The Hague Centre
for Strategic Studies

The New Great Game:
Securing critical minerals today for a clean energy system tomorrow

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HCSS Geo-economics

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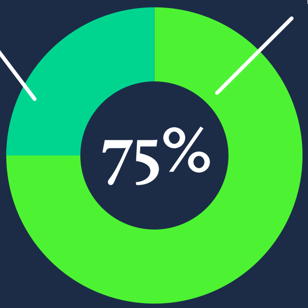
The European Energy Sector

The Hague Centre for Strategic Studies

The energy sector is responsible for 75% of GHG emissions:

Other Sectors 25%

Energy Sector 75%

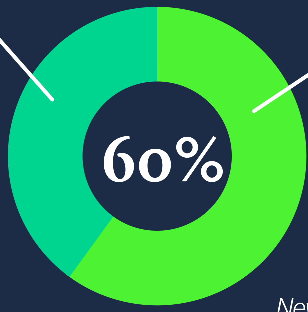


Source: Net Zero by 2050, IEA (2021)

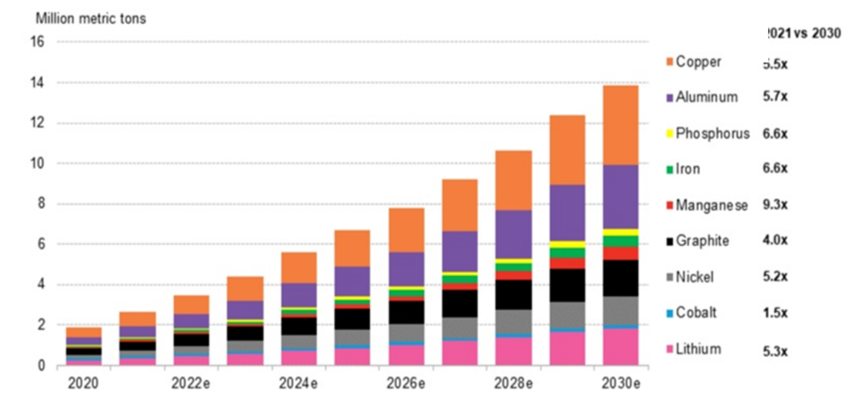
By 2050 there is a need for 60% installed solar PV, wind, hydro and large batteries:

Others 75%

Solar PV, wind, hydro & batteries 60%



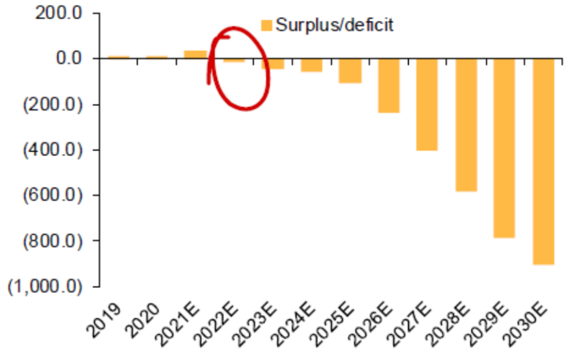
Source: BloombergNEF New Energy Outlook (2021)



This requires 400% more critical minerals:

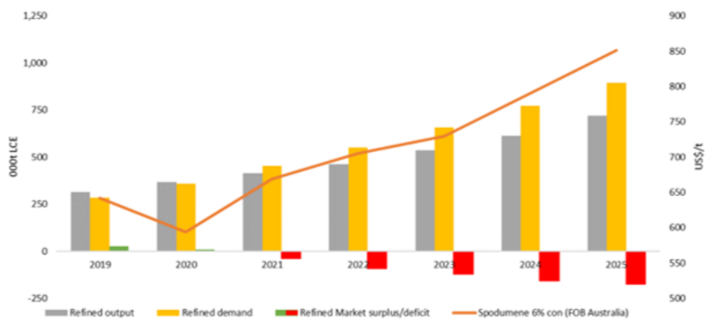
- Lithium
- Nickel
- Cobalt
- Copper
- Graphite
- Manganese
- Rare Earth

Source: BloombergNEF Battery Metals Monthly (2021)



Bringing a mine up to exploitation can take up to 10 years, further compounding the deficit in mining capacity.

Source: Macquirie Research (2021)



The EU currently has no processing capacity. Demand for refining capacity will outstrip supply by 2021.

Source: Benchmark Minerals Intelligence (2019)

EU Options:

- **Include producing countries in integrated value chains**
- **Secure inflow using non-disruptive instruments**
- **Include downstream manufacturers in mining and processing**
- **Include foreign expertise, but keep ownership**
- **Include pension funds in financing**
- **Have public campaigns on importance of critical minerals**

Executive Summary

Under the Paris Climate Agreement (also known as CoP21), 190 countries and the EU have committed themselves to limit global warming through the reduction of greenhouse gas (GHG) emissions.

The energy sector is responsible for producing roughly 75% of the world's GHG emissions, making it the forefront of the battle against global warming. There is, therefore, tremendous pressure on both energy producers and energy consumers to increase the use of renewable energy and other clean technology in the energy mix. By 2050 more than 60% of the installed power capacity is predicted to come from solar pv plants, wind farms, hydropower plants and large-scale batteries.

Building clean energy systems however requires an undisrupted supply of the raw materials that are needed to produce clean energy applications. The International Energy Agency (IEA) projects that by 2050 the demand for critical minerals coming from clean energy applications will have to be increased with at least 400%. The larger part of that demand will come from clean energy applications like electric vehicles and stationary energy storage using batteries. The minerals to make these raw materials have become critical to the energy transition and the ratification of CoP21 may turn out to be a tipping point for two industries that Europeans have fallen out of love with: mining and chemical processing.

With little commercial mining and close to zero processing of critical minerals on its territory today, Europe finds itself in a very vulnerable position. Although China is leading the game, it is becoming apparent that no economic power will be able to build its supply chain entirely by itself. Europe needs to be proactive and pragmatic as all major economic powers have now formulated strategies to build their own and preferably local supply chains.

Although Europe has joined the game relatively late, it is in a good position to become an important player in the critical minerals supply chain due to its historically strong ties with most of the resource rich countries. The chess game of securing access to critical minerals and expanding local processing capacity has truly begun.

Alliances with resource rich countries will have to be forged, talent and expertise from all over the world need to be attracted and capital needs to be deployed across the entirety of the supply chain in order to succeed in this *New Great Game*.

1. Introduction

The energy sector is responsible for producing around 75% of the world's greenhouse gas emissions (GHGs).[1] With more than 190 countries committed to combat global warming under the Paris Climate Agreement (CoP21) there is tremendous pressure to increase the share of renewable energy and other clean energy technology in the energy supply mix. We consider it our moral duty to our children and the generations to come, to pass on a planet that is cleaner and safer than ours today. But building clean energy systems requires undisrupted access to the minerals that are needed to build these systems. A typical battery powered electrical vehicle (EV) requires six (6) times the mineral inputs of a vehicle with an internal combustion engine (ICE), and an onshore wind farm requires nine (9) times more mineral resources than a gas-fired power plant.[2] These mineral resources need to be explored for, mined and processed before they can be used in end-applications. Today, the People's Republic of China (PRC) dominates critical parts of the supply chain of these minerals, and this will continue to be the case at least for the next decade. The focus of newcomers like the EU and the USA should be on how to secure a firm position in this supply chain. An open dialogue between public and private stakeholders is necessary to deal with the paradox that some advocates for stronger environmental, social and governance (ESG) rules and regulation do not want to acknowledge: the transition to a cleaner energy system requires an increased commitment to the mining and processing of critical minerals. Two activities that we, especially in the West, have fallen out of love with. These two activities, however, have always been and still are pivotal to human civilization and advancement.

This paper defines critical minerals as minerals that:

(i) are vital for many end-applications, with those end-applications having been identified by countries as crucial for the (economic) well-being of their societies; and
(ii) have no (economically) viable substitutes, and
(iii) face potential disruption in supply due to geological scarcity, geopolitical tension, trade policy or other factors.

These important minerals provide the foundation blocks for metals and alloys used in mobile phones, flat screen monitors, wind turbines, electric cars, solar panels, and many other (high-tech) applications including applications in the aerospace and defense industry.

1 IEA (2021), Net Zero by 2050, IEA, Paris https://www.iea.org/reports/net-zero-by-2050

2 IEA (2021), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

The energy sector is one of the top 5 sectors that rely heavily on critical minerals.[3] And as Figure 1 below illustrates, increasing the portion of clean energy solutions in the energy mix means increasing the demand for critical minerals. The scope of this paper is limited to lithium, nickel, cobalt, copper, graphite, manganese, and rare earth elements (REEs) since these minerals are crucial in the production of the two biggest drivers in critical minerals demand: EV production and battery storage applications.

Although Europe deploys plenty of capital into downstream applications for clean energy like lithium-ion batteries (LiBs) and EVs, the necessary investments in mining and processing of raw materials are lagging. This could lead to a situation in which the production of critical minerals and their processed chemical compounds might not be sufficient to meet the ever-growing demand downstream.

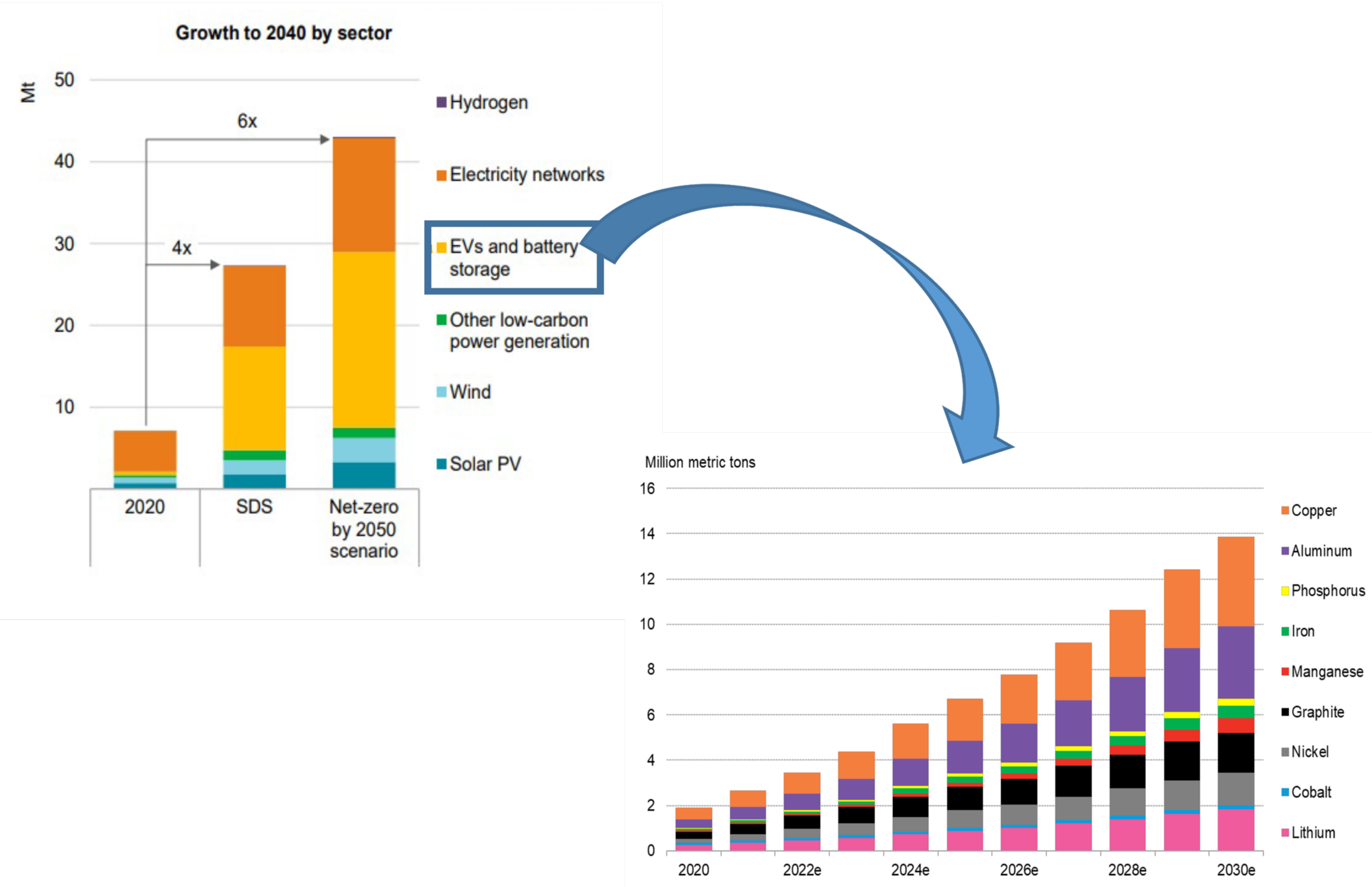


Figure 1. EV and battery storage lead the charge in critical minerals demand. Source: IEA (2021) and BNEF (2021).

To become a leader in clean energy technology Europe needs to set up resilient supply chains for the minerals it considers critical. This requires a well-coordinated, proactive, and inclusive approach. An approach in which it needs to accelerate its efforts in creating private – public partnerships and stimulate a broader based dialogue between stakeholders including the general public to raise awareness of the importance of critical minerals to society. This paper is meant to stimulate the dialogue between key stakeholders in the critical minerals supply chain. It offers practical tools to help European corporations and institutions in becoming players in the critical minerals supply chain that end users cannot ignore.

3 The US Geological Survey has identified 5 sectors that rely heavily on critical minerals: aerospace, energy, defense, telecommunication and transportation. See for more information on the role each critical mineral plays individually per sector: https://pubs.usgs.gov/of/2018/1021/ofr20181021.pdf

2. **A New Great Game**

For the larger part of the 19th century, the British and the Russians played a diplomatic and political chess game to secure the routes to and ultimately control over Central and South Asia. Some minor border incidents aside, it never came to a direct military confrontation between the Russians and the British. But the ambitions of the two empires and the potential prize lurking in the end (i.e. control over the Indian Subcontinent), pushed both empires into a game that lasted for almost a century. Most of the time both parties were busy forging alliances with leaders in neighbouring regions but sometimes, as in the case of Afghanistan, it included pre-emptive military campaigns to make sure the other party would stay away. This game is referred to as *The Great Game*.

We are living in a time that has all the ingredients for a *New Great Game*. But this time it will not be about securing border control and access to the Indian subcontinent. *This* Great Game will be about securing control over the minerals that are critical to so many appliances in our daily lives, including the technology that drives the transition to a clean and sustainable energy system. The transition from an energy system that gravitates around hydrocarbons such as oil and gas to an energy system that gravitates around the use of renewable energy sources such as solar and wind may seem like a straightforward exercise with only benefits. But factors like price fluctuations and supply disruptions will remain factors to reckon, even as the dependency on hydrocarbons like oil and gas decreases over time. One might even say that these two factors become even more important, given the smaller number of countries that dominate the mining and processing of critical minerals at the moment (see *Figure 2* below).

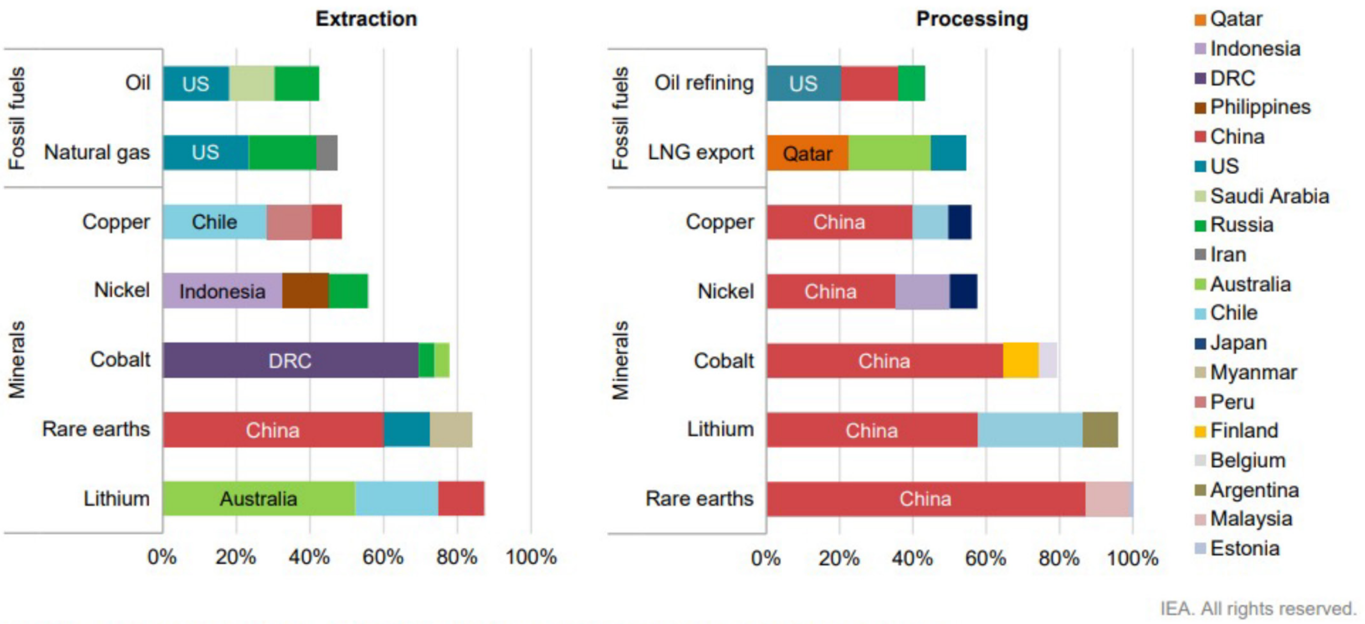


Figure 2. Share of top three producing countries for selected minerals and for fossil fuels based on 2019 data.
Source: IEA (2021).

Today, the People's Republic of China is leading the way in the critical minerals supply chain (and by light years). The Chinese government has already mandated the Ministry of Industry and Information Technology (MIIT) to support the creation of a completely domestic supply chain for the production of EVs. Under the '*Made in China 2025*' policy instruments, at least 25% of new vehicles produced in China should be EVs by 2025. This means that by 2025 more than 5,000,000 cars sold in China will have lithium powered batteries and electric motors containing rare earth elements in them.[4] At same time, projections by *Bloomberg New Energy Finance* (BNEF) on EU EV sales by 2030 show us the size of Europe's ambitions: by 2030 Europe will sell 10 million EVs. And this is where the analogy with the Great Game comes to mind.

The mere scale of the PRC's ambition shows the challenge that late comers like the EU and the USA face: in order to catch up and keep up with China, other countries need to start securing access to critical minerals. China in the meantime is executing its policies with clinical precision. Its first and foremost concern is to establish a domestic supply chain and achieve a certain level of independence in the critical minerals supply chain within this decade. It will be unaffected by those who are left without a chair when the music stops (i.e., when there is not enough supply to meet everyone's demand).

Minerals can be extracted in different ways, but the most common ways today still require some form of drilling and mining in places where companies and governments expect these minerals to be concentrated. Just like with oil and gas, the geophysical development of the Earth has led to an uneven allocation of critical minerals. There are only a handful of countries and regions in the world where critical minerals occur in economically viable quantities. This uneven allocation makes the mining and processing of critical minerals increasingly geopolitical in nature, with the new prize being: unrestricted access to places where these minerals can be mined and processed in a responsible and economically viable manner.

Today's players might look different, but their methods and determination will turn out to be remarkably similar to that of the Russian and the British in the 19th century. Slowly but surely the EU and the United States have come to realize that integrating these minerals into their respective supply chains is crucial to be able to offer society the end-applications it needs. Just like in the 19th century it will become very important to forge political and diplomatic alliances to secure and counterbalance the dominant position that some countries have today in the critical minerals supply chain. Europe will not be able to secure enough critical minerals by itself. (Re-)building an independent regionalized supply chain for critical minerals requires input from four key players: (i) those who understand what it takes to operate mining projects, (ii) those who are able to build and operate processing facilities to upgrade critical minerals so that they can meet the ever growing consumer requirements downstream, (iii) those who are able to fund it and (iv) those who are able to educate the public on the importance of critical minerals and the sacrifices required to secure their supply. Europe will need to forge alliances with resource rich countries, in particular countries that historically have a good relationship with Europe. Countries like Australia, Canada, Argentina, Brazil, Chili, and South Africa are resource rich countries with a strong connection to Europe. These countries will have to become the new focus points for European 'resource diplomacy' while East-Asian countries like Japan and South Korea should be invited to invest in the research & development of new materials and components in the critical minerals supply chain.

4 Institute for Security and Development Policy, '*Made in China 2025 Backgrounder*': https://isdp.eu/content/uploads/2018/06/Made-in-China-Backgrounder.pdf June 2018 and Reuters, '*China wants new energy vehicles sales in 2025 to be 25% of all car sales*', https://www.reuters.com/article/us-china-autos-electric-idUSKBN1Y70BN 3 December 2019.

3. The Elephant in the Room

Climate change has become a very important factor in the financing and investment policies of financial institutions. Recently, the European Central Bank (ECB) announced that it will make climate change a key component of its financing policies. The ECB will not only assess the investment and financing policies of the European banks that it supervises but will also evaluate its own portfolio of assets to make sure that these do not include corporations or institutions that do too little to combat climate change.[5] But the private sector too is focusing on its clean energy investments. As we can see in *Figure 3*, a lot of capital is deployed into the manufacturing of downstream applications like batteries and EVs. However, relatively little is deployed into the upstream parts of the supply chain, i.e., the *mining* and *processing* of critical minerals. The discrepancy between the investments made *upstream* and the investments *downstream* is a whopping US$ 80 billion. The issue is that with the large investments made in downstream applications like electric vehicles and large battery factories, the demand for the minerals that are crucial for the production of these end-applications will explode and by 2050 will reach levels 4 or even 6 times higher than today's.[6] These critical minerals need to be mined and processed before being useful. Mining and processing therefore remain crucial to the supply of critical minerals but bringing a mine to commercial production can take up to 10 years and qualifying critical minerals as the high purity material that can be used in end-applications like batteries is a process that takes at least 9-12 months. In other words, investing too little or too late in the mining and processing of critical minerals today can create supply disruptions in the future leaving societies exposed to exponential price increases for solar panels, wind turbines and electric vehicles so desperately needed for the transition to a cleaner energy system. The transition to a cleaner energy system will fail or at best suffer huge delays.

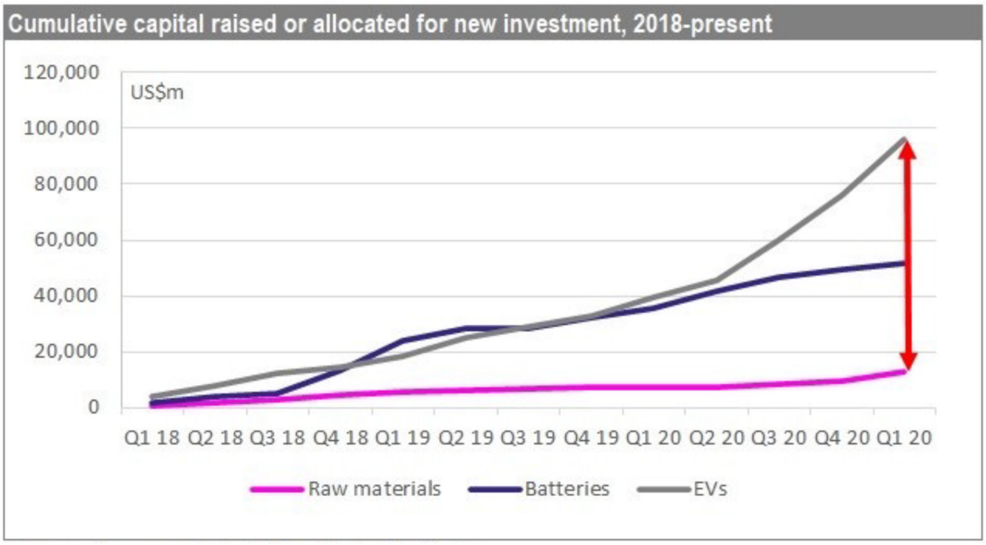


Figure 3. The downstream and upstream investment discrepancy. Source: Batter Materials Review December 2020.

5 Interview of ECB President Christine Lagarde with the Financial Times, 12 July 2021.

6 IEA (2021), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

3.1 A mine is not something you switch on

Mining takes time, money, patience, luck, and a certain risk appetite. It is a high risk but potentially high reward business. *Figure 4* is a simplified life cycle flow chart for a typical mining project. A mine is not something you can just switch on to produce more minerals. A lot of work and uncertainty proceeds the actual production of minerals.

It all starts with a mining company exploring an area in search of ore bodies (also referred to as 'deposits') that contain the mineral(s) they wish to produce. Finding an ore body is like looking for a needle in a haystack, it can take years and if you are lucky, you will find a deposit. Suppose that the mining company finds an ore body. It then needs to define it. This means it needs to understand the extent, location, and economic value of the ore body. Since it does not have much data on the ore body, it needs to conduct additional work to refine its definition of the ore body to understand its size and the grade of the deposit. The grade determines the quality of the ore.[7] Together with the size of the deposit, the grade of the ore will give the mining company a rough estimate of the volumes of minerals it will be able to extract from the deposit. Initially this work will contain a lot of estimations.

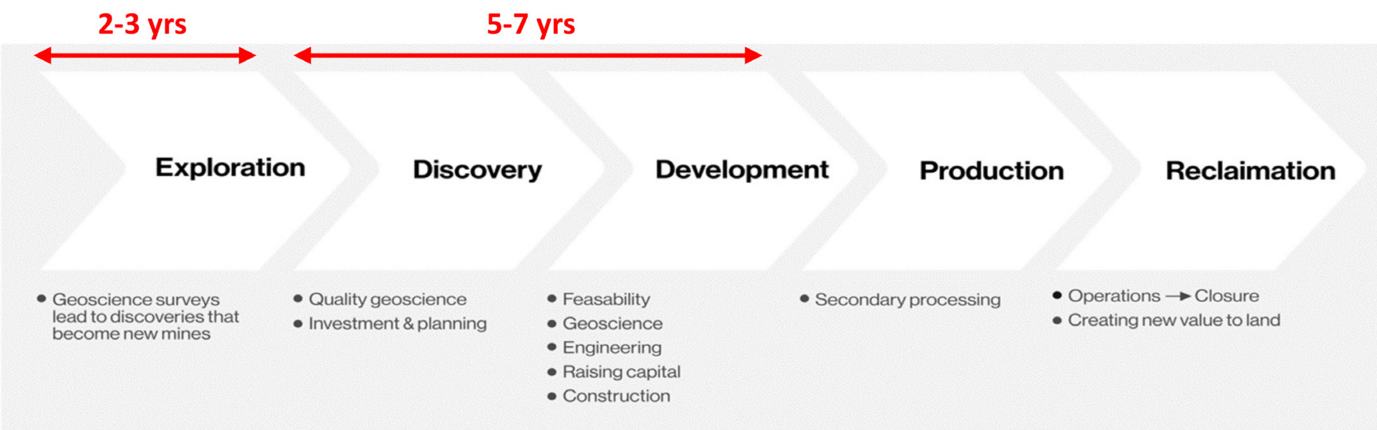


Figure 4. A typical life cycle for a mining project. Sources: Crux Investor and MRG Intelligence 2021

This estimation is used to conduct a pre-feasibility study to determine the theoretical economic value of the ore deposit. The purpose of a pre-feasibility is to identify the project's key risks and ways to mitigate these as much as possible at this stage. Mitigation measures could require additional investments or more (engineering) studies. After these investments and additional studies, the next step is to conduct a full feasibility study to evaluate the technical and financial risks and the (financial) robustness of the project. The financial robustness of the project depends on a couple of things such as: (1) the price the mining company believes it will be able to get for minerals, preferably under long term offtake agreements, (2) the expected *C1 cash cost* at which it can produce the minerals[8], (3) royalties, taxes and duties imposed by the jurisdiction where the deposit is located, (4) the projected capital expenses (CAPEX) and operating expenses (OPEX) to develop, construct and operate the mine for multiple years to come which allows the company to calculate the future cash flow, (5) the ability of the company to raise capital required to pay for CAPEX and OPEX in the early years of the project and (6) the cost of raising such capital (i.e. the higher the country risk, the more

7 The *grade* of ore refers to the concentration of the desired material it contains. The value of the metals or minerals a rock contains must be weighed against the cost of extraction to determine whether it is of sufficiently high grade to be worth mining.

8 *C1 cash* cost is defined here as only the net production cost to mine the ore, extract the metals and minerals required and process them so that they become marketable products.

stringent the demands of capital providers which always comes at a cost for the company for instance in the form of higher interest payments or stricter payback terms).

The firmer the conclusions of the feasibility study, the smaller the number of uncertainties. The goal of conducting a feasibility study is two-fold: first, it allows the company to decide whether it wants to continue with the project or whether it wants to walk away from the project. Second, feasibility studies are typically a precursor for obtaining external funding or finding partners to co-develop the project and share the risk. They also allow the mining company to reach out to potential customers and start talking about offtake agreements for the minerals and potentially for some of the byproducts. Definitive feasibility studies are therefore also referred to as *bankable feasibility studies* as they provide all stakeholders with a detailed report of the project, the risks involved and the way the company intends to mitigate these risks. A bankable feasibility study is therefore a key milestone in the financing of the project. It can easily take companies two to three years to conclude such studies. Alongside these studies, companies often also opt to advance regulatory approvals (i.e., permitting), commence some early Front End Engineering & Design (FEED) work and order some of the long-lead items. With a bankable feasibility study and hopefully commitments from financiers, partners and potential customers, the company will be in a position to make a Final Investment Decision (FID). The FID is the point at which a mining company approves the project's development. If approved, the company will commence engineering, procurement, and construction (EPC) works.

From the moment a company discovers an ore body, it can take five to seven years to bring it to the point where it can start producing the minerals and metals that the company wants to sell. Add this period to the time that companies have spent on the exploration for ore bodies and one can start to see that it can easily take up to 10 years before a mine actually starts commercial operations. When commercial operations start, the mine will initially produce far below its designed maximum capacity (also referred to as *nameplate capacity*) as it can easily take another 18 to 24 months for the mine to ramp up its production. Typically, mines reach about 80% of their nameplate capacity.

Once all the ore that the mine can produce profitably has been recovered, reclamation begins to restore the land used by the mine and make it suitable for future use. Typically, mining companies need to reserve funds to pay for reclamation in the future. These expenses therefore need to be included in the feasibility study as part of the assessment of the financial robustness of the project.

In conclusion: mining is a complex activity that requires a combination of skilled people, capital, a friendly and stable jurisdiction and above all lots of patience. People who advocate an acceleration of the transition to a hydrocarbon free energy system need to realize this and start advocating the mining of critical minerals at the same time. It is the place where the supply chain starts.

3.2 Critical Minerals need processing: it's the purity, stupid!

As stated in my previous paper, minerals cannot be put into end-applications like EVs, smart phones and computers fresh from the mine.[9] They need to be chemically processed into compounds with the right purity levels before being useful to their end customers. A good example is supplying materials to EV manufacturers like Volkswagen and Tesla. In order to convince the consumer that EVs are as *safe, powerful and reliable* as their internal combustion engine (ICE) counterparts, these automakers need EVs with high performing, reliable lithium-ion batteries (LiBs). High performing LiBs require chemical compounds that contain different mixtures of high purity nickel sulphate, cobalt sulphate, manganese (sulphate), lithium compounds for the battery's cathode and graphite for the battery's anode. It is the EV OEM that dictates the quality requirements of these minerals before they can be used in lithium-ion batteries.[10] Low quality chemical compounds can cause damage to the electrodes of the batteries. These damages can lead to overheating of the battery which deteriorates the performance of the battery, ruins the experience of the user and in the most extreme case may even compromise the safety of the car.

Today, the industry refers to chemical compounds with high purity levels as chemical compounds with '3N' or even '4N' purity levels. The *N* stands for *Nine*. A 3N chemical compound is a chemical compound with a 99.9% purity level, meaning that there is a tolerance of only 0.01% impurity in the compound. 4N chemical compounds tolerate even less deviations (i.e., 0.001% of impurities). Any chemical processor will tell you that the issue with producing battery quality material is not so much the purity. It is the daunting task of *consistently* keeping the impurities within the tolerance levels.

In addition to the *3N* or *4N* purity requirements imposed by the EV OEMs, there is increasing pressure on the processors to improve their Environment, Social and Governance (ESG) policies and track record. As illustrated in Figure 1, most of the processing today occurs in China. Although China's government has recently started to crack down on illegal activities such as poor working conditions and the dumping of toxic chemicals by processors, there is still a long way to go before major European EV makers like Volkswagen and BMW (who both buy their processed material in China) will be able to certify that their respective supply chains meet the high European ESG standards.

The European EV OEMs are under pressure to meet the EU's stricter greenhouse gas emission standards.[11] Not complying with these standards leads to penalties under EU regulation. The strategy of European carmakers seems to be to sell more EVs, thereby bringing down the average emission levels of their fleet of cars sold (which currently is still very much dominated by conventional, GHG emitting cars). The price, range and safety of an EV are crucial considerations for people who buy an EV for the first time and these features need to be competitive against the features of a conventional car. All these features depend on the quality and performance of the battery. Which is why chemical compounds of battery minerals undergo a thorough *qualification*. This qualification refers to the process which processors need to go through in order for their material to be contracted by a battery (component) maker.

9 See: https://hcss.nl/report/batteries-require-battery-minerals-should-europe-ramp-up-its-efforts-to-secure-them/

10 EV OEM stands for *Electric Vehicle Original Equipment Manufacturer* and is another name for electric vehicle makers. This includes for instance the likes of VW and Tesla.

11 See for more information on the EU's new reduction targets: https://ec.europa.eu/clima/policies/strategies/2030_en

Qualification is a continuous process because minerals that are mined never have the exact same specification and chemical compounds never have the exact same purity levels. Initial qualification procedures for material can easily take up to nine months and is a continuous process that requires starting over and over again every time the processor brings in a new badge of material. One can imagine that the complexity of the task and responsibilities of those who operate a processing facility increases with the day as consumers (especially in European markets) become more demanding and ESG polices tighten. But the challenge around processing is not only about getting the quality right. It's also about making sure that the processing facilities have enough feedstock. EV OEMs and battery manufacturers require large volumes of processed lithium, nickel, manganese, cobalt, and graphite. A very simple 'back on the envelope' calculation can help to explain this.

Bloomberg New Energy Finance (BNEF) projects that by 2030 there will be 10 million EVs sold in Europe. Let's assume that the average EV will be powered by a 50kWh battery pack with a nickel, cobalt and manganese-based cathode and a graphite anode. Based on today's most commonly used cathode and anode chemistry Europe would require: 400,000 t of lithium, 100,000 t of cobalt, 300,000 t of nickel, 400,000 t of copper and 625,000 t of natural graphite.[12]

In theory, a processing facility can be realized within two to three years from its Final Investment Decision. In reality however, there are many challenges that can easily double that lead time. To start with, permitting in Europe is something that requires patience and perseverance. Secondly, tighter ESG regulation and the constant pressure to deliver higher purity chemical compounds increase the operational expenses (OPEX) of processing facilities, reducing the margins for those who operate them. Reducing margins is not very encouraging for processors and could potentially lead to a bottleneck in the critical minerals supply chain as processors refuse to expand their refining capacity. For Europe, such a scenario could be disastrous for its aspiration to build up its own, more regionalized supply chain.

12 1 kWh of energy storage in a battery with a NMC 523 cathode typically requires 0.8 kg of lithium, 0.2 kg of cobalt, 0.6 kg of nickel, 0.8 kg of copper and around 1.25 kg of graphite.

4. How critical is critical?

EVs and battery storage capacity will lead the demand for critical minerals due to their growing importance in curbing global greenhouse gas emissions. Lithium, nickel, cobalt, copper, graphite, manganese, and Rare Earth Elements (REE) will be crucial elements in the production of EVs and batteries. It is worth looking at some of the challenges that are expected in the supply chain of each respective mineral. This will help to put the more general numbers on supply and demand in a broader context. A mine may seem to have sufficient supply for the next decade, but it might not be the sort of supply that battery producers are looking for, still posing a risk to the supply chain of clean energy solutions.

4.1 Lithium

Demand for lithium-ion batteries (LiBs) is projected to grow at a compounded annual growth rate (CAGR) of 33% to reach just over 1 TWh by 2025, with the larger part of the demand growth coming from batteries for EVs as illustrated in *Table 1* below.[13] 1 TWh in battery capacity demand requires between 700,000 and 800,000 t of lithium carbonate equivalent (LCE).[14] Global production of LCE in 2020 was about 350,000 t meaning that in the next four years, production needs to double in order to meet the global demand in LiBs. A colossal challenge, especially for Europe, given that it does not produce any LCE on a commercial scale today.

Global Battery Demand (GWh)	2017	2018	2019	2020	2021E	2022E	2023E	2024E	2025E	CAGR (20-25E)
Power battery	**88**	**128**	**144**	**181**	**260**	**386**	**527**	**724**	**1,014**	41%
EV	85	123	132	167	244	367	503	690	968	42%
Small power battery	3	5	12	14	16	18	21	24	28	15%
Electric ships	-	-	0	0	0	1	3	10	18	146%
Consumer battery	**70**	**68**	**71**	**73**	**76**	**79**	**83**	**86**	**90**	4%
Smartphones	17	17	17	16	19	20	22	23	24	8%
Laptop & Tablet	18	19	20	21	21	21	21	22	22	1%
Other products	35	33	34	35	37	38	40	42	44	4%
EES Battery	**4**	**9**	**15**	**21**	**27**	**33**	**40**	**48**	**56**	21%
Total Global Battery Demand (Gwh)	**162**	**205**	**230**	**275**	**363**	**498**	**649**	**858**	**1,159**	**33%**

Table 1. Projected Global Battery Demand. Source: Macquarie Research, April 2021.

With 500 Gwh of battery capacity set as a target for 2030, Europe will need to secure around 400,000 t of LCEs per year.[15] These LCEs need to be processed, upgraded, or converted to battery grade LCEs before they can be used in the chemistries required for a LiB's cathode.

13 One TWh equals 1 billion kWh in energy storage capacity.

14 *Lithium Carbonate Equivalent* or *LCE* is the collective name for lithium chemical compounds used in cathodes. The rule of thumb used in the industry is that a typical EV requires 0.7 to 0.8 kg of LCE for 1 kWh of energy storage capacity.

15 Our 'back on the envelope' calculation assumed a 50 kWh batter pack for each EV sold in 2030. 10 million times 50kWh makes 500 million KWh which equals 500 Gigawatthours (GWh).

At the moment, Europe does not have any refining capacity to do this. This is concerning as most of the world's refining of lithium today takes place in China (with the Russian Federation as a distant second). Europe is very much exposed on the supply side and when looking at the global refining capacity it becomes clear that refining capacity will fall short drastically in the next two to three years (see *Figure 5*). It is therefore time that Europe starts to build its own capacity. Northvolt in Sweden is a nice example and will probably be Europe's first battery ecosystem to serve the European market. Many more projects like Northvolt are needed to meet the demand that's coming within the next decade. [16]

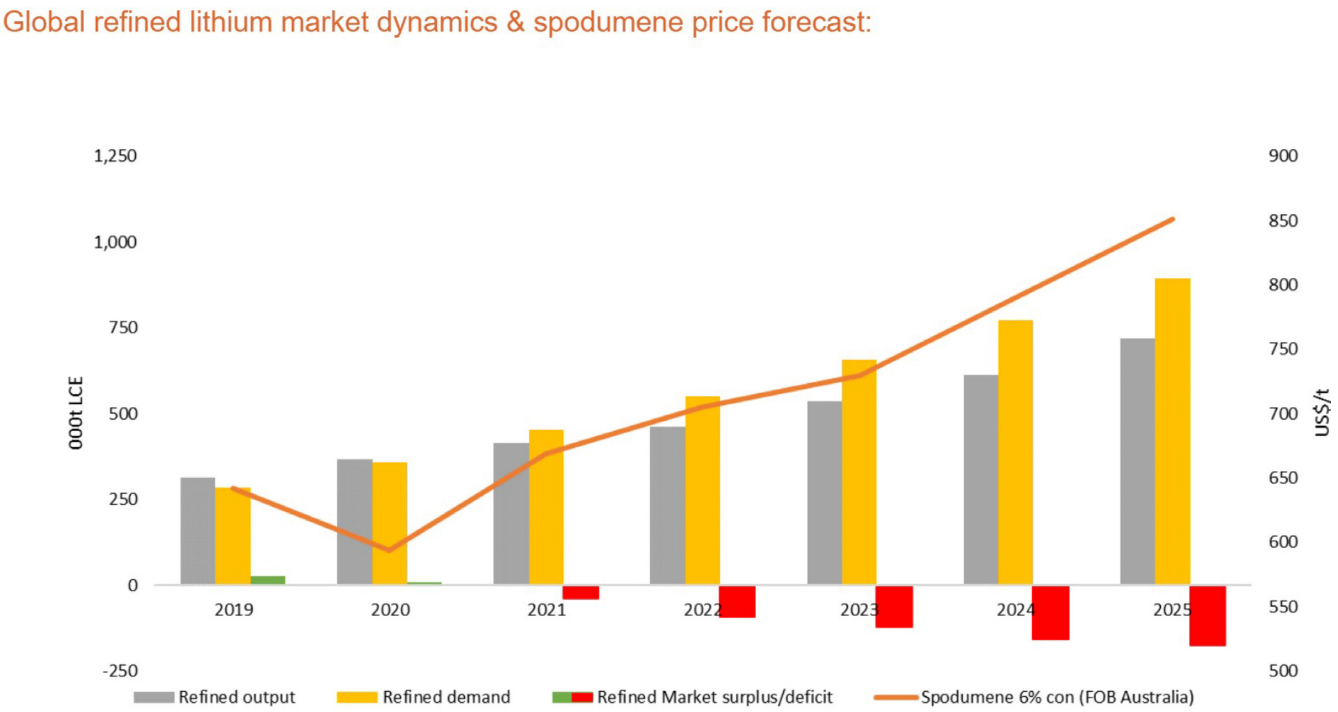


Figure 5. Global refining capacity is looking at larger deficits by 2025. Source: Benchmark Minerals Intelligence (2019).

4.2 Nickel

Automotive electrification is set to become the single-largest contributor to the growing demand for nickel in the next decade. Nickel has become a very important mineral for EVs due to the fact that EV makers prefer batteries with a higher energy density as this increases the power and range of the EV. Under the current battery technology, nickel and cobalt are the critical elements to keep high energy density batteries stable. As more battery producers and EV makers try to thrift the use of cobalt by replacing it with nickel or manganese, nickel's role in the energy storage sector is set to become more significant in the next decade. As with all other critical minerals, nickel cannot simply be extracted from ore and put into an end application. For lithium-ion batteries, nickel needs to be processed into *nickel sulphate* which is a high purity chemical compound. Today, producing nickel sulphate has its challenges. First, there is only a very limited number of feedstock types that is suited for its production. These include *Class 1* nickel and certain intermediate nickel products such as nickel matte, Mixed Sulphate

16 See: https://en.wikipedia.org/wiki/Northvolt

Precipitate (MSP) or Mixed Hydroxide Product (MHP).[17] Second, producing nickel sulphate from suitable intermediates often requires a processing method called *High Pressure Acid Leaching* (HPAL) which takes a toll on environment and communities as we have seen in Indonesia.[18]

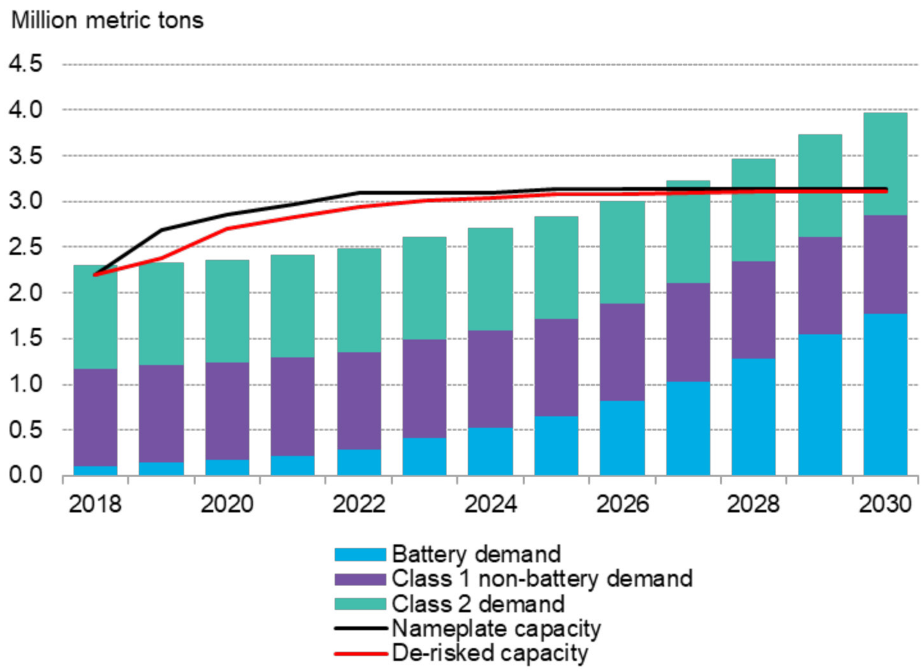


Figure 6. Projected demand development for nickel over the period 2020-2040. Source: BNEF (2021).

Despite the recent announcement of the world's biggest nickel producer *Tsingshan* that it has successfully produced nickel matte from Nickel Pig Iron (NPI), a *Class 2* nickel type, normally not suitable as feedstock for batteries, it remains to be seen how disruptive Tsingshan's process will be. First, it seems as if Tsingshan's new process requires a lot more energy which will not benefit the ESG footprint of the product. Second, producing nickel sulphate from *Class 1* nickel often comes with a nice by-product: cobalt. Having cobalt as a by-product improves the economics for nickel producers. Third and finally, the iron content in NPI can negatively impact the purity levels of the nickel sulphate output from Class 2 extraction. Cathode manufacturers tolerate only extremely low iron contents in the nickel sulphate they purchase. Until these challenges are resolved Class 1 and nickel intermediates remain the most important sources to feed the EV supply chain, posing some real challenges for the production of batteries and EVs.

17 Nickel products can be classified into two categories: *Class 1 nickel* which meets a purity standard of at least 99.8% of nickel metal, and *Class 2 nickel* which has a purity level of less then 99.8%.

18 HPAL stands for *High Pressure Acid Leaching*. As the name suggests, it's a process that requires two things that governments want to reduce: energy (and lots of it) to create high pressure and acids which leave a mark on communities and the environment in the form of hazardous tailings disposals. Indonesia recently banned deep sea tailing disposals.

4.3 **Cobalt**

Cobalt is widely used in alloys to make (engine) parts that require strength and durability at high temperatures. These alloys are also known as *super alloys* and are used in aerospace (jet engines) and the defence industry (rockets). Traditionally, super alloys have been the most important application for cobalt. However, over the past 20 years a new market has increased in significance for cobalt demand: batteries. From smartphones to high-end EVs, the batteries that power these machines have chemistries in which cobalt plays a prominent role as a stabilizer. Cobalt allows cathode makers to apply chemistries that increase the energy density of the battery without worrying too much about its chemical stability. The expectation is that by the end of the decade EV batteries will have become the primary application for cobalt with an annual demand for the mineral of at least 120,000 tonnes per year, an increase of more than 300% compared to the demand coming from EVs today.[19] However, a couple of factors limit the supply and use of cobalt. First, almost all cobalt produced today originates as a by-product from copper and nickel production, as illustrated in the simplified flowsheet in *Figure 7.* It takes hydrometallurgical and pyro metallurgical processes to separate cobalt from the nickel or copper produced, an energy intensive and ecologically draining production method. Second, as with lithium and nickel, cobalt needs further processing before it can be put into end-applications. Cobalt sulphate is the chemical used in cobalt-based batteries. China is the main producer of cobalt sulphate today. With 70% of the global cobalt refining capacity on its territory, China plays a pivotal role in the cobalt supply chain. And it will likely continue to do so in the next decade because the competition (Finland and Belgium in the EU and Canada in North America) is unlikely to catch up before the end of this decade. Which dovetails into the third and final limiting factor: the limited alternatives to today's suppliers. Today, the Democratic Republic of Congo (DRC) is by far the largest producer of cobalt and China is by far the largest exporter of cobalt sulphate. Although these countries play a critical role in the cobalt supply chain, they also have a complicated relationship with the EU. Combined with the concerns raised by human rights organizations around the poor working conditions in some of the smaller mines in the DRC, the appeal to thrift the use of cobalt is becoming stronger.

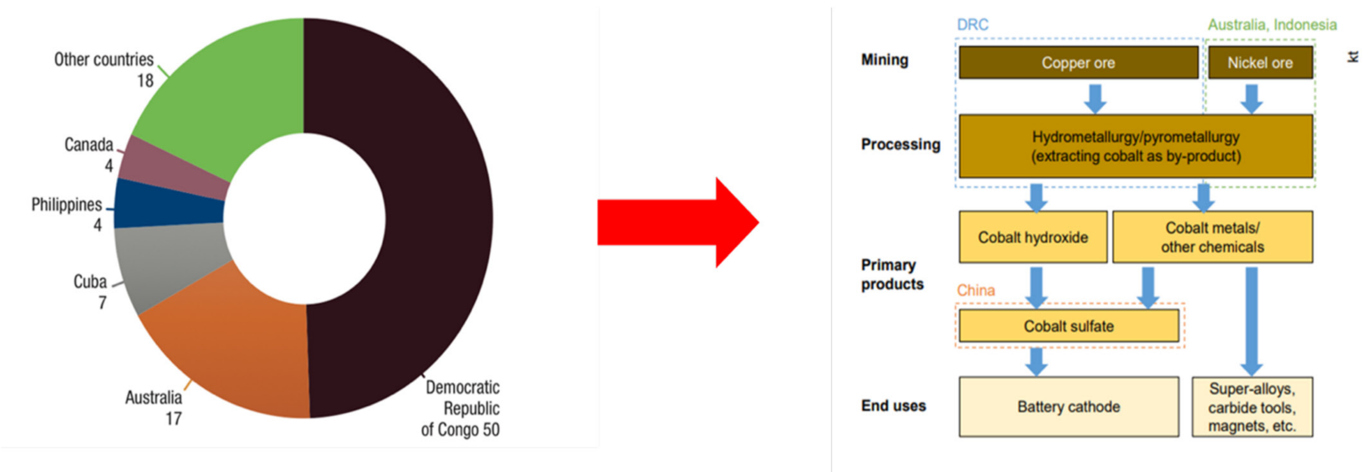


Figure 7. Top producers of cobalt combined with a simplified cobalt sulphate production flowsheet. Sources: UNCTAD (2019) and IEA (2021).

19 *Global Cobalt Outlook 2021-2030*, BNEF 24 May 2021

4.4 Copper

World copper consumption is projected to grow at an average 2.5% per year to reach almost 28 million tonnes by 2025 (see *Table 2* below). Copper's high conductivity and durability gives it a crucial role in many end applications. Although end-applications like EVs, lithium-ion batteries and renewable energy systems are becoming more important, the largest demand for copper today derives from electricity networks and applications in construction.[20] Demand from electricity networks is expected to get a boost as the need for fast charging stations will increase exponentially with more EVs coming on the roads. Fast chargers require thick, high amperage cables with copper being the preferred conductor. Currently, China consumes half of the world's copper. China's 14th *Five Year Plan* announced accelerated investments in high-speed rail, telecommunications, electrification of transport and renewable energy solutions like solar PV plants and wind parks.[21] All these end-applications need copper and lots of it. And with the trillion-dollar infrastructure plan announced by the Biden administration, demand from the United States is expected to increase as well. China's plan and the ambitions of President Biden can potentially create a very tight market in the coming years. Looking at Table 2, two things become clear: copper consumption has overtaken copper production from mines and refineries, explaining the recent price hikes for the metal.[22] Second, copper stock-piles will decrease in the coming years and by 2026 will reach volumes just enough to meet global consumption for only 1.7 weeks. Low stockpiles are a recipe for disaster. As we have seen in other markets (like LNG), having enough stock capacity is crucial to mitigate unex-pected market disruptions. At the same time there are a couple of structural challenges that the industry will have to overcome to significantly increase the copper production in the mid to long term. First, mine operators face declining ore grades. This might not be an issue in a high price environment but since mining projects are long term projects, prices would need to remain high (enough) to justify the higher cost of extracting smaller volumes of copper. Second, commer-cially viable copper deposits are geographically scarce. Currently, roughly 40% of primary copper production comes from Chili and Peru and this is likely to remain that way in the coming decade.[23] In addition, it's becoming increasingly more expensive to produce primary copper. The 20 or so projects that are under development in the world have a combined CAPEX of US$65 billion. The expected output from these projects is 3.3 million tonnes of additional primary production. Put that in the context of 2020 annual demand for copper (just over 25 million tonnes, see Table 2) and it becomes clear why the market is so nervous at the moment.

World	Unit	2020	2021^{f}	2022^{f}	2023^{z}	2024^{z}	2025^{z}	2026^{z}	CAGR^{r}
Production									
–mine	kt	20,761	22,131	23,238	24,307	24,525	24,648	24,771	3.0
–refined	kt	24,134	25,292	26,026	26,572	27,130	27,537	27,978	2.5
Consumption	kt	24,213	25,459	26,110	26,662	27,044	27,608	28,031	2.5
Closing stocks	kt	1 315	1 148	1 064	975	1 060	989	936	-5.5
–weeks of consumption		2.8	2.3	2.1	1.9	2.0	1.9	1.7	-7.8
Prices LME									
–nominal	US$/t	6,169	8,258	8,056	7,724	8,093	8,672	8,877	7.6
	USc/lb	280	375	365	350	367	393	403	7.6
–real^{b}	US$/t	6,292	8,258	7,891	7,395	7,575	7,936	7,942	4.8
	USc/lb	285	375	358	335	344	360	360	4.8

Table 2. Copper Outlook. Source: Office of the Chief Economist. Resources and Energy Quarterly, March 2021.

20 Office of the Chief Economist. Resources and Energy Quarterly. March 2021.

21 Ibid.

22 Reference to LME and spot prices, see Office of Chief Economist p.124

23 Benchmark Minerals Intelligence, Gianni Kovacevic. Q1 review 2021.

4.5 Graphite

Graphite has two characteristics that make it useful for a diverse set of end-applications. First, the honeycomb-like structure makes graphite flexible but strong at the same time. Second, the many layers of which graphite is made of offer a perfect spot to catch and release lithium ions that travel back and forth between a battery's positive electrode (i.e., the cathode) and a battery's negative electrode (the anode) whilst the battery charges and discharges. The first characteristic makes graphite very important in the manufacturing of steel, the second characteristic makes graphite the mineral of choice for lithium-ion batteries and their end-applications. As illustrated in the section on lithium demand, LiB capacity is set to grow to 1 TWh by 2025. Unless some superior technology becomes scalable before 2025, all these batteries will need graphite for their anodes. Although a deficit in the supply of natural graphite is not expected in the next few years, there are a couple of important factors that will affect the supply of graphite to batteries.

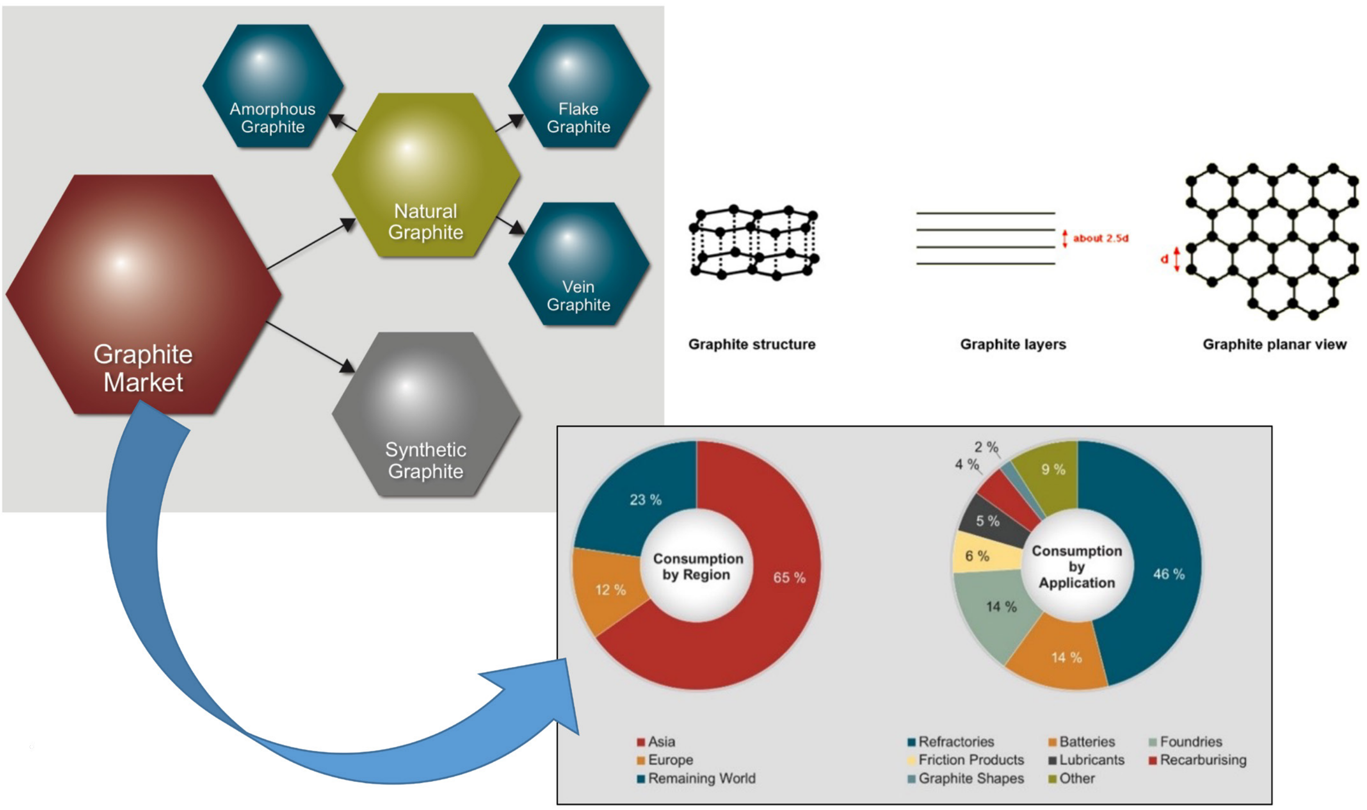


Figure 8 from left moving clockwise – (i) different graphite types in the market, (ii) graphite structure, (iii) graphite demand by region & application. Sources: Deutsche Rohstoffenagentur (2020) and Battery Materials Review (2020).

There are five different graphite types currently produced in the world (see *Figure 8* for an overview of the different graphite types). Today, the two primary graphite types used for lithium-ion batteries are: *flake graphite* and *synthetic graphite*. China is the world's biggest producer of synthetic graphite. Synthetic graphite is produced from by-products of oil refining (petroleum cokes for instance). The production of synthetic graphite is energy intensive, eco-unfriendly, lengthy, and capital intensive. Anode makers are using synthetic graphite because it has long held an edge over flake graphite by delivering superior performance in the anode. While China is the world's biggest producer of synthetic graphite, it is also the world's biggest consumer of it as the world's largest battery manufacturers are located in China. This will put a strain on the export of synthetic graphite which, due to its bad ESG footprint, also will have to deal with the scrutiny of EU environmental regulation.

Given the fact that the performance of flake graphite in anodes has improved over the recent years and the fact that the production of flake graphite is less capital intensive, quicker and cleaner than the production of synthetic graphite it is expected that there will be increased investments in natural (flake) graphite projects outside of China over the coming years. It then becomes very important for the EU to secure a foothold in these projects, and get involved in the development of these projects. This way, the EU will get graphite into its supply chains which is crucial if it wants to meet its ambitions with lithium-ion batteries. But securing access to natural graphite also means that the EU can secure enough natural graphite to meet demand in the other sectors that are of strategic importance such as steel production.

4.6 **Manganese**

As mentioned in the section on nickel, EV makers are actively seeking ways to increase the use of nickel and manganese in the cathode chemistries of lithium-ion batteries. *High Purity Electrolytic Manganese Sulphate Monohydrate* (HPMSM) and *High Purity Electrolytic Manganese Metal* (HPEMM) are used as feedstock for the type of batteries that Europe wants to use in high performing EVs. However, only 2% of global EMM production in 2019 was high purity with no selenium.[24] Selenium dioxide is added to manganese to remove impurities and helps to reduce the cost of refining manganese. However, selenium is harmful to the environment and is not suitable for manganese sulphate used in batteries. Selenium-free EMM is produced in China and South Africa. Manganese Metal Company, in South Africa, is the largest refiner of high purity selenium-free manganese with a production capacity of about 30,000t. Euro Manganese Inc. is building Europe's only selenium-free EMM refining facility in the Czech Republic, targeting the HPMSM market. The shift away from cobalt dominated cathodes will create an increased demand for both HPEMM and HPMSM. Here is the issue though: HPEMM and HPMSM have a limited feedstock. Today, it is only economically viable to extract high purity manganese from ores containing manganese carbonate. Only 2% of all manganese holding orebodies in the world are manganese carbonate ores. And there is literally only a handful of projects outside of China that have the potential to produce manganese carbonate.[25] With just one manganese refining project within its border the EU is dependent on the available refining capacity in countries like China.

4.7 **Rare Earth Elements (REE)**

Although it is common to refer to rare-earth elements (REEs) as one group of critical minerals, it is worth clarifying that REEs comprise of 17 different elements which can be classified in two types, depending on each element's weight and atomic number:

- **Mid- to heavy REEs (MHREEs).** These REEs appear in lower volumes per ton of rare-earth deposits, thereby making them more difficult to exploit economically. MHREEs are commonly used in glass and laser optics, metals and alloys, and semiconductors.
- **Light rare earth (LREEs).** LREEs are mainly used in permanent magnets and electronics, with neodymium being especially important for the production of permanent magnets.

24 Global Manganese Outlook 202o-2030, BNEF 18 December 2020.

25 Fernley, Matt, *Some Manganese is more equal than others*, Battery Minerals Review, 2 November 2020

Currently, permanent magnets are the biggest drivers behind the demand in REEs and this demand from permanent magnets manufacturers is set to increase over the next decades as illustrated in *Figure 9* below. Today, it is China that dominates the production of permanent magnets. About 90% of today's supply is controlled by China.[26]

Permanent magnets improve the performance of generators and electric motors. Both in terms of increased energy density and operational longevity. This last point is notably important for offshore wind farms as these sites are located at more distant sites and operate under tougher conditions. Having low maintenance and efficient generators keeps operating expenditures (OPEX) under control.[27] Wind turbines and EVs are two important drivers behind the demand for permanent magnets and given the crucial role these two-end application play in the transition to a cleaner energy system as illustrated earlier in Figure 2, it should not come as a surprise that the demand for permanent magnets will rise this decade. And, at least until there is a viable alternative to them, REEs will remain in the spotlight of manufacturers of wind turbines and EV makers.

But producing the REEs that are required to manufacture permanent magnets is not an easy thing. REEs occur in ores as a group, clustered together containing both LREEs and MHREEs. Some REEs, particularly MHREEs, occur in lower concentrations in deposits than others.

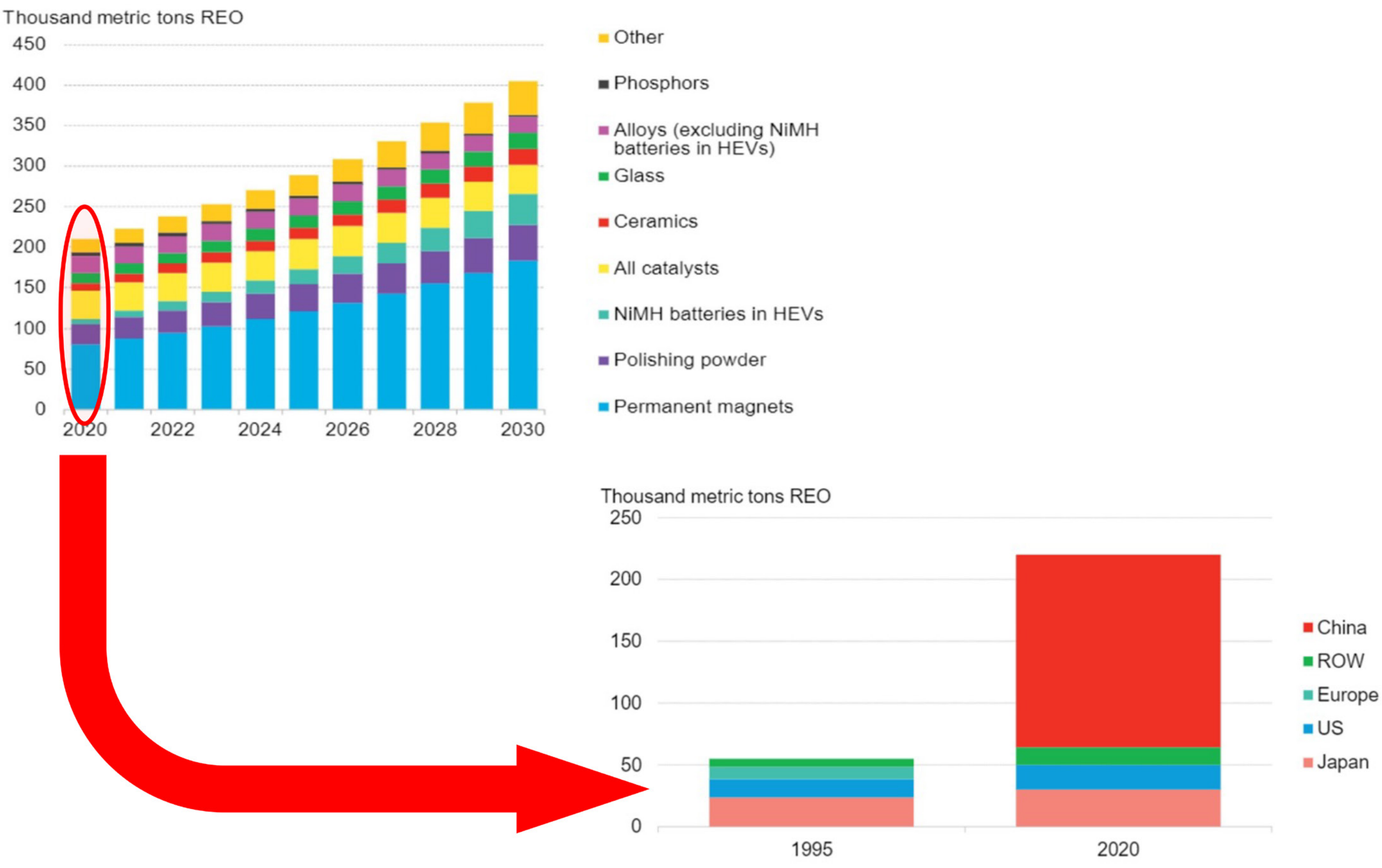


Figure 9 China based manufacturers of permanent magnets are the main drivers of increased demand for REEs. Sources: BNEF (2020) and US Congressional Library (2020).

26 See: https://hcss.nl/report/securing-critical-materials-for-critical-sectors-policy-options-for-the-netherlands-and-the-european-union/ and https://www.reuters.com/business/autos-transportation/china-frictions-steer-electric-automakers-away-rare-earth-magnets-2021-07-19/

27 '*Rare Earth Demand in Clean Energy*', BNEF 14 September 2020.

For example, to produce enough dysprosium and neodymium (two REEs that are very important for the production of permanent magnets), miners end up producing more of other, less critical elements like lanthanum and cerium as well. Much more in fact than needed. This oversupply pushes down the price of lanthanum and cerium even further. In the meantime, producers have to average the price and costs across the basket of REEs they produce for every ton of ore processed. If prices for lanthanum and cerium are too low, producers will not be incentivized to produce more volumes of REEs to obtain elements like neodymium and dysprosium that are in high demand. This phenomenon is referred to by the industry as 'the balance problem' and it has led to an oversupply of lanthanum and cerium in 2016. Since then, the industry has started to look for ways to solve the balance problem as it can seriously threaten the supply of the more valuable elements that are required for permanent magnets. Possible solutions that are explored today include: increasing the application options of less valuable REEs (i.e., look for new ways to make lanthanum useful) and increasing R&D efforts to use less or no REEs altogether. Although this last point seems like a 'no-brainer' one has to keep a couple of things in mind. First, it takes time to find or develop a substitute. Second, creating a technically viable substitute that can be produced in a scalable manner outside of a laboratory is equally challenging. Finally, and this is especially true for offshore wind projects, it is important to realize that a lot of planning, thought, calculations and financial modelling is put into the development of an offshore wind project. The planning and purchasing of crucial parts of a project is done years before a project is ready for commercial operation. Changing turbine types is not something that can be done overnight. Therefore, it is very likely that most of the projects for offshore wind generation that are in the pipeline today will still use turbines with direct-drive generators that contain permanent magnets as essential parts of their operation, even if there is a substitute for REEs tomorrow.

5. How does Europe become a player in the New Great Game?

The summary of the potential bottlenecks in the supply chain of each respective critical mineral will hopefully have made it clear(er) that all these critical minerals have one thing in common: they will be in high demand for the next decades and within the next five years each one of them will have their own supply chain challenges to deal with. Most of these challenges will be in the mining and processing parts of their respective supply chains. As explained in Chapter 1, setting up a mining project and bringing it to the point that it can effectively start producing minerals takes time, effort, patience, money, talent, and a healthy dose of luck. And setting up a processing facility requires talented people who excel at chemical engineering and understand what it takes to build the facilities that are so desperately needed to warrant a steady supply of high-quality chemical compounds. If the EU wants to become a significant player in the critical minerals supply chain, it will need to forge alliances. It will need to be inclusive. On many levels.

5.1 Include producing countries in the process of adding value to their minerals

Gone are the days when countries supplied raw materials to European corporations who would add value to these raw materials in Europe, upgrade them into intermediate and end products only to sell them back with higher margins to people and corporations in the country where these raw materials came from in the first place. Today, producers of minerals want to be part of a vertically integrated supply chain so that more value from that supply chain flows back to the home country. And this is not only something that third world countries wish for. Even a country like Australia, a developed nation with a skilled labour force, struggles to create more value for itself. In 2018, the country only captured 0.53% of the value generated in the entire lithium supply chain.[28] It is therefore crucial for European companies who wish to secure long-term supply of critical minerals to do their homework on the host country and understand the challenges and opportunities around possible vertical integration. Tesla is a great example of a corporation that understands this. Initially, Tesla entered Australia through its collaboration with mining companies to secure spodumene concentrate, a lithium bearing hard rock that is a crucial feedstock for the cathode active material going into the batteries that go into Tesla's high end EV models. A couple of years ago, during an interview with an

28 'The Lithium-ion Battery Value Chain: New Economic Opportunities for Australia', Future Smart Strategies (2018).

Australian media outlet, Elon Musk learned that parts of Australia regularly suffer from power outages. Musk swiftly acted on this challenge by installing what was then the world's largest stationary energy storage system (ESS) to support the grid.[29] Within 65 days the system was up and running, providing the grid with a useful back up and reducing future supply disruptions. This project, known as the *Tesla Hornsdale Power Reserve,* offers some valuable takeaways for European companies. First, doing a project like Hornsdale wins you the hearts and minds of local people because you serve a need and solve a structural problem. Second, Hornsdale showed that there is still a potential for establishing battery manufacturing facilities in Australia. Ever since Toyota closed its factory in 2017 there has not been any automotive manufacturing in Australia and many people started to question whether Australia could ever play a role in the lithium-ion battery supply chain given that the larger part of the demand for batteries comes from EV manufacturing. Hornsdale has shown that there is a need for batteries in Australia albeit not to serve the automotive industry but rather the market for stationary energy storage for grid support. European companies and institutions like EIT InnoEnergy can jointly invest in setting up R&D facilities or battery packing facilities in Australia. And when negotiating offtake agreements with Australian producers of spodumene concentrate, European companies can offer to jointly invest in adjacent processing facilities to convert that spodumene into lithium salts or even lithium hydroxide, the feedstock for cathodes.[30] A country that has mastered this type of 'resource diplomacy' over the past decades is Japan. Given the absence of domestic upstream capacity, Japan pursued securing its critical minerals supply chains through a combination of trade, investments in overseas mining projects, stockpiling, and R&D in substitutes and recycling technologies. The *Ministry of Economy, Trade and Industry* (METI) sets outs the policy framework while *Japan Oil, Gas and Metals National Corporation* (JOGMEC) is responsible for the execution by making investments abroad.[31] METI and JOGMEC work in close collaboration with Japanese corporations. Here, in the Indo-Pacific region, Japanese corporations are welcomed with open arms when they express an interest to be involved in energy related projects. The reason for this is that governments and companies across the Indo-Pacific region (including Australia) realize that bringing on board one of the Japanese *Keiretsus* like Toyota, means bringing in a knowledgeable partner with decades of (engineering and commercial) experience but also with access to other parts of the supply chain. This is due to the nature of Japanese Keiretsus who operate as an (almost) fully integrated conglomerate that include companies on the downstream side of the critical minerals supply chain and can use these critical minerals.[32]

The EU can adopt a similar approach. Today, spodumene concentrate from Australia is shipped to China where the real value is created by processing the spodumene into battery grade hydroxide which Chinese companies then sell under mega-contracts to EV makers like VW and BMW in Europe. Europe should offer resource rich countries like Australia a 'value add package' by giving the producing countries a chance to play a role downstream so they can capture more value out of the supply chain. The recently announced partnership with Canada (another resource rich nation) is a step in the right direction.[33]

29 Hornsdale Power Reserve is a 150MW/194MWh grid-connected energy storage system co-located with the Hornsdale Wind Farm in the Mid North region of South Australia.

30 Lithium salt is an intermediate chemical compound with a higher content of lithium metal. Because it is more concentrated, you need less volumes of it to produce battery grade lithium hydroxide which goes into battery cathodes. Less volumes means less shipping, storage and other transportation costs. Saving not only money but also significantly improving the CO2 footprint of the supply chain.

31 *Measures to Secure the Stable Supply of Rare Metals*, METI July 2007 in combination with the *New International Resource Strategy*, METI March 2020.

32 See also: https://en.wikipedia.org/wiki/Keiretsu

33 https://financialpost.com/news/economy/canada-eu-in-raw-materials-pact-to-cut-china-reliance

5.2 Secure the inflow of critical materials without disrupting international trade

At the launch of the *European Raw Material Alliance* Peter Altmaier, Germany's minister for Economic Affairs and Energy referred to the growing international protectionism and mentioned the importance of supporting EU companies and stakeholders active in the critical minerals supply chain.[34] State aid and government support is always a very sensitive subject, especially for countries who wish to play fair under the rules of international trade treaties and organizations like the WTO. Although there is a fine thread to walk here, it is worth taking a more long-term view on trade policies by including tools and incentives that are as little disruptive to international trade as possible. Securing a steady supply of critical minerals and chemical compounds is the ultimate goal. For instance, the EU could consider giving companies that wish to import essential chemical compounds temporary exemptions (so called *holidays*) on import duties and the VAT calculated over the value of such chemical compounds. By giving such exemptions the European market becomes a more attractive trade destination. As the numbers of *Macquirie Research* illustrate in Table 1, the demand for batteries is projected to grow at a compounded annual growth rate (CAGR) of 33% to reach just over 1 TWh by 2025, with the larger part of the demand growth coming from batteries for EVs.[35] 1 TWh in battery capacity demand requires between 700,000 and 800,000 t of lithium carbonate equivalent (LCE).[36] Global production of LCE in 2020 was just below 350,000 t meaning that in the next four years, production needs to double in order to meet the global demand in LiBs. A colossal challenge, given that Europe does not produce any LCE on a commercial scale today.[37] The EU will therefore need to import the larger part of its lithium (compounds) to meet the growing local demand for battery capacity. Levying import duties and VAT on lithium products may seem like a good plan to increase state revenues but in reality, it discourages traders, producers and EV makers to opt for the European route to market and process their product. Although China levies import duties and VAT of 15% over the value of imported lithium compounds, producers and traders of lithium compounds consider it worth the additional costs. This is due to the fact that, apart from the Russian Federation, there is no other country that has enough processing capacity.[38] Furthermore, with a market that is projected to reach 5 million EVs sold in 2025, China is a very attractive end market to sell and process critical minerals like lithium. By using incentives like a tax and import duty holiday, the EU will make the marketing of critical minerals to Europe more attractive. This has the potential to provide Europe with a steadier supply of critical minerals.

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34 Frederic Simon, *"Europe faces up to China's supremacy on raw materials."* Euractiv, 5 October, 2020, https://en.euractiv.eu/wp-content/uploads/sites/2/special-report/Critical-raw-materials-EUMICON-Special-Report-2020-1.pdf

35 '*Lithium Market Outlook*', Macquirie Research 12 April 2021. One TWh equals 1 billion kWh in energy storage capacity.

36 *Lithium Carbonate Equivalent* or *LCE* is the collective name for lithium chemical compounds used in cathodes of LiBs. The rule of thumb used in the industry is that a typical EV requires 0.7 to 0.8 kg of LCE for 1 kWh of energy storage capacity.

37 'tpa of LCE' stands for tonnes per annum of *Lithium Carbonate Equivalent*. The most common way to trade lithium is in the form of LCEs.

38 15% may not seem like a lot but under today's prices for technical grade LCEs from Chili or Argentina a 15% add on can easily mean another US$1000 / tonnes in additional costs if the product needs further processing in China to meet the requirements of lithium-ion battery producers.

5.3 Include manufacturers of downstream end-applications in mining and processing

Europe should encourage the creation of vertically integrated partnerships. The EU has made some good steps in creating associations and other umbrella organizations for different players in the critical minerals supply chain. Organizations like the *European Battery Alliance* and the *European Raw Material Alliance* offer a platform for players from different parts of the critical minerals supply chains to meet each other. Although a good start, more can be done to encourage the involvement from big players that dominate the supply chain downstream, in the mining and processing part (upstream). Bringing the downstream and upstream parts of the supply chain together at an early stage has a couple of benefits for both sides. First, an early involvement of EV makers and battery makers in the processing of critical minerals will help the companies that operate the processing facilities to tune their processes and products early on in such a way that the chemical compounds that come out of their facilities meet the technical specifications that the end-applications require. The sooner a processing facility can be tuned to meet the technical specifications of the end customer, the better. Changing processing flowsheet afterwards is more expensive. Second, early staged collaboration paves the way for sharing (financial) resources. Junior mining companies for instance require investors to fund them through the early (and riskier) stages of exploration and development. Established EV makers and battery makers like LG or Panasonic can support these junior mining companies by taking a share at the level of the mining project, an equity share in the company directly or by offering credit facilities in return for future offtake of the minerals produced. Finally, as ESG requirements become more important, end-applications like EVs will be scrutinized more and more on their ESG track record and footprint. And it will not just be the downstream part that will be subjected to the scrutiny of government agencies, banks, and investment funds. It will be the product's ESG footprint over the *entire* supply chain, including the mining and processing part of the supply chain. By including the downstream producers in operations upstream from an early stage, companies upstream will be in a position to adapt their flowsheet and operations at an early stage to remain compliant to ESG requirements. This will expand the marketability of their product. *Figure 10* illustrates the idea of an early involvement of end users in the parts of the critical minerals supply chain that are more upstream. The illustration shows the case for lithium, but the same principle applies to the other critical minerals.

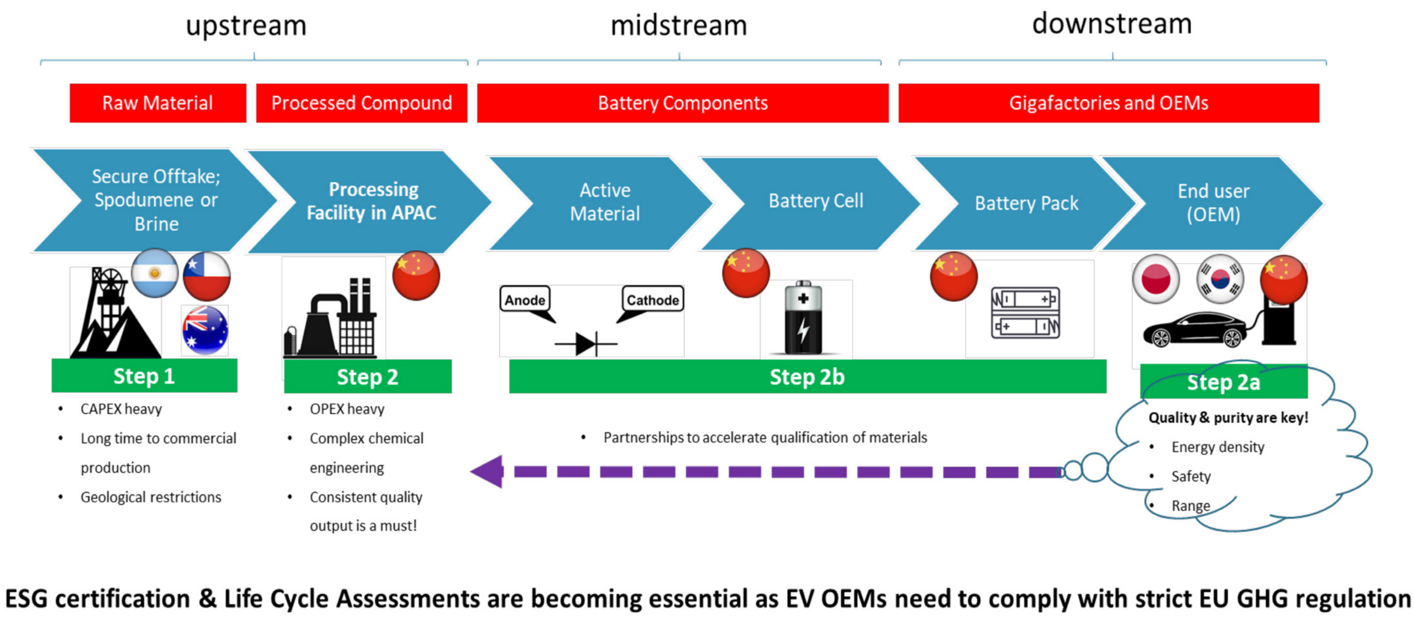

Figure 10 The benefits of earlier involvement of end users in upstream projects. Source: MRG Intelligence, 2020.

5.4 Include foreign expertise to set up your supply chain (but keep ownership and control of it)

The expertise that Chinese companies have built up over the past 40 years in producing high purity chemical compounds on an industrial scale is unprecedented. It becomes painfully clear that Europe not only needs to secure raw materials but also needs to secure the talent to process the raw materials. *Knowledge is power* so if Europe really wants to become less dependent on foreign powers, it needs to ramp up its investments in R&D and skilled labour. The establishment of collaborative institutions like the *European Institute of Innovation and Technology* (EIT) is very encouraging in this sense. The EIT forms the backbone of *EIT InnoEnergy*, a platform that has the potential to create a true European ecosystem in which academics, corporations, start-ups, and governments work together to realize a more region-alized critical minerals supply chain in Europe. However, the reality is that it will take a couple of years before Europe fully benefits from these initiatives. In the meantime, to be pragmatic, Europe should be open to source the technology and skills it needs from abroad. Including from Chinese companies that offer to implement their technology and know-how in mining and processing. There is nothing wrong with a Chinese company building a processing facility in Europe, with a European company keeping ownership and control over it. Europeans have had a tendency to point to East-Asian nations and corporations as unsophisticated *copy cats* of Western innovations. The arguments that are used against Chinese companies today are the same used against the Japanese companies in the 1980s. But nothing prevents Europe to be as pragmatic as East-Asians and copy *their* methods today. The Chinese government spurred the development of its own supply chain for critical minerals in mainland China through the import of advanced technologies and machinery and by encouraging joint ventures with foreign companies to accelerate the production of high quality products downstream.

All while keeping the door closed for foreign ownership in the mining sector.[39] Today, the supply chain for critical minerals is a space very much dominated by technology from East-Asian companies. Korean conglomerates like SK Innovation and LG lead the way in the development and production of batteries with higher energy density while CATL, a Chinese battery producer, is the world's largest producer of cobalt free lithium-ion batteries and only one of the three battery suppliers to Tesla (the other two being the Japanese company Panasonic and the Korean LG Energy Solutions). Europe does not have to reinvent the wheel. As these companies are keen to expand their business overseas and access growing markets like the European one, it offers EU members a chance to negotiate similar investment terms and structures as the Chinese did when they started to build their own critical minerals supply chain almost 40 years ago. In the meantime, each EU member needs to ask itself whether it is doing enough to get more young people excited for a role in chemical engineering, geophysics, geology or environmental engineering. The combination of nourishing talented young people in Europe and sharing knowledge between Europe's government institutions, academics and corporations will be crucial in Europe's quest to set up a more independent and regionalized supply chain for critical minerals.

5.5 Include pension funds in the financing of mining and processing projects

At more than 1400 billion Euro, the capital managed by Dutch pension funds is almost twice the value of the Dutch gross domestic product.[40] Dutch pension funds seek an almost predictable return on their assets under management. However, with ECB interest rates at a historical low pension funds need to find more creative ways to generate attractive yields over a long period of time to fulfil their (equally long term) obligations vis-à-vis pensioners. The time of investing all your funds into treasury bonds has long gone. With a clear commitment of the EU to pursuit the goals of CoP21, the transition to a cleaner energy system is almost guaranteed. Mounting pressure on European automotive makers to reduce the average GHG emissions from the fleet of cars sold in Europe forces these car makers to invest in the production of EVs, which in turn guarantees the demand that battery producers seek. With all big European car makers pledging to produce more EVs in the next decade, Europe is looking at more than 500 Gwh of battery capacity by 2030.[41] That in itself should give some comfort to European pension funds that there will be a significant demand for critical minerals and their chemical compounds over the next decades.

It is absolutely correct that mining is a high-risk business with many uncertainties. However, as explained in Chapter 1, a mining project has different stages and as the project matures the project gets de-risked. Pension funds could take a portfolio approach to mining, investing not just in one project, region, company, or critical mineral but in several. Making investments in companies or projects that integrate upstream mining with the processing of the critical minerals they produce, can provide even more attractive returns since there is a secured feedstock for the processing facility.

39 Yujia He, "*Re-Control the Market for Strategic Power: China's Regulation of its Rare Earth Industry*", (Ph.D. dissertation, Georgia Institute of Technology, 2016), p.175, https://smartech.gatech.edu/bitstream/handle/1853/58561/HE-DISSERTATION-2016.pdf

40 https://www.pensioenfederatie.nl/website/the-dutch-pension-system-highlights-and-characteristics

41 See Figure 5.

And there is an upside for the mining industry and processors too. Pension funds pay a lot of attention to the ESG policies of the companies they invest in. Having a pension fund as an investor, with potentially a representative of a pension fund in the board of directors, means increased scrutiny over the ESG behaviour of mining companies and processors. This is something that will improve the ESG standards in the critical minerals supply chain and, as in the case of an early involvement of EV makers in the upstream parts of the supply chain, can prevent painful corrections of operating standards afterwards.

5.6 Include the public: a campaign to highlight the importance of critical minerals

There is tremendous pressure on (supra) national governments to accelerate the transition to a cleaner energy system. At the same time, the public doesn't always seem to realize what is required to make this happen. Everything in this world comes at a price. Using solar PV panels, rolling out EV charging stations or even replacing your petrol fuelled car by an EV, all these things require minerals that need to be dug up and processed. Are we, as a society, willing to pay that price? If we wish to accelerate the transition to a clean energy system, then we should accept that such a transition will never be perfect and requires new investments in the mining and processing of critical minerals. The only way to make this choice very clear to the public is through a permanent campaign that raises awareness for the significant role that these minerals play in the energy transition but also the geopolitical elements of the need to create a more robust (and regionalized) supply chain. We have seen in the US that having a President drive a F150 *Lightning* and making the case for EVs and an independent critical minerals supply chain has had a positive effect on the public's attention for electric vehicles and the need to start producing more critical minerals at home.[42]

People in Europe are blessed to live in constitutional states that function properly (most of the time). This means that citizens can express themselves freely and have a right to participate in the regulatory and permitting procedures that govern the development of mining and processing projects in their vicinity. Europe has a completely different political system than China and it should cherish that. But if it wants to keep up with China's pace in developing its own supply chain for critical minerals, it needs to get the public engaged into the subject of critical minerals. Since Europe does not have an autocratic regime to dictate state policies and determine how these get executed, one of the few ways to accelerate the execution of critical minerals policies is to make sure you have the support of the public.

There are very few people in Europe today that would make an issue out of the fact that the agricultural sector is one of the biggest beneficiaries of EU subsidies and other government support mechanisms. It is clear that without these support mechanisms, prices for meat and dairy products would increase sharply and perhaps even make these products scarce. There seems to be a 'social contract' between governments, the agricultural sector and the public that local food production is worth being protected. If we can agree on such a social contract for the production and supply of food, should we perhaps consider doing the same for the production and supply of critical minerals?

42 President Joe Biden's test drive of Ford's full EV F150 truck was an expression of support for EVs made in the USA, by US companies. Biden used the occasion to advocate his US$ 1 trillion infrastructure plan which includes much needed investments in the US critical minerals supply chain.

Conclusion

Europe has a long way to go in catching up and keeping up with the current leaders in the critical minerals supply chain. Although lagging, Europe is in a position to craft alliances with nations who play or can play a pivotal role in the critical minerals supply chain. Countries like Australia play a key role in Europe's supply chain as it has the natural resources to produce and supply (part of) the critical minerals that Europe needs. Although there is strong competition from Chinese companies in securing the natural resources from countries like Australia, Europe should not forget that it has strong cultural ties with a lot of the resource rich countries. This is something to build on. But Europe should also look at how other economic powers play the game and learn from it.

Europe can follow the example of Japanese *Keiretsus* like Toyota and Honda who are welcomed with open arms in projects because they open markets for the producers of critical minerals and offer a way to capture more value out of the critical minerals supply chain, especially downstream.

As consumers of downstream applications like EVs become more demanding, quality and qualification of critical minerals and their chemical compounds become ever more important. Europe's aspiration to become a key player in the critical mineral supply chain can only be realized if it secures not only the raw materials but also the processing and refining capacity to upgrade raw materials into quality products. While building up its knowledge and R&D infrastructure, it should not shy away from leveraging the expertise and experience that East-Asian countries like China, South-Korea and Japan have built up over the past decades. The clean energy space is very much an East-Asian story. Some of the biggest East-Asian companies have a leading role in the critical minerals supply chain and are leaders in developing new technology for downstream applications. Most of these companies want to expand their business activities overseas and deploy their technology and production techniques to other parts of the world. As long as Europe and European companies remain ownership and control over their projects and resources, leveraging on existing technology of others may not be a bad thing to do. It allows Europe to push its clean energy agenda forward as it lays a strong foundation for its own knowledge infrastructure on which it can build in the future.

Each of the critical minerals has to deal with bottlenecks in their respective supply chain. None of them will be spared. Tackling these challenges and securing a steady and sufficient supply of critical minerals requires a comprehensive, integral approach in which Europe pulls together all the funds, talent, and expertise it has at its availability. This requires an inclusive approach in which players downstream engage early with players and projects upstream to help optimize production processes, assuring a steady supply of high-quality products to be used in end-applications. Europe has all the elements to undertake such a comprehensive, inclusive approach and to set-up its own critical minerals supply chain. It just needs a more coordinated effort and quicker response time to ensure it does not get locked in by the aspirations of the other players in this *New Great Game*.

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