grab the opportunities to develop several or all parts of the emerging battery and alloy/magnet value chains in Sweden. This will create high paying jobs and increase prosperity in Sweden.

To increase the chances of this scenario, we suggest three types of policy actions.

First, pave the way for investments that are close to decision. In an immature and fast developing, interdependent value chain, companies are looking to see if other companies are investing. If geographical proximity is an issue, which it may be in some parts of these value

² Ministry of Enterprise and Innovation (2016)

chains, such signals are amplified. We suggest that government removes unnecessary bottlenecks to get the first investments executed. Specifically, we see nearby opportunities in mining of graphite (batteries), rare earth elements (alloys/magnets) and potentially the setup of a battery factory, which might boost the interest of possible Swedish lithium deposits. Streamlining government practices and communications across authorities to reduce uncertainty around government ambitions would furthermore reduce the risk facing companies and thus incentivise investments.

Second, facilitate access to knowledge of technological opportunities and collaboration across the value chain to promote flexible and risk sharing partnerships. Fast growing technologies and markets imply high risk across the value chain because customer's needs and future technology change rapidly. To reduce this risk companies are looking for a new type of collaboration with its suppliers borne out of flexibility and risk sharing. Government co-ordination and network facilitation that reduces companies' costs of exploring and engaging in such partnerships would incentivise investments.

Third, create technological advances that private companies can access and build on. The fast pace of technological progress means that firms need to be on top, if they are to have any chance of success. This requires access to the most recent knowledge and to the newest breakthroughs as companies will not find it worthwhile investing in such high risk endeavours themselves. Sweden already possess strong academic research environments. We suggest to re-prioritise current research and development budgets towards these technologies and recycling and reach out to EU based research environments and programs. Moreover, we stress the importance of creating test beds where public research is adapted to commercial needs and scale. Sweden already has successful test bed examples such as *PIMM* and collaborations between companies such as LKAB and Atlas Copco. This too is in line with the focus of Smart Industry.

High commercial risk due to market failures are driving the need for public intervention. For the alloys/magnets value chain heavily depended on rare earth elements, the risk is magnified by the current Chinese dominance. Moreover, we find signs of economies of scale and geographical co-location/cluster effects in the battery and alloy/magnet value chains. The implication may be a case of the ketchup effect: Investments and jobs are more likely to come in Sweden in abundance or not at all. Other countries, most noteworthy Germany, have already launched strategies with the aim of making it the future centre for companies producing and supporting the same innovative technologies.

Chapter 1

New value chains

In order to assess the future need for metals and minerals for green technology innovations we need to first define what we mean by green technology innovations. We define them as innovations aimed at reducing environmental impact of production through *increasing resource efficiency, renewable energy or recycling*.

These technologies will of course use many different metals in their production, of which some are already being exploited in Sweden like e.g. iron ore or copper. For the purpose of this report, we focus only on *new metal value chains*, i.e. metals currently not extracted in Sweden, and we only look at a subset of current and future green technologies and the materials that are key to the production of these.

It is clear that many other technologies qualify as green based on our definition. However, in this report we do not aim to cover all green technologies and innovations. As we were commissioned directly by Tillväxtanalys to look at the rare earth elements (REE) value chain and related technologies, we can look at two additional value chains to be able to conduct a thorough and useful analysis.

When deciding which green tech innovation to focus on, we look for the following three specific characteristics:

1. At least one of the key materials used in the innovation should be possible to extract in Sweden.
2. There should already be a significant activity level within the green techs in Sweden. Activities can be research and development or large private investments.
3. The green techs should exhibit high expected growth rates governed by an investment friendly business environment.

In Table 1, we have listed a number of green technologies and evaluated how well they match the three specified characteristics.

Table 1 Do these green technologies meet our criteria?

	1.	2.	3.
	(New) key materials available for extraction in Sweden	Ongoing activities in Sweden, research and business	High expected growth rates
Lithium-ion batteries	✓	✓	✓
Permanent magnets	✓	✓	✓
Special alloys	✓	✓	✓
Fuel cells	✓	✓	✓
Solar panels		✓	✓

Note: These green technologies are only a selection; many other could have been added. A black tick indicates that the criteria is met, a grey tick indicates that the criteria is partly met and no tick indicates that the criteria is not met.

Source: Copenhagen Economics, assessment based on desk research.

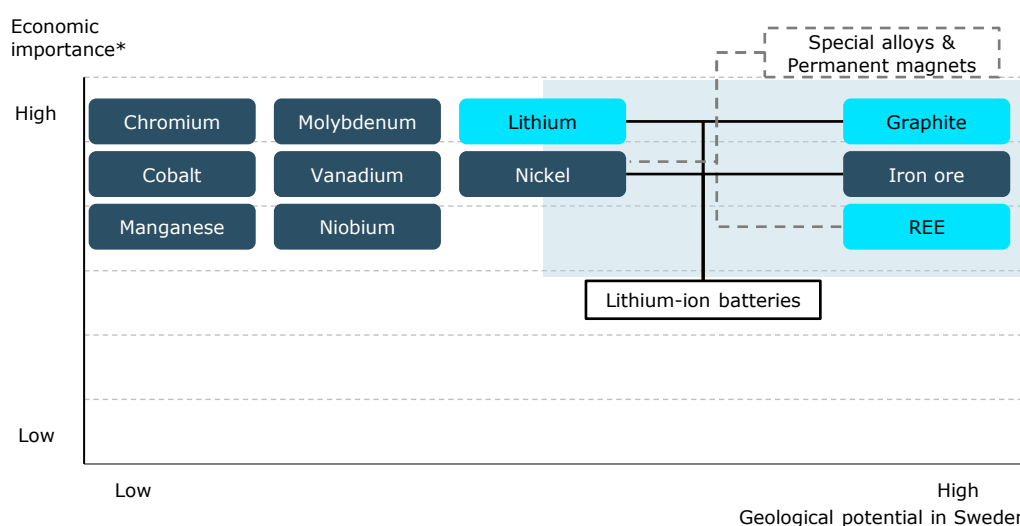
We choose lithium-ion batteries over fuel cells as they cover both lithium and graphite, and both permanent magnets and special alloys are relevant for the REE value chain analysis. We do not choose solar panels as we have not identified any commercial interest for the relevant raw materials available for extraction in Sweden such as silica. This does, however, not mean that fuel cells and solar panels are uninteresting or insignificant for an environmentally sustainable development, merely that they fall outside the scope of this analysis.

In the following, we present the assessment made for each criteria, the background for choosing lithium-ion batteries, permanent magnets and special alloys.

1.1 Key materials available for extraction

To host future value chains in Sweden it is important that the key raw material have a good geological potential. We define the potential of the raw material by its use and the quality of Swedish deposits. It must be a part of profitable green technology applications and they must be available for extraction in Sweden.

All materials in Figure 1 are key in production of lithium-ion batteries, permanent magnets, special alloys or fuel cells. On the y-axis, they are evaluated on their economic importance based on the assessment made by the European Commission in 2013. On the x-axis, they are evaluated on the geological potential in Sweden.

Figure 1 Swedish geological potential and economic importance

Note: This is a selection of materials used in production of lithium-ion batteries, permanent magnets, special alloys and fuel cells. *Economic importance is defined as the proportion of each material associated with larger industrial sectors, together with its contribution to European GDP. The sum of this is then scaled according to total European GDP to define the overall economic importance of a material. A complete figure showing the results of the commission's assessment from 2013 is available in the appendix.

Source: Geological Survey of Sweden (2016b) and European Commission (2014)

The materials subject to further analysis are lithium and graphite for the production of Lithium-ion batteries and REEs for production of permanent magnets and special alloys. They are all of economic importance according to the assessment by the sEuropean Commission in 2013.

Interestingly, these three materials and their value chains span over very different levels of maturity in Sweden. Graphite has previously been extracted in Sweden, but not in recent years. REE is available and the deposit at Norra Kärr has been developed fairly close towards production, but the final permitting is yet to fall into place (see below). Lastly, lithium exploration is only in its infancy.³ Thus, our analysis may hold relevant insights for other value chains at different levels of maturity.

Commercial interest for extraction of lithium, graphite, and REE

Even though there are well-known deposits of the three metals in Sweden, see fact box for a selection of available deposits, none of the metals are currently being extracted.⁴

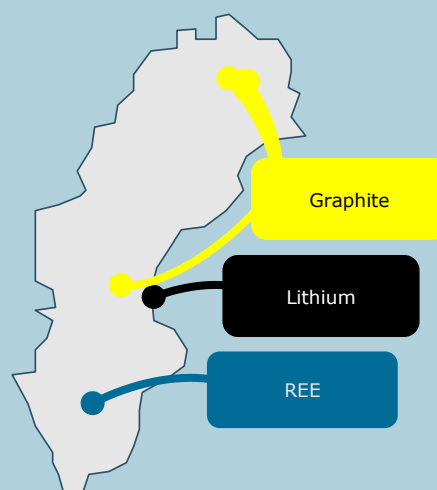
³ Geological Survey of Sweden (2016b) and Geological Survey of Sweden (2014)

⁴ Geological Survey of Sweden (2016b)

REE, lithium and graphite potential in Sweden

The Swedish geology is rich, it contains many different types of metals and minerals. The potential for extraction of graphite and REE is promising. The Woxna graphite mine has previously been active, and there are deposits of high-grade graphite in the north of Sweden.

The potential for lithium is more uncertain. However, there are a couple of known deposits, one of them is Bergby on the east coast in central Sweden, and in Finland, there are promising findings as well.



Source: Copenhagen Economics based on Leading Edge Materials (2016a) and Sirén (2016) and interviews with McManus (2016) and Ranggård (2016)

Graphite has previously been extracted in Woxna Graphite mine in central Sweden, between 1996 and 2001. Leading Edge Materials owns the mine and received a renewed extraction licence in November 2016.⁵ Another noticeable player in graphite is Talga Resources, an Australian company with deposits in the north of Sweden. From their deposit Nunasvaara they have sampled graphite of such quality that they expect to be able to obtain graphene using a very cost efficient technology. For more information on graphene, see fact box below.⁶

Graphene

Lately, the material *graphene* has received a lot of interest in both academic and applied research and innovation. Graphene is, basically, single-layer graphite. It is highly conductive, very strong and flexible, impermeable etc. and is therefore believed to have very widespread, future applications such as high frequency electronics for 5G systems, sensors, water desalination and improved batteries for electric vehicles. Commercial applications of graphene are already now emerging in for example high-end products for sports.

On-going research in Sweden and in the EU Graphene Flagship project led by Chalmers University of Technology in Gothenburg involve academia as well as actors from multiple industry sectors and across value chains.

Source: Copenhagen Economics based on Borg (2013) and interview with Carlsson (2017)

⁵ Interview with Ranggård (2016)

⁶ Interview with McManus (2016)

The main player within lithium is Leading Edge Materials, currently pursuing exploration in Bergby in central Sweden.⁷ The exploration has only recently commenced and the results are not yet available. However, the Fennoscandian Peninsula, reaching over Norway, Sweden, Finland and parts of northern parts of west Russia, may hold valuable lithium deposits. The mining company Keliber Oy have completed a preliminary feasibility study for its lithium project in Kaustby and Syväjärvi, Finland, and are moving forward.⁸

Leading Edge Materials (previously Tasman Metals AB) is also the main player within REE. Their project in Norra Kärr contains a large proportion of heavy REEs and is low on radioactive materials such as uranium.⁹ The project has, however, not yet been approved for extraction due to appeal proceedings. The Mining Inspectorate of Sweden is currently reviewing the license application.¹⁰

1.2 Ongoing activities

When establishing a new industry it is important to build on existing activities, as it will be difficult and costly to establish an industry without any existing relevant knowhow, and most likely it would not be competitive. There are relevant research and activities ongoing in Sweden within both lithium, graphite, and REE.

Research programs at Swedish universities related to lithium mainly focus on lithium-ion batteries. At both Ångström Advanced Battery Centre in Uppsala and Chalmers University of Technology in Gothenburg different types of lithium batteries constitutes the core research within batteries. Many technologies that are alternatives to lithium-ion batteries, so-called ‘next generation batteries’, are for example lithium-sulphur and lithium-air batteries. The research focus is to improve the quality and overall performance, allowing them to last longer, have a higher energy density and improved capacity.¹¹

There are many ongoing research initiatives related to graphene. The areas with highest commercial potential are energy storage and batteries for electric vehicles. This makes the graphene research closely related to the lithium research mentioned above. The initiatives involve both universities and industry. One example is the proposed competence center TIGR (Technology for Industry from Graphene) at Chalmers Graphene Centre that aim to improve the possibilities for the industry to benefit from new research, facilitating the entry of graphene into commercial industries and innovations.¹²

Also for REE, there is Swedish based research. Research on separation of rare earth metals is based at KTH Royal Institute of Technology¹³, and the research on neutrons at The European Spallation Source (ESS) in Lund may offer useful synergies.¹⁴ In a more commercial

⁷ Leading Edge Materials (2016a)

⁸ Sirén (2016)

⁹ Interview with Ekberg (2016)

¹⁰ Geological Survey of Sweden (2016a)

¹¹ ÅABC (2017)

¹² Interview with Carlsson (2017)

¹³ Interview with Ekberg (2016)

¹⁴ ESS (2017)

setting, companies such as Höganäs and Sandvik how strong capabilities in high quality coatings and alloys for the steels and metals industry.¹⁵

1.3 Future outlook for technologies

Lithium-ion batteries are heavily dependent on lithium and graphite, while permanent magnets and special alloys are heavily dependent on REEs. All product markets are forecasted to have a strong development in the near future.

Lithium-ion batteries

Lithium-ion batteries are important for several green technology innovations. They are widely used in hybrid and electric vehicles and there is a potential in energy storage of renewable energy and the development of smart grids. Generally, the batteries are widely used in products that are expected to grow in demand.¹⁶ For example in 2015, lithium-ion technologies accounted for more than 95 percent of new energy-storage deployments.¹⁷

The use of lithium-ion batteries has increased more than any other battery type and TechSci Research estimates that the lithium-ion battery market will grow by around 17 percent a year until 2021.¹⁸

REE

REE based permanent magnets can provide high levels of magnetic power even in very small applications and are currently indispensable to a lot of modern technology. For example, they are used in energy generation such as wind.¹⁹ The wind power industry has been experiencing double-digit growth rates over the last decade and has emerged as one of the most interesting markets going forward until 2020.²⁰ With permanent magnets already being a key application in many growing markets, application of permanent magnets are expected to grow as well. For example, in 2015 the market size was valued at USD 13 billion and is expected to reach USD 31 billion by 2020, an increase of 10 percent a year.²¹

Many special alloys contain nickel, chromium, cobalt, molybdenum and REEs as major alloying elements, providing a maximum service temperature of about 1,000°C. Their resistance against corrosion and high temperatures play a critical role in many applications, including aircraft jet engines, heat exchangers, nuclear power plants, and ovens.²² Increasing demand for highly durable materials is expected to drive the demand for special alloys in the coming years. In 2015, the global high performance alloys market size was estimated at USD 7.51 billion and is it expected to increase by 9 percent a year until 2019.²³

¹⁵ Höganäs (2017)

¹⁶ Albemarle (2016)

¹⁷ D'Aprile et al. (2016)

¹⁸ TechSci Research (2016)

¹⁹ Grand View Research (2016)

²⁰ GWEC (2016)

²¹ Grand View Research (2016)

²² Nickel Institute (2016) and USGS (2016b)

²³ Technavio (2015)

In the next chapter, we map the value chains of lithium, graphite and REEs as key input for lithium-ion batteries, special alloys and permanent magnets and identify opportunities for Sweden within these value chains.

Chapter 2

Opportunities

Sweden is endowed with a range of different metals and minerals deposits, has a long history of mining, and offers good access to infrastructure, cheap energy and specialized support services. Hence, it may be natural to assume that Sweden can host more value chains than it already does and thereby create new, domestic manufacturing jobs.

2.1 Access to a resource is not enough

A key insight, however, is that having access to a resource is not sufficient for the following value chain to be entirely located in Sweden. In fact, only the parts of the value chain in which Sweden has a so-called relative comparative advantage should be located in Sweden, i.e. activities in which Sweden is relatively more productive. This implies that nations will tend to have more domestic production of goods or services in which they are relatively more productive. Another implication is that if the government supports domestic production within areas in which the country does not hold a comparative advantage, the country actually loses wealth.

Applying this insight to the case of Sweden and how much of a value chain can be expected to be located here, we know to look only for those value chains where Sweden could have a comparative advantage in production. Hence, we have to look beyond the physical access to the resource, which is only a necessary but not sufficient requirement to host an entire value chain.

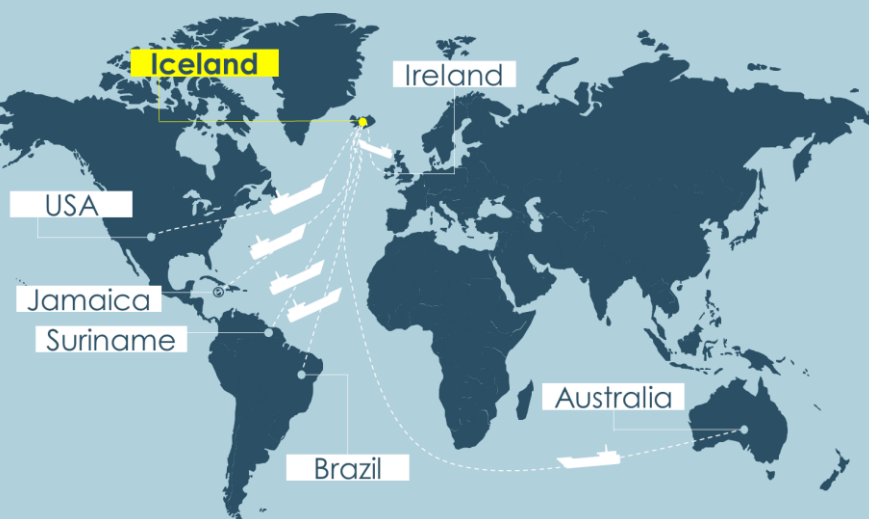
This point is not just theoretically sound, it can be directly observed in the real world as well. Below we provide the example of alumina smelting in Iceland, which has developed the industry despite not having access to the mineral resource (bauxite) domestically. Rather, Iceland is abundant in cheap electricity from hydropower; a key cost driver in smelting and a comparative advantage for Iceland.²⁴

²⁴ In the following, we use the notion of strongholds and comparative advantages interchangeably.

Energy – an Icelandic stronghold

Hosting entire value chains is not necessarily the best way of generating economic wealth. Rather, specialization in activities or parts of value chains in which a nation has a so-called relative comparative advantage will add more economic value. The implication of specialization is that nations will only have domestic production of goods or services in which they are relatively more productive.

There is no bauxite mining in Iceland, but cheap energy constitutes a comparative advantage in smelting, which is why many alumina companies ship material to Iceland from all over the world.



Source: Copenhagen Economics based on Rio Tinto Alcan (2017) and Alcoa (2017)

Which future value chains and which parts of them we can expect to be hosted in Sweden is therefore dependent on Swedish strongholds along these value chains.

As an industrialised country, Sweden's main comparative advantage is likely to be in knowledge-intensive activities.²⁵ Yet, there are other strongholds, determined by access to resources such as water for the production of cheap hydropower, or knowledge and skills that has developed over time, that are applicable to the REE, lithium or graphite value chains. We find that Sweden has strongholds within finance and insurance, electricity, gas and water supply, chemicals production, and motor vehicles, cf. Table 2.²⁶ These are all relevant to the mining industry, at different points along a mining value chain.

²⁵ OECD (2015)

²⁶ Background data is available in appendix.

Table 2 Swedish strongholds

Sector	Strongholds	Relevance for metal value chains
Finance	<ul style="list-style-type: none"> - Easy access to risk capital in Sweden 	<ul style="list-style-type: none"> - Mining and metal value chains require vast amount of capital - Investing in 'technologies of the future' is associated with high risk
Electricity supply	<ul style="list-style-type: none"> - Abundance of hydro and nuclear power, - Well-developed grid - Cheap and stable access to grid 	<ul style="list-style-type: none"> - Metal value chains intensive in electricity - 'Green electricity' can provide a competitive edge compared to 'dirty mining'
Chemicals	<ul style="list-style-type: none"> - Sweden has a strong legacy within the pharmaceuticals industry and a 'chemistry cluster' in Stenungsund - Important chemical (and other) research at ESS in Lund 	<ul style="list-style-type: none"> - Processing of some materials are complex and may even differ from ore to ore, which calls for highly specialized and skilled geochemists and chemists in general
Motor vehicles	<ul style="list-style-type: none"> - Long and strong tradition in Swedish motor vehicle industry - Research in and design of electric vehicles (Volvo, Scania) 	<ul style="list-style-type: none"> - Potential synergies between local production of 'battery materials' and large local consumer of batteries and REE-applications in cars - Very strict CO2 reduction requirements for truck transportation sector may create stronger incentive to innovate

Note: Background data available in appendix.

Source: Copenhagen Economics based on OECD, Eurostat and Statistics Sweden, cf. appendix

Sweden has a relatively large market for risk and seed capital, the kind of financing that is important to e.g. junior prospecting and mining companies. Hence, raising capital in a high-risk sector like mining may be easier in Sweden than in many other jurisdictions in mainland Europe.²⁷ Easy and cheap access to grid power is another stronghold, as power is a large cost component in most mining and ore processing.²⁸ Sweden's traditional stronghold in chemical research and production could be relevant for refining of both REE, graphite and lithium just as Sweden's motor vehicles is an important destination for many final applications of both rare earths and lithium-ion batteries.

Together with the access to the physical deposits of graphite, REE, and potentially lithium, these strongholds may represent opportunities for Sweden to host specific activities along the value chains, but barriers such as competitive disadvantages or risks may exist as well.

The value chains for REE, graphite and lithium are global in the sense that material produced in one corner of the world is traded and shipped around the globe to find use in various final applications in another. However, in some parts of the value chains, vertical integration or long-term partnerships and contracts may be important to secure a certain quality or security of supply or production for some other reason is placed in proximity to the mine. For example, there may be obvious synergies for a 'battery value chain' to be reaped from domestic production of *both* graphite *and* lithium production and the following production of batteries. Below we assess the economic activities in these value chains and the implications it may have for location in Sweden.

²⁷ The Danish Ministry of Business & Growth (2016). Background data is available in appendix.

²⁸ Copenhagen Economics (2016)

2.2 Rare Earth Elements – a Swedish opportunity?

We find that parts of the REE value chain could possibly be viable in Sweden. The extraction phase (mining of ore), and the concentration phase (the first steps of ore processing), are supported by good geological potential, easy access to cheap and abundant grid power, and relevant high-level research at Swedish universities. However, disputes over mining rights may hinder the development. The separation phase, i.e. the later steps of the ore processing, requires very advanced and expensive expertise currently not available in Sweden. Therefore, Sweden would most likely not be competitive against existing producers, mainly Chinese, in this part of the REE value chain. Regarding the final application of REEs there are Swedish companies specialized in alloys etc. and relevant research at several universities.

China is the single most important producer of REEs with 85 percent of global production in 2015. China is also the only rare earths producer represented throughout the entire value chain from mine to production of final goods. China is followed by Australia (8 percent of global production) and a number of countries producing only small amounts.²⁹ See fact box below for a description of rare earth elements and the market.

Rare Earth Elements

Rare earth elements is a group of 15 chemical elements that are, in spite of their name, not very rare. In fact, they are quite frequent in the earth's crust, but often difficult to extract due to low concentrations in the hostrock. Often their extraction involves large amounts of acid and handling of radioactive by-products like uranium or thorium, contributing to the industry's reputation as 'dirty'. Yet, rare earth elements, especially neodymium and dysprosium, are to a large extent indispensable in modern green-tech applications such as hybrid cars and wind turbines. In addition, consumer goods like smartphones are intensive in REEs.

For many years, China has been dominant in REEs and in 2011 Chinese export restrictions caused global REE prices to increase by four to nine times in less than a year. With reference to the restrictions, the US filed a complaint to the World Trade Organization (WTO) in 2012 that was supported by multiple REE importers such as the European Union, Japan and Canada. The Dispute Settlement Panel ruled against China stating that the restrictions gave Chinese firms privileged access to the REEs, which was against the principle of "non-discrimination" that WTO members are obligated to follow.

REEs are not traded in commodity markets like iron ore or copper, but typically as OTC (over-the-counter) products and via long-term contract between suppliers and buyers. Production of REEs is very specialized, often vertically integrated and with quite high barriers of entry.

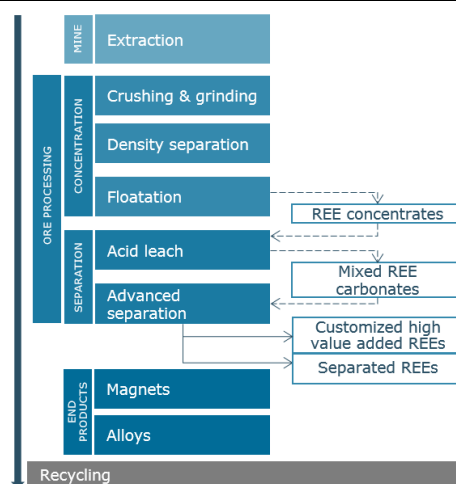
Source: Copenhagen Economics based on WTO (2015) and Barakos et al. (2016)

²⁹ USGS (2016a)

The geological conditions for REE extraction in Sweden are very good, with the deposit in Norra Kärr being of high quality and with a relatively high concentration of the most valuable materials, the so-called *heavy* rare earths, while at the same time having a low radioactive content.³⁰ Hence, given that commercial interest already exist in extracting this deposit, we find it likely that extraction of REEs could take place in Sweden, but disputes over mining rights between regulator, The Mining Inspectorate of Sweden, and the mining company Leading Edge Materials (formerly Tasman Metals AB), must of course be resolved for this to happen.³¹

Figure 2 below maps the value chain for REE production. The early stages of processing (crushing and grinding and concentration) are often performed next to or in proximity to the mine due to transportation costs and disposal of tailings. This is a result of the low concentration of REEs in the mined ore; the largest part is waste rock with no or little value. To keep unit costs down, it is often more economic to perform concentration next to the mine and we see several reasons why this part of the value chain could be viable in Sweden. First, is the easy access to cheap and abundant grid power, and power is the key cost driver in this stage of production. Next is the availability of skilled labor and specialized support industry for the mining sector, and finally highly specialized nuclear research and handling of radioactive waste at Chalmers University of Technology in Gothenburg, which may present a rare earth miner in Sweden with unique partnership opportunities.³²

Figure 2 The Rare Earth Elements value chain



Source: Copenhagen Economics based on ERECON (2015), desk research and interviews with O'Brock (2016) and Ekberg (2016)

The next step in the ore production process, the separation of the individual rare earths, is the primary cost component in production of rare earths.³³ In this phase, the concentrate is

³⁰ Interview with Ekberg (2016)

³¹ Cf. Copenhagen Economics (2016), p. 40

³² Cf. Chapter 1

³³ Cf. Interviews with Saxon (2016) and O'Brock (2016)

treated with acid to extract the rare earths from the hostrock to produce mixed REE carbonates, which is the first salable product in the REE market.³⁴ In order to separate the individual rare earths or produce customized mixtures or qualities of rare earths, ore-specific chemistry and highly specialized knowhow is required. Currently, only a handful of facilities outside of China is active in this segment. Hence, to establish a specialized REE separation industry in Sweden would come at a high cost and would probably not be competitive against Chinese producers and established, yet small scale, facilities in France and Estonia. Several characteristics of the REE market support this: Rare earths are not standard commodities traded on exchanges like iron ore, silver or gold, but rather ‘over-the-counter’ between a few buyers and sellers. China is by far the biggest producer and has proved able and willing to influence prices of REEs with its massive export cuts in 2011.³⁵ To overcome this supply risk, buyers and sellers of rare earths tend to enter into long-term contracts and it may therefore be difficult for a new entrant to gain market shares, let alone make money. As a concrete example, even the vertically integrated, American producer, Molycorp, filed for bankruptcy in 2015, as it proved unable to make a profit at post-2011 price levels.

Final applications of rare earths are of course hybrid motors and wind turbines but also telecommunication, lasers, solar-energy conversion, magnetic and special alloys and catalysts. The main production of these products takes place in China and European producers often import final parts rather the rare earths themselves.³⁶ Sweden, however, has existing skills in production of alloys, powders and coatings for e.g. the steel industry, which could potentially be applied in future production of final goods using REEs as well.

Finally, developing technologies for recycling of rare earths might pose an opportunity for Sweden given on the one hand Sweden’s strong position in collection and recycling of metal scrap and the very low (1 percent) recycling rate for REEs from end-of-life products on the other.³⁷

In sum, and based on Sweden’s existing strongholds, we find it likely that Sweden could host parts of a rare earths value chain; extraction, concentration and potentially some final applications, but most likely *not* separation of REEs. In other words, Sweden could play an integral part of a wider, European REE value chain, with separation happening with a partner in either France or Estonia, presenting European producers with an alternative to Chinese REEs. Yet, we also realize that initiating mining activities and forming partnerships across the value chain is associated with high risks due to China’s strong role and high entry barriers. These risks may deter private investments meaning that an REE value chain across Europe will not necessarily evolve on its own. Potentials for a Swedish value chain do exist, but risks may need be reduced before it will materialize. We discuss this in more detail in the next chapter.

³⁴ In this product, the rare earths are liberated from the rocks in which they were found, but are still chemically bound and hence cannot be used directly in production before further refinement.

³⁵ ERECON (2015), p. 6.

³⁶ Kommerskollegiet (2011)

³⁷ ERECON (2015), p. 48.

2.3 Battery production – a Swedish opportunity?

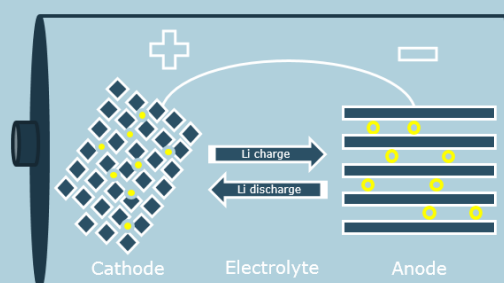
We find that a battery value chain, building on graphite and lithium, could possibly be viable in Sweden. The geological potential for graphite is good and may prove to be so for lithium as well. The long Swedish mining tradition and previous experience from graphite mining support this. Further down in the battery value chain, the easy access to cheap and abundant grid power constitutes a very important stronghold offering the opportunity of a competitive industry.

Recently, Sweden has drawn attention as a location for battery production the company SGF Energy showing interest due to Sweden's competitive energy costs, high skilled work force and available research and knowledge in battery technology and chemistry at Luleå and Uppsala Universities or Chalmers in Gothenburg. Also, companies realize that there may be possible synergies to reap from *integrated* research in both anode (e.g. graphite) and cathode (lithium) materials, and from being close to development and design of new motor vehicles at e.g. Volvo or Scania, key purchasers of rechargeable batteries.³⁸

More than just lithium in a lithium-ion battery

Lithium-ion batteries are currently the fastest growing type of rechargeable batteries. In 2015, China, Japan and South Korea together hosted 88 percent of all global manufacturing of lithium-ion batteries and a large share of battery materials such as cathodes and anodes. Europe and the US is, in comparison to Asia, home to an immature lithium-ion battery industry. However, the new Tesla 'gigafactory' is expected to significantly alter the manufacturing landscape when they enter their market with an expected manufacturing capacity of 35 GWh.

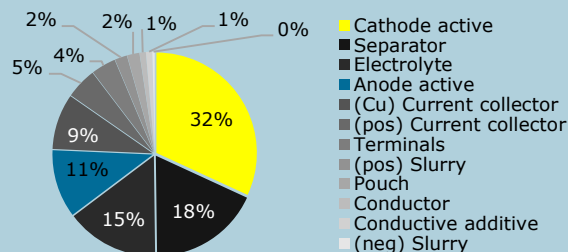
Lithium-ion batteries uses a cathode (positive electrode), an anode (negative electrode) and electrolyte to connect the cathode and the anode, see illustration below. The cathode is metal oxide (lithium) and the anode consists of porous carbon (graphite). During discharge, electricity is generated when the ions flow from the anode to the cathode, i.e. from the negative side to the positive side, and charge reverses the direction.



Production cost split has been estimated by Chung et. al (2016) to 32 percent to cathode and 11 percent to anode production, see figure below. Hence, having easy access to

³⁸ Interview with Saxon (2016)

both lithium (cathode) and graphite (anode) material in proximity to a battery factory may be a comparative advantage for Sweden.



Source: Copenhagen Economics based on Chung et al. (2016) and interview with Björefors (2016)

It should be noted, though, that Sweden is not the only possible location for a battery factory: Also Finland, Hungary and Poland have been mentioned as potential candidates, cf. Box 1 below. At the same time, Germany has already come a long way since the adoption of a national strategy, including domestic production of batteries for electric vehicles. As scale in production may be an important factor, how many battery factories can actually co-exist in Europe, it is a question whether Sweden as an investment opportunity has the necessary traction and speed in permitting processes to be able to join this 'race' in time.

Box 1 How many battery factories can co-exist in Europe?

Economies of scale are important in production of batteries due to high investment costs. However, several countries in Europe are looking to battery factories as a source of 'compensatory' manufacturing jobs and as an important step in a transition towards a lower CO2 footprint. Also, there might be a first-mover-advantage stemming from the importance of scale, where the first country or countries establishing a battery factory acquires a large share of both demand and existing competence on the input side.

Ongoing European activities

Germany has shown interest in the battery intense markets, for example through the establishment of a national platform for electro mobility, cf. Box 3. Furthermore, Matthias Müller, Group CEO at VW, plans to launch more than 30 pure battery-powered vehicles by 2025 and has confirmed that the car manufacturer wants to build a battery factory in Germany.

Finland, and especially the city of Vaasa, is making efforts investigating the possibility of applying for a Tesla Gigafactory to be established in the area. Similar investigations and efforts are being made in the Netherlands, France, and Germany.

South Korea's LG Chem is planning to establish a battery plant in Poland to supply European automakers. They have strong political support from Deputy Prime Minister Mateusz Morawiecki.

Another South Korean company, Samsung SDI, has launched the construction of its battery factory in Hungary. The commercial operation is planned to begin in second half of 2018 and they will invest around 400 billion won to build production lines with an annual capacity of batteries for 50 000 pure electric vehicles.

Source: Copenhagen Economics based on interviews with Carlsson (2016) and Kadowaki (2017), and Süddeutsche Zeitung (2016), Strzelecki (2016), Samsung SDI (2016), Yle (2016), Fraunhofer ISC (2013)

Another challenge may be that the respective graphite and lithium value chains are distinct and, in a Swedish context, have very different levels of maturity. Therefore, we assess the graphite and lithium value chains and the Swedish strongholds and challenges along them individually below.

Graphite value chain

China and India together held 90 percent of the world's graphite production in 2015. Europe hosts small-scale production three graphite mines in Austria, Germany and Sweden.³⁹ Graphite consist of carbon⁴⁰ and is mainly used in anode production for lithium-ion cells and batteries, in friction materials, lubricants and refractory materials.⁴¹ It is also the sole component of the new material graphene.

Graphite

Graphite is a stable form of carbon with good conductive characteristics. It is widely used as anode material in e.g. lithium-ion batteries, but also in various other applications in construction and manufacturing, requiring lower quality graphite.

Graphite is a 'flaky' material and it is generally easier to produce high quality graphite from large (jumbo) flakes than small flakes. Flake size does, however, not matter for the production of battery quality graphite, as the material is grinded anyways.

Source: Copenhagen Economics based on Deloitte (2015) p. 84 and Asbury (2016)

After 15 years at 'care and maintenance', the Woxna graphite mine in Dalarna County in Sweden received approval to re-open the graphite mine in November 2016.⁴² Thus, extraction of natural graphite is found to be both possible and attractive from a commercial point of view, and other deposits are currently explored and developed by e.g. Talga Resources that has a promising find in the north of Sweden with high grades of graphite.⁴³

Traditionally, the first processing steps of flotation and screening, cf. Figure 3 below, usually takes place in proximity to the mine, and existing Swedish strongholds in mining and chemical research suggest that this will also be the case in Sweden. The product resulting from this process is, however, of a relatively low grade (94 percent) and a fairly low value product for uses in e.g. the steel industry, and further processing is needed to reach 'battery grade' material, selling at much higher prices.⁴⁴

³⁹ Grafitbergbau (2017), AMG Mining (2017) and Deloitte (2015), p. 84

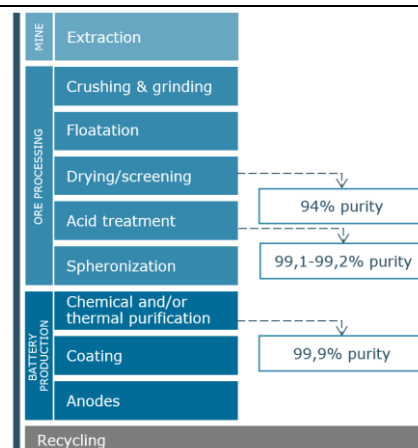
⁴⁰ Carbon is a non-metal and have more varied properties than metals, cf. Royal Society of Chemistry (2016). It is possible to produce synthetic graphite, however it is not found to be competitive in emerging applications often requiring large flake graphite and/or high-purity grades, cf. Roskill (2015).

⁴¹ Deloitte (2015), p. 84

⁴² Geological Survey of Sweden (2016b) and Geological Survey of Sweden (2016a)

⁴³ Talga Resources (2017) and interview with McManus (2016)

⁴⁴ Interview with Saxon (2016)

Figure 3 Natural graphite value chain

Source: Copenhagen Economics based on Leading Edge Materials (2016b), Deloitte (2015), p. 84 and interview with Saxon (2016)

As for final applications, graphite for use in batteries must be of very high quality (99.9 percent purity) and the production process becomes increasingly complicated and specialized. For production of battery quality graphite, i.e. uses in anodes and coatings, the graphite is treated with acid and then grinded and shaped into very small spheres through the process of spheronization.⁴⁵ The two companies closest to engage in graphite extraction in Sweden, Woxna Graphite⁴⁶ and Talga Resources, are both hesitant on where to locate this part of the value chain. The available alternatives to location in Sweden is northern or central Europe. Some worries related to long lead times when introducing new chemical processes etc. in the Swedish Environmental Code have been raised. Hence, it is not obvious that this part of the production step will be placed in Sweden, but we do not see any obvious barriers either.

The final production of anodes and coatings and the necessary knowhow is currently centred in Asia and we do not see any obvious existing strongholds for Sweden to build on in order to develop and host this part of the value chain. Yet, commercial interest in establishing a Swedish battery factory and import these specialised skills from Asia, has been shown by the company SGF Energy. Currently, only small-scale battery manufacturing takes place in Europe, and the majority of the batteries used in Europe is imported.⁴⁷

There is a lot of research taking place within graphene, both in Europe and in Sweden specifically, which may pose additional opportunities for high quality production and treatment of graphite and graphene in Sweden, cf. Chapter 1.

⁴⁵ After acid treatment, but before spheronization, graphite reaches a quality of about 99,1-99,2% purity with applications in manufacturing of expandable graphite, cement products, coatings, 3d printable materials, composite plastics, fire retardants, absorption products, specialty lubricants etc.

⁴⁶ Owned by Leading Edge Materials.

⁴⁷ Deloitte for DG GROW (2015), p. 85

Similar to rare earths, we see an opportunity for Swedish based companies to take a lead in recycling of graphite with current recycling rates of only about 10 percent and to develop technologies for recycling lithium-ion batteries, building on an existing strong position in recycling and in battery research at e.g. Ångström Advanced Battery Center at University of Uppsala.

In sum, we find it likely that Sweden could be attractive for investments towards a graphite value chain in extraction and concentration and potentially even up until final production of batteries and thus battery quality graphite. We find this development to be even more likely if another key input in re-chargeable lithium-ion batteries, namely lithium, will also be mined in Sweden in the future. In that sense, we see the development of a full lithium-ion battery industry value chain in Sweden to depend on development of both graphite and lithium resources in Sweden.

Barriers to this development are represented by lack of access to local or even European production facilities and knowhow in anodes and coatings, and relatively lengthy permitting procedures in Sweden, which could cause Sweden to fall behind in the race to host Europe's battery factories.

Lithium value chain

Around 80 percent of the world's lithium production was sourced from Chile and Australia in 2015. Portugal is the only European producer of lithium concentrate.⁴⁸ High value end products such as batteries and electronics require high purity of lithium and thus high value added production after mining.

Lithium

Lithium is the lightest of all metals, has the greatest electrochemical potential and provides the largest specific energy per weight. Lithium consumption for batteries (35 percent) has increased significantly in recent years due to increased use of rechargeable lithium batteries in portable electronic devices, electric tools, electric vehicles, and grid storage applications. Other applications include ceramics and glass (32 percent), lubricating greases 9 percent, air treatment, alumina production plus a number of other products.

The two (main) sources of lithium are brine and hard rock. Producing from brine is often believed to be cheaper than hard rock due to ease of extraction, lower capital expenditure requirements and less complicated exploration procedures. Both sources are, however, equally important measured by production. Currently a facility under development in Mexico aims to extract lithium from clay.

According to the national geological survey of the United States (USGS), lithium supply security has become a top priority for technology companies in the United States and Asia: *'Strategic alliances and joint ventures between technology companies and exploration*

⁴⁸ USGS (2016a), p. 101

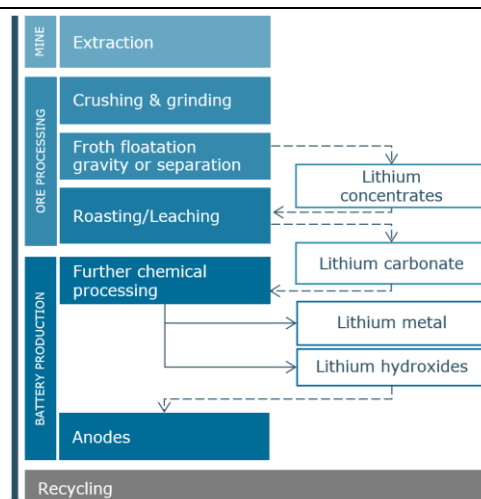
companies have been, and are continuing to be, established to ensure a reliable, diversified supply of lithium for battery suppliers and vehicle manufacturers.' The same issue and solutions could be relevant in Europe. We discuss this further in Chapter 3.

Source: Copenhagen Economics based on Battery University (2017) and USGS (2016a), p. 101.

Lithium deposits have been identified in Sweden but exploration is still in its infancy. It is currently uncertain whether it is economically feasible and viable to extract (hard-rock) lithium in Sweden. Should Leading Edge Materials, currently holding an exploration license in Bergby between Hudiksvall and Gävle,⁴⁹ find it commercially attractive to develop the deposit further towards mining, Sweden generally holds good pre-requisites for mining given its long legacy in mining, availability of skilled labor, access to energy and transport infrastructure, support industries etc.

After mining, the ore is concentrated to a lithium concentrate, which is the first saleable, but rather low-value, product, see Figure 4. To refine lithium further to either lithium carbonate or the higher value product, lithium hydroxide, a very energy intensive acid-roast process is needed.⁵⁰ This process is very energy intensive. New plants are currently being built in Australia, Chile, Argentina and Canada illustrating that 'first world countries' can be competitive in this step, as would Sweden given low energy costs from hydro and nuclear. Similar to the case of graphite, getting the necessary permits, e.g. environmental, planning etc., to construct such treatment facility in Sweden may pose a challenge to private companies interested in bringing this further.

Figure 4 Lithium value chain



Note: This figure illustrates the value chain for lithium sourced from hard-rock

Source: Copenhagen Economics based on Leading Edge Materials (2016b), Deloitte (2015), p. 84 and interview with Saxon (2016)

⁴⁹ Geological Survey of Sweden (2016a)

⁵⁰ Interview with Saxon (2016)

As mentioned above, high-end lithium-ion battery production and the necessary knowhow is currently centred in Asia, but of course, battery factories, like e.g. Tesla's Gigafactory in Nevada, are developing outside of Asia, including Europe. By 'importing' knowhow from Asia, SGF Energy may be able to move forward a battery factory in Sweden and Swedish produced lithium could be a feedstock for this plant if synergies are sufficiently strong. However, there are also other commercial applications of lithium and existing strongholds in e.g. Swedish steel production that may be able to support future lithium production in Sweden. Another opportunity could again be found in developing more efficient recycling methods for lithium-ion batteries. Currently, there is very limited recycling of lithium-ion batteries and to our knowledge no such in Europe.⁵¹

In sum, even though we find that Sweden could possibly host a battery value chain, there are also possibilities to host parts of a battery value chain should the final production be placed in another European country like Germany, Finland or Poland. Swedish graphite or lithium may very well serve as a key input in European battery production.

⁵¹ According to USGS (2016a), a U.S. company has since 1992 been recycling lithium-ion batteries at its facility in British Columbia, Canada. In 2009, the company was awarded 9,5 million US dollars by the U.S. Department of Energy to construct the first U.S. recycling facility for lithium-ion vehicle batteries.

Chapter 3

Policies

In the previous chapter, we found that opportunities may exist for a battery industry and a ‘partial’ REE value chain in Sweden, but also that barriers may exist for these industries to develop on their own. Some of these barriers are market risks high entry barriers and high concentrations of market power, while others are technological risks driven by uncertainty about which future technologies will prevail or lack of knowledge, keeping private investors from investing and developing these industries. This is particularly relevant for upcoming and immature markets, where R&D is an important cost driver and where uncertainty as to the future technologies, products, or market dynamics is large and where companies through their choices and investments today are ‘betting on’ the dominant technologies of tomorrow. Finally, there are institutional risks embedded in the political and regulatory system that pose risk throughout the entire value chains; will mines receive permissions to mine and how long will it take for a battery factory to be cleared within the Environmental Code. As a result, investments may not materialize and Sweden may therefore fail to realize the economic potential from hosting new value chains.

We find that by introducing risk mitigating policies, Sweden could possibly realise an economic potential from new ‘battery’ and ‘REE’ industries of 200-500 million SEK a year, from increases in productivity in the overall economy. This of course necessitates the adoption of policies that succeed in reducing critical risks and spur private investments. We find that Sweden should consider policies to reduce friction for investments close to decision (short term impact initiatives), facilitate access to knowledge of technological opportunities and collaboration across value chains (medium term impact initiatives), and create technological advances that private companies can build on (long term impact initiatives).

3.1 Economic potential

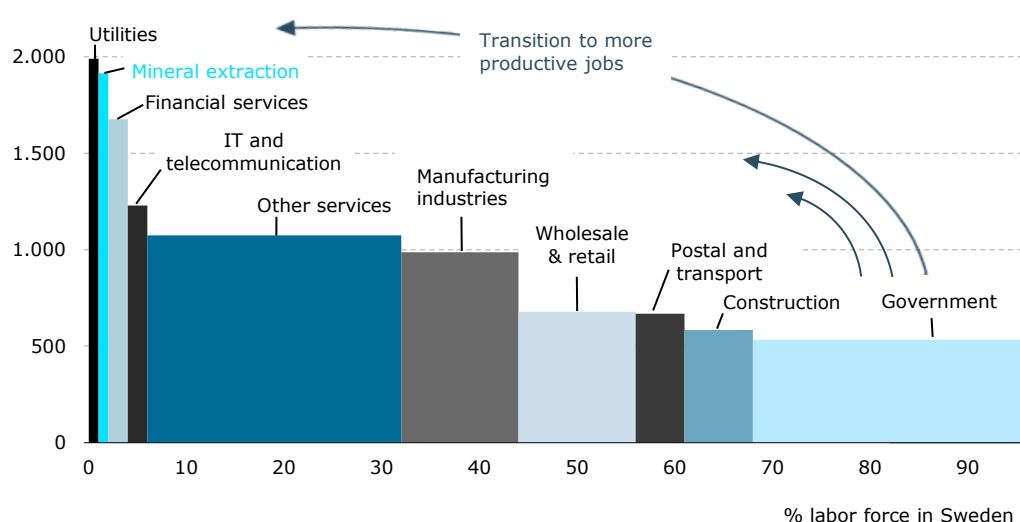
The extractives sector in Sweden is a high-productive one and we expect that new value chains will be so as well. This implies that if jobs move from less productive ones, in e.g. construction, to the mining sector and the new value chains, the overall productivity in Sweden will increase, thereby making Sweden richer. This follows from two effects; 1) increasing the employment in high productive sectors and 2) reaping synergies from knowledge spillovers or cluster formations around new value chains.

Productivity measures the effectiveness with which the resources available to an economy, such as labor, capital, and knowhow, are used to produce goods and services. The productivity of labor (i.e. the individual worker) typically increases with the availability of capital and knowhow. For example, a mineworker is more productive in a mine operated with a modern fleet of trucks and machinery, than when equipped with a pickaxe and a canary. This point is illustrated in Figure 5, where the capital-intensive mineral extraction and utilities’ industries show very high value added output per full-time equivalent worker. This

also implies that the more a country specialize and increase the share of the labor force employed in high productivity industries, the more productive, and wealthier, the overall economy will be.

Figure 5 Swedish industries' labor share and productivity

Value added per FTE
employee, 1000 kr.



Note: Data is for 2014. FTE is full-time equivalent. The placement of the government sector far to the right is not comparable to the placement of the others, as its productivity is estimated based on wages and therefore underestimated.

Source: Statistics Sweden (Labour input (ESA2010) by industrial classification SNI 2007. Year 1980 – 2015)

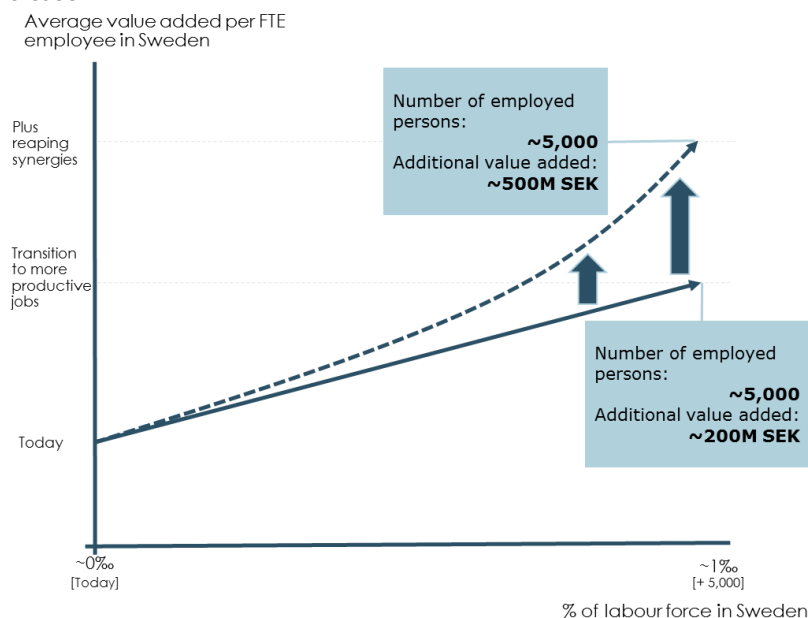
In addition to a transition towards more productive jobs, even the high productive jobs can become more productive if synergies or technology effects can be realized and reaped. Examples include cluster effects (i.e. knowledge spill-overs from co-location or integration along and across value chains) or realization of first mover advantages, economies of scale in production etc. The extent of such effects on productivity is difficult to estimate.⁵² In Box 2 below we demonstrate the consequences of a 10 percent productivity increase and find that a 5000 job large REE and/or battery industry, could add another 300 million SEK to an annual increase in value added production of 200 million SEK. This illustrates the massive effect of being able to harvest synergy effects.

⁵² Spencer et al. (2010) and Madsen et al. (2003) find support for increases in productivity between 9 and 33 percent from cluster effects.

Box 2 Economic potential of REE and battery industries

Assuming that REE- and battery industries are high-productive, attracting whole or partial value chains holds the potential of enriching the Swedish society by both increasing employment in high-productive sectors and by realizing synergies.

Newly created employment in the REE and battery value chains would then move people from industries with lower productivity and thus add value via the extra output of each employee. New jobs would also be partly filled by foreign labor, which would add even more value to the economy because the labor force and the overall production capacity increase.



If 5000 jobs are created in Swedish REE- and battery industries, including a battery value chain from mine to a downstream large-scale battery factory, REE mining and production of mixed REE concentrate, the additional value added production from the transition towards more productive jobs alone, would be around 200M SEK a year. If these industries were successful in reaping synergies, a productivity gain of e.g. 10 percent would thus increase the added value to 500 SEK a year for the same number of jobs (5000).

Note: Value added estimates include effects from attracting foreign labor to the potential industries in Sweden. Calculations are available in appendix.

Source: Copenhagen Economics based on Statistics Sweden (Average basic salary, monthly salary and women's salary as a percentage of men's salary by region, sector, occupation (SSYK 2012) and gender. Year 2014 – 2015), Feasibility Study for the Tanbreez REE project in South Greenland (confidential report), Spencer et.al. (2010), Madsen et.al. (2003) and interviews with Ranggård (2017) and Carlsson (2016)

3.2 Great risks

As mentioned above, REE and 'battery' value chains cannot necessarily be expected to develop on their own in Sweden due to additional high risks for the individual, private investor. Table 3 summarizes that the risk level for both potential industries is medium to high.

Table 3 Risk characteristics of potential, future value chains

Risks		'Battery industry'	'REE industry'
Technological risk	<i>Insecurity about the future technology and speed of development, complementary and substitute technologies, products and inputs</i>	High <ul style="list-style-type: none"> - Large research in different battery technologies and materials for cathodes and anodes - Uncertainty with respect to future scientific breakthrough in fuel cells, solar panels etc. 	Medium-High <ul style="list-style-type: none"> - Expertise and know-how in China and a limited number of non-Chinese companies - Ore specific chemistry
Market risk	<i>Uncertainty about suppliers and customers in future value chains, lack of flexibility, economies of scale and possibly co-location advantages, incumbent(s) response to market entry</i>	Medium <ul style="list-style-type: none"> - Rapid development in market - Uncertainty as to flexibility and new business model partnerships in value chain 	High <ul style="list-style-type: none"> - China strong incumbent - In-transparent markets
Institutional risk	<i>Design of legal rules, speedy application procedures, schemes and standards to support or counter-act industry</i>	Medium <ul style="list-style-type: none"> - Risk of lengthy permitting processes for new mines - Tough environmental requirements may hinder or delay battery factory 	High <ul style="list-style-type: none"> - Chinese dominance - Risk of lengthy permitting processes for new mines - Tough environmental requirements

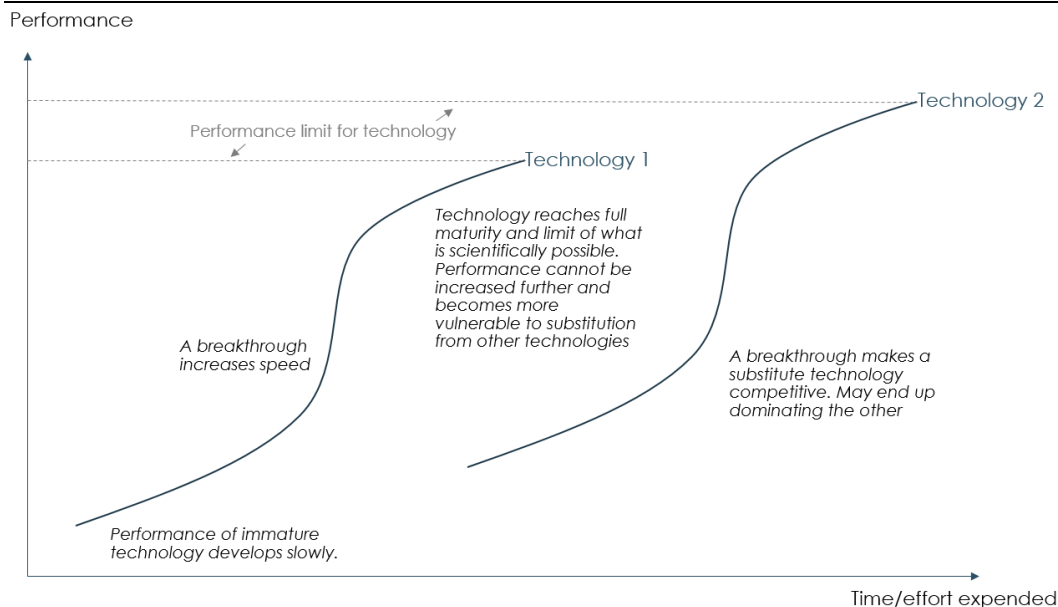
Note: Compared to Hellsmark, H. et. al. (2016) we have fewer categories as we have collapsed Market and Organizational risk

Source: Copenhagen Economics based on assessment in chapter 2 and analytical framework from Hellsmark et.al (2016)

First is a relatively high level of technological risk in both the battery and REE value chains due to uncertainty about future technologies of batteries and technologies using REEs, the speed of which these will develop and substitute technologies evolve. This type of risk is not unique for batteries or REEs but relevant for 'upcoming' or 'future' markets in general, where R&D is an important cost driver and where uncertainty as to the future technologies, products, or market dynamics is large and forces companies to 'bet on' the technologies of the future.⁵³ Chinese dominance along the entire REE value chains adds further to the risk dimension for this value chain.

Over their lifetime, many technologies follow a pattern where a period of slow discovery is followed by a period of rapid advances, and eventually a period of saturation as the technology is perfected. This pattern is often described by the 'technology growth s-curve', cf. Figure 6. Many of the green technologies expected to be important in the future, such as lithium-ion batteries and several technologies using REE's, may currently be found on the lower half or steep most part of the 's', as the technologies are subject to great uncertainty about the future as technological breakthroughs are either anticipated or already happening at rapid speed.

⁵³ McKinsey & Company (2012), p. 120

Figure 6 Technology growth s-curve

Source: Copenhagen Economics based on Sandström (2013)

Next is the level of market risk, which we also find to be quite high in the two industries. Market risk covers uncertainty about future suppliers and customers, economies of scale and possible co-location advantages, incumbent(s) response to market entry etc. This is especially critical in REE, where China's dominant role and the opaque market structure makes it difficult for new entrants to enter let alone predict market outcomes.

Finally is institutional risk, which may also be considerable for both value chains. When technologies are immature and markets dynamics are quickly changing, it is often difficult for regulation and policy to follow suit. This time lag may for example hinder businesses from responding to new market conditions. In other situations, regulation and policy, or lack hereof, can end up shaping the market outcome, for example, subsidies for electric vehicles can reduce incentives to improve performance of combustion engines. Specific standards for performance or design may also counteract or shape industry.

3.3 Policy implications

As mentioned, high risks along the battery and REE value chains, due to their relative immaturity, could cause investments to stay away and Sweden to fail to realize a potential for increased productivity, higher value added, local jobs etc. However, all is not lost; policies can be designed to decrease or spread risk, and thereby incentivize the development of these industries.

Risk reducing policies

Public policies aimed at improving societal outcomes by reducing risks in the private sector is nothing new. One example is research and knowledge generation. As research results do not always benefit the research unit undertaking it, the private incentive to undertake research without a direct commercial outlook can be modest, but as knowledge tend to spread and find unforeseen applications and uses, the societal value of research can be much larger than the private research unit realises. Hence, research is often supported by public funds, in order to take away the risk of ‘unsuccessful’ ground research from the private sector, while still making it available to the public. In other words, this type of policy aims to reduce technological risk, cf. Table 4. Within the conceptual framework of the ‘s-curve’, this type of policy aims to bring technologies from the lower part of the ‘s’ forward to the accelerating and steep part of the curve by making available knowledge to the private sector.

Table 4 Risk reducing policies

Risks	Examples of public risk reducing policies
Technological risk	<i>Government funded and supported R&D to strengthen companies incentive to conduct own R&D&I</i>
Market risk	<i>Government funded network activities to reduce coordination failure, provide for new (risk sharing) partnerships, diplomacy and trade agreements</i>
Institutional risk	<i>Adoption of national, industry strategies. Review of legislation, harmonization and standardization. Removal of administrative hurdles.</i>

Source: Copenhagen Economics based on analytical framework from Hellsmark et al. (2016) and McKinsey & Company (2012)

Market risks can be reduced for the individual firm by sharing it with other companies in the value chain; either within the same part of the value chain (e.g. research partnerships or joint ventures) or across companies in different parts of the value chain (long or flexible contracts for supply or off-take for example). The government may take actions to facilitate networks or clusters to facilitate risk sharing and coordination among companies represented in the value chain that will allow them to move further along the s-curve. Other actions may be market making and trade enabling to reduce market risk.

Policies to reduce institutional risks are about ensuring stable framework conditions and clear political direction. A classic example would be streamlining regulation and permitting procedures to increase speed and foreseeability of regulatory processes and thereby companies’ ability to and appetite for making long-term investments.

Government policies will often not reduce only one type of risk but several. Box 3 below provides an example of a national strategy from the German government in the area of

Electric Mobility, aiming to reduce both technological, institutional and market risk for German companies and producers in the field.

Box 3 The German National Platform for Electric Mobility

The German approach

In 2011, a national strategy was formulated between federal government, industry, science, and trade unions, setting common goals for Germany as a leading supplier in electric mobility by 2020, i.e. the entire value chain from batteries, over electric vehicles to web-based services for electric mobility.

The policy measures are a mix of direct monetary incentives and stimulus (tax breaks, subsidies, and public procurement), research and innovation support schemes and review of legislation.

The policies target different phases of development of the value chain in order to make it market based, i.e. economically viable and self-sustainable.

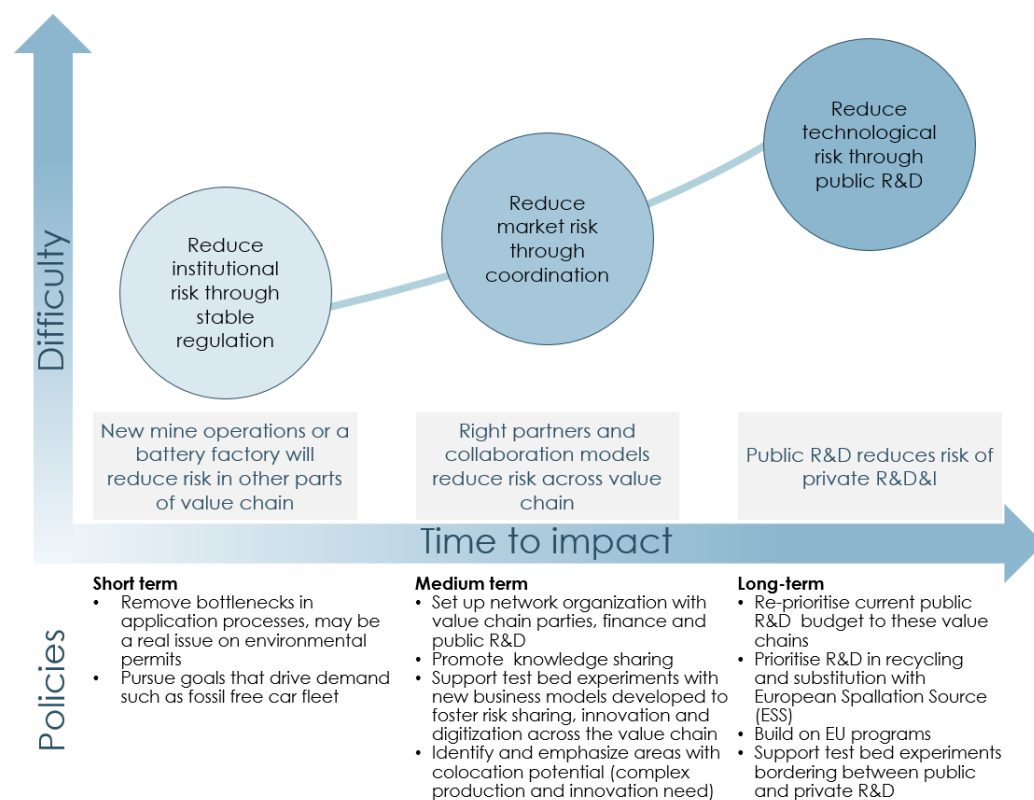
The strategy is financially ambitious, as of 2016 the environmental bonus for battery-powered electric vehicles and plug-in hybrids amounted to 1.2 billion €, and between 2017-2020 360 million € per year is devoted for research and development, cf. appendix.

Source: The German National Platform for Electric Mobility (NPE) (2017)

Policy mix to reduce risks in the short, medium and long term

So, how could policies be designed to incentivize these important investments in battery and REE value chains and to make sure they end up in Sweden? A few basic ground rules should be followed: First, policies should be aimed at reducing risk. Second, policies should be non-distortionary and hence not by their design form market outcomes by 'picking the winners'. Rather, they should depart from what would be economically self-sustainable outcomes in the absence of risk. Hence, we should start from areas and activities where commercial interest already exists, e.g. in graphite or REE mining, but most likely not chemical separation of REEs in Sweden.

Policies have different 'lag time' i.e. some will have effect on the market already in the short run, while others, such as R&D support, will prove effective in the longer run. Figure 7 below illustrates a 'package' or mix of policies that will reduce risk and impact on the market in both the short, medium and long term.

Figure 7 A risk reducing policy mix

Source: Copenhagen Economics

Short term impact: Remove obstacles for investments close to realisation

Policies with short-term impacts are all about harvesting low hanging fruits, i.e. removal of obstacles and risks that will relatively quickly incentivise stakeholders to change behaviours, such as making an investment rather than not. Such policies could include removal of bottlenecks in application processes, for example on environmental permits, which tend to be lengthy and complicated in Sweden. Other policies may pursue goals that drive demand such as a fossil free car fleet. Such policies could reduce both institutional and market risk.

Medium term impact: Facilitate knowledge and collaboration

We find that Sweden could most likely also benefit from forming network organisations with representatives from the value chain, finance and public R&D to promote knowledge sharing and risk sharing models. Networks may also work to identify and emphasise areas with co-location potential between complex production and innovation need and to support test bed experiments of not only new technologies but new business models as well. New business models could be driven by increased digitalization, risk sharing or innovation across the value chain. One very good example from the mature iron and steel cluster is the

high profile research programme of LKAB, SSAB and Vattenfall with support from the Swedish Energy Agency⁵⁴. The companies are aiming at jointly developing a new technology and steel making process with zero carbon dioxide footprint and are financing research worth 100 million SEK during the coming four years.⁵⁵ As battery and REE value chains are immature in Sweden, similar initiatives are likely to require outside support and facilitation. One reason is that it simply takes time to build networks and trust, another reason that companies in an upcoming industry may not find it worthwhile to invest in network activities like this as the gains are reaped by not just themselves but other companies as well. Therefore, government can play an integral role in facilitating and driving forward such a network, potentially over time towards ‘clusterfication’. To reap these benefits even in the medium term, they should be initiated today.

Long-term impact: Create technological advances to build on

In fact, Sweden already have a range of policies and programs with long-term impact in research and innovation within the mining sector such as SIP STRIM co-financed by VINNOVA, Formas and the Swedish Energy Agency.⁵⁶ Existing public R&D budgets could be re-prioritised in order to promote battery or REE value chains and/or recycling and substitution technologies for batteries and REEs. Swedish based and funded programs could also build on existing EU programs to ensure maximum impact and scale in later production. The SIO Grafen programme, building on the EU Graphene Flagship, is an example of facilitating ground research in a material with no current commercial use, in order to position Sweden well in the future, cf. Box 4.

⁵⁴ The Swedish Energy Agency (2016)

⁵⁵ The Swedish Energy Agency (2017). Note: The result from this joint venture may, however, not be available in the medium term.

⁵⁶ SIP STRIM (2017)

Box 4 Graphene Flagship and SIO Grafen

The Graphene Flagship

There are many research initiatives directly or closely related to the new material graphene. In 2013, the European Commission founded the Graphene Flagship, a €1 billion project aiming at bringing together academic and industrial researchers from universities and companies all over Europe in order to bring graphene from the laboratories into society by involving the entire future value chain of graphene. Graphene is predicted to create economic growth, new jobs and new opportunities, both technical and industrial.

Chalmers University of Technology in Gothenburg is coordinating the project, and the Chalmers Professor Jari Kinaret is the Director of the Graphene Flagship. Chalmers is striving to develop a best practice model for how European universities can take graphene from the research lab to the industry shop floor, and they are currently one of the main European players in the graphene research field.

SIO Grafen

In addition to the Graphene Flagship, Chalmers is responsible for the Swedish project SIO Grafen, an innovation program supporting the graphene development in Sweden. It is financed by the Swedish government agencies Vinnova, the Swedish Energy Agency and the Swedish Research Council Formas. The vision of SIO Grafen is to make Sweden one of the world's top ten countries in graphene by 2030. In order to meet this vision, SIO Grafen is offering innovation-funding possibilities for groups of Swedish companies and have a budget of €2 million per year.

One example of a research initiative that is among the finalists in the VINNOVA competence centre call is the Technology for Industry from Graphene (TIGR) competence centre. It involves academia, several major Swedish industry companies in telecom, aerospace and automotive and SME:s working across value chains. From mining of graphite, production and modification of graphene, through materials and component production to system producers and integrators. The total budget for TIGR is 240 million SEK over ten years, and the main research areas are functional materials, electronics, and energy storage.

Source: Copenhagen Economics based on The European Commission (2017), Borg (2013) and SIO Grafen (2017) and interview with Carlsson (2017)

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