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Battery supply chain – Roles for Europe and Finland?

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The global battery and electric vehicle (EV) supply chain is at a crossroads. With 100s of forthcoming EV premieres by major manufacturers in 2020–2025, the phenomenon is about to go mainstream. Optimistic scenarios suggest that, by 2030, every second new passenger car sold globally could be an EV. Even a more realistic EV share of one-fifth suggests that the global automotive industry is about to undergo its most significant techno-economic transition yet.

The automotive industry is strategically important in many developed countries and the sector has political clout even beyond its economic significance. When it comes to geopolitics, the global battery/EV supply chain looks quite different from that of conventional fossil-burning cars.

Since 2015, China has been executing its *Made in China 2025* industrial strategy. Consequently, it is currently the world's leading battery/EV market in terms of both volume and sophistication, it has the lowest EV manufacturing costs (going beyond just labor costs), and it has the fastest learning -by-doing (in a domain that is yet to discover its best practices and dominant designs).

The EU has been pro-active in meeting the Chinese challenge. Its collaborative platform, Battery Alliance, was launched in 2017. Battery-related *Important Projects of Common European Interest* (IPCEI) are currently under development. The EU's new strategy is due at the end of 2019.

Cobalt is the most critical raw material in the battery/EV supply chain. The Democratic Republic of the Congo accounts for 70% of the current global supply, whereas Finland accounts for 2% and is the only provider within the EU. Furthermore, Terrafame has the largest cobalt reserves globally and Freeport Cobalt in Kokkola represents 10% of cobalt's global refining capacity. Finland also has certain strengths in the battery/EV supply chain beyond cobalt (in raw materials, e.g., in nickel; in other parts of the supply chain, e.g., in recycling), but realizing them requires both determined political actions and investments.

Introduction

Decarbonizing transportation is one of the most important ways of addressing climate change. Indeed, during the past decade, we have witnessed dramatic annual growth rates in both electric vehicles (EVs) and in batteries embodied in them.[1]

The increasing prevalence of EVs is the primary driver of the demand for batteries. Thus, even though the primary focus of this insight is on batteries, we discuss EVs as well. We map out the global battery/EV supply chain and debate Europe's and Finland's future roles in it.

EVs range from mild hybrids, perhaps only storing coasting/braking energy and otherwise relying on fossil-burning engines, to fully electrified ones (i.e., battery EVs, BEVs; an intermediate case being plug-in hybrid EVs, PHEVs). Toyota Prius was launched in 1997; the first Tesla Roadster was delivered to customers in 2008. Despite the rapid growth in the past decade, EVs are only now – in 2019/2020 – about to enter mainstream, but the market is expected to explode in the coming decade, as Exhibit 1 indicates.

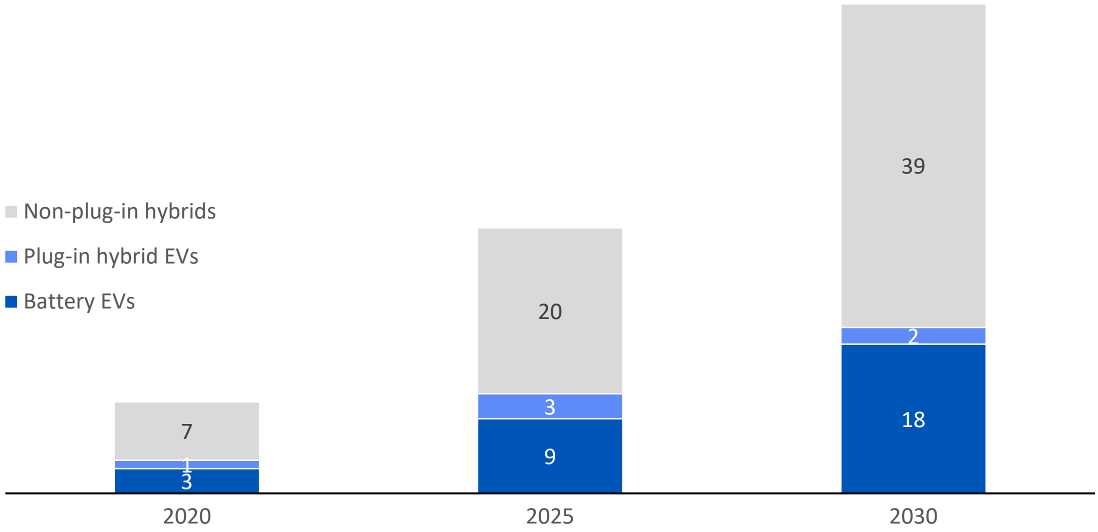

Exhibit 1: EVs' share of all vehicle sales worldwide in 2020, 2025, and 2030, by segment, %.
Source: JP Morgan Chase 2018, Driving into 2025 – The future of electric vehicles.

In 2020–2025, all major car manufacturers will introduce EVs across most segments, which increases availability and pushes down the prices of EVs closer to those of conventional internal-combustion engine vehicles. As a result, "true" EVs, i.e., BEVs and PHEVs, will account for some one-fifth – and according to some estimates as many as one half (which we find implausible) – by 2030 (Exhibit 1). Even the lower estimate would nevertheless suggest that, in the coming decade, we would witness the most significant economic and technical transition in the history of the car industry.

Future projections are uncertain, but virtually all available estimates point towards rapid growth in the coming years and decades. The International Energy Agency predicts that by 2025 the global EV market will be worth about $570bn, of which China's market share would be over 60%.

The main accelerator of EV demand is the expected decrease in price, which is to a large extent driven by battery prices, as currently about 40% of the EV production costs are attributed to batteries. Technological development and increased activities in all parts of the battery supply chain have already dramatically decreased battery pack costs (Exhibit 2), and this development is not expected to cease any time soon.

[1] We primarily consider passenger vehicles and thus, despite their importance, we do not discuss busses, trucks and other commercial vehicles, e-scooters, or air/sea transport. Moreover, when discussing batteries, we assume that the current mainstream battery chemistry is dominant also in the future, although we acknowledge that circumstances change as technology advances.

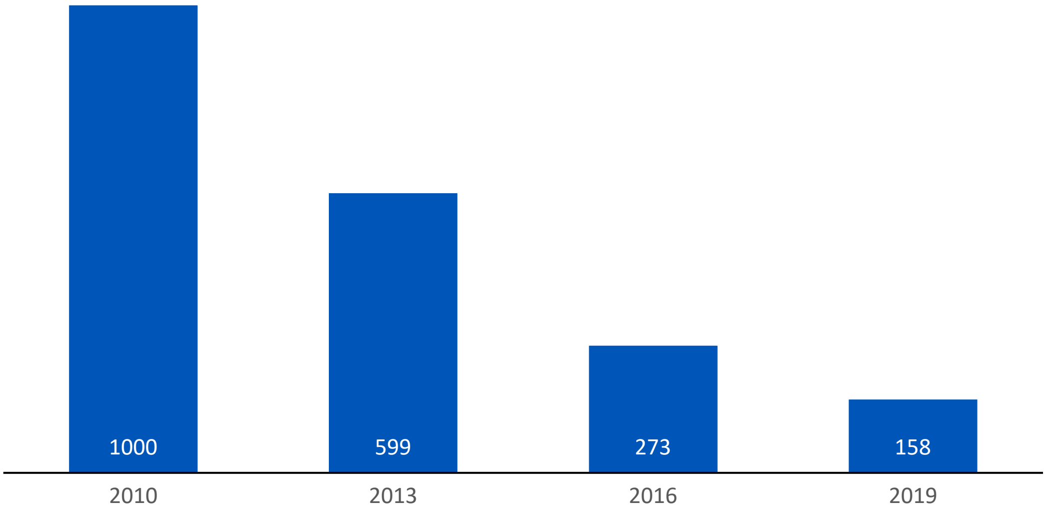

Exhibit 2: The cost of lithium-ion battery pack, $ per kilowatt hours.
Source: Bloomberg New Energy Finance, October 2018.

There have been global initiatives to develop all phases of the battery/EV supply chain. So far, certain phases are concentrated to specific geographical areas, often China. The European Union has launched its own efforts to command aspects of this strategically important domain.

Finland not only has the largest lithium and cobalt reserves in Europe but also a wide diversity of expertise. It is also a significant producer of nickel. It could viably nurture the largest battery ecosystem in Europe with considerable global clout. This does, however, call for massive investments and necessitates significant public sector involvement.

Global supply chain of lithium-ion batteries

Lithium-ion have emerged as the commercial favored and the fastest-growing alternative for batteries in EVs.[2] The raw material intensity and costs of batteries – and usefulness in non-stationary applications – depend on their energy density, which has been constantly improving at a rate of approximately 10% per annum.[3] Battery production has grown 3- to 6-fold in the past 5 years and is expected to grow another 3- to 6-fold in the coming 5 years, which is putting considerable demands on the whole supply chain.[4]

A lithium-ion battery cell consists of four main parts:[5]
– *Anode*, the positive electrode, mostly consisting of graphite (either natural or manmade).
– *Cathode*, the negative electrode, primarily composed of lithium, cobalt, nickel, and manganese.
– *Electrolyte* (liquid,)[6] in which lithium ions flow between anode and cathode during charge/discharge.
– *Separator*, which keeps anode and cathode apart and stabilizes the cell.

[2] Battery materials and structures are under intense scientific inquiry. The observations in this insight are conditional on the currently most applied technologies. Also, commercial aspects of battery use are conditional on scientific advances, as are geopolitical implications.

[3] https://www.economist.com/briefing/2017/08/12/after-electric-cars-what-more-will-it-take-for-batteries-to-change-the-face-of-energy

[4] It is estimated that the combined market for lithium-ion batteries will grow at an annual compound rate of over 16%, reaching 92 billion by 2024 (https://www.marketresearchengine.com/lithium-ion-battery-market1). Moreover, demand is expected to grow globally to 700 GWh during the same period and could reach even 4,000 GWh by 2040 – compared to under 80 GWh today (Benchmark Mineral Intelligence, October 2018).

[5] Devices that accept, store, and release electricity via electrochemical reactions are considered batteries. Primary single-use batteries are found in flashlights and similar small devices. However, here we consider *secondary rechargeable batteries used in relatively large scale of applications*. Underneath our intended scale are small batteries, e.g., in mobile phones and in increasing range of "internet of things" devices (these batteries, especially at the smaller end, warrant their own discussion, as a growing mass of sensors that are not necessarily cost-efficiently reachable for recharging may require re-thinking of both power sources and energy use); above our intended range is bulk power management in electricity grids, which – at this point in time – is taken care of by a few non-battery solutions (primarily pumped hydro). As for the application domain, we mostly consider the application of *lithium-ion batteries in "true" EVs*, i.e., BEVs and PHEVs.

[6] Or, down the road, a solid one, although we do not discuss these scientific advances here.

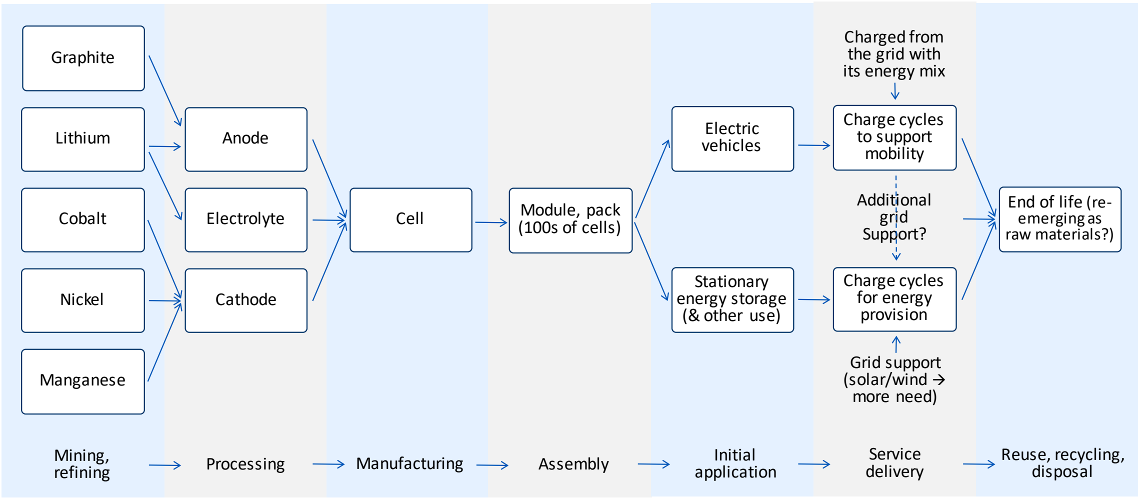

Exhibit 3: An illustration of the global lithium-ion battery/EV supply chain.
Source: The authors.

Exhibit 3 provides an illustration of the global lithium-ion battery/EV supply chain, starting from the aforementioned raw materials and basic elements of a battery cell.

Cobalt

Cobalt is a crucial ingredient of current lithium-ion batteries. Today, about 140,000 tons of cobalt is mined annually; about 90% is this supply is a by-product of copper or nickel mining.

The Democratic Republic of the *Congo* accounts for 70% of the global cobalt mining. Only 2% is mined in the EU – *all in Finland* –, even though known deposits exist and are under development in, e.g., Spain and in Sweden. By 2030, Europe is estimated to supply some 6% of its overall cobalt consumption.[7]

In Finland, cobalt is mined in Talvivaara, Kylylahti, and Kevitsa; Sakatti is under development. The Talvivaara mine has the largest cobalt reserves in the world (about 300,000 tons). [8]

Some 60% of the current capacity to refine cobalt ore is in China. Furthermore, about 80% of refining capacity under construction is in China. The largest refinery outside China is Freeport Cobalt in Kokkola, Finland, which accounts for some 10% of current global capacity.[9]

Cobalt has been classified as a critical raw material by European Commission due to its high importance and supply risk.[10] The Joint Research Centre of the European Commission estimates that – despite efforts to: boost the supply of "virgin" cobalt, recycling and reuse, technological advance (and thus reduced use), and substitution (the replacement of cobalt by other materials) – the supply of cobalt will significantly outstrip demand by 2030 (Exhibit 4) making , e.g., the projection in Exhibit 1 unattainable.

Cobalt prices have also shown to be volatile, which causes uncertainty in the short run. Additionally, there is a considerable country risk concerning Congo and its cobalt supply.

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[7] Alves Dias, P., Blagoeva, D., Pavel, C., & Arvanitidis, N. (2018). Cobalt: demand-supply balances in the transition to electric mobility. European Commission, Joint Research Centre, EUR-Scientific and Technical Research Reports. Publications Office of the European Union.

[8] Adolfsson-Tallqvist et al. (2019). Final Report: Batteries from Finland. Business Finland. https://www.businessfinland.fi/globalassets/finnish-customers/news/news/2019/batteries-from-finland-report_final-report_28.3.2019.pdf

[9] Alves Dias et al. (2018).

[10] McKinsey & Company (2018). *Lithium and cobalt: a tale of two commodities.*

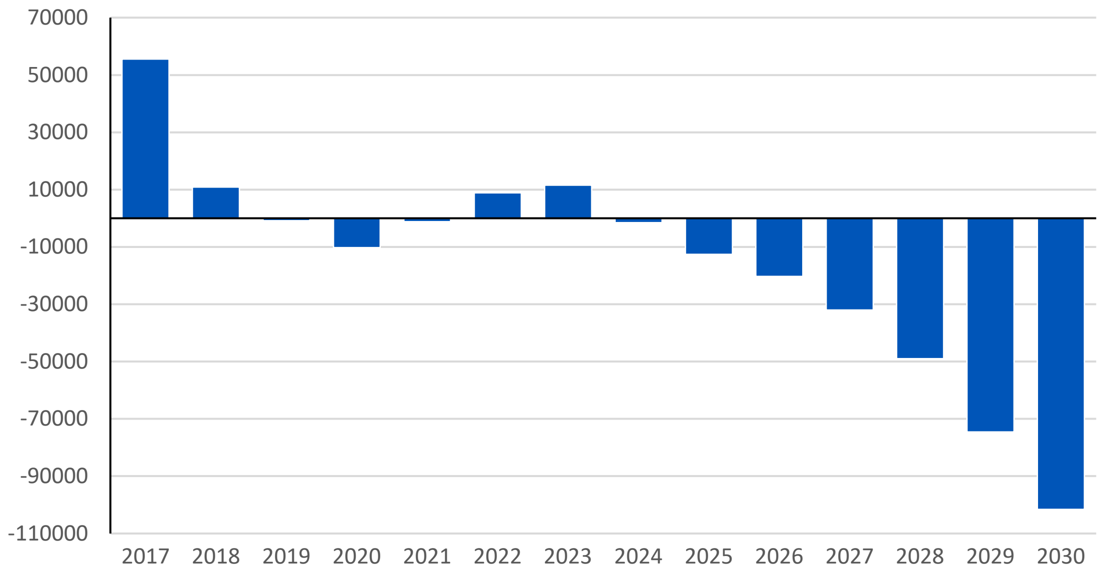

Exhibit 4: The *difference* between global cobalt *supply* (mining+recycling) and *demand* (after substitution), in tons of cobalt (if negative, there is a deficit, i.e., the demand is not met by available supply).
Source: Alves Dias, Blagoeva, Pavel & Arvanitidis (2018). European Commission, Joint Research Centre.

Other battery minerals

When it comes to lithium, practical challenges are similar to – albeit less severe –cobalt. China, Australia and Chile account for about 85% of the global lithium mining; China alone accounts for about 55% of refining. While there is currently no lithium mining in Finland, Keliber has plans for both mining and refining in the country.

Nickel is the most important metal in the cathode and its demand is expected to increase also due to substitution from cobalt. While nickel is a crucial mineral, the situation of its supply is better than that of cobalt. Terrafame in Finland mines nickel (and cobalt) and has plans for further refinement of nickel and cobalt needed for EV batteries.[11]

Mining and refining of graphite are heavily concentrated in China, but there are multiple graphite mines in Finland too. However, the demand for high-level purity artificial graphite, which is developed in Finland among other countries, is expected to increase in the future.

There is a wide range of other raw materials needed for lithium-ion batteries, such as manganese, aluminum and copper, but they are less critical in the supply chain and are thus not discussed here.[12]

Later stages of the battery supply chain

After raw material mining and refinement, battery chemical processing and battery cell manufacturing represent the next phases of the supply chain. These two stages are mostly executed in massive-scale centralized operations.

China accounts for about 62% of the world's current battery cell manufacturing capacity; with 14%, Europe is not insignificant.[13] Despite efforts to persuade foreign investors to open facilities in the country, Finland does not currently host cell manufacturing facilities. The Swedish Northvolt is expected to start cell production in 2020, which is to be ramped up to 32 GWh by 2023, making it the largest in Europe.[14]

Battery module and pack assembly is primarily done by EV manufacturers or by their subcontractors via a process that is less scale-intensive than battery cell production. In Finland, Valmet Automotive assembles

[11] Terrafame (2017). The capacity of the plant would be about 150,000 tons of nickel sulphate and 5,000 tonnes of cobalt sulphate annually, making Terrafame one of the most significant nickel sulphate producers in the world.

[12] Adolfsson-Tallqvist et al. (2019).

[13] Benchmark Mining estimates referring to year 2023.

[14] Adolfsson-Tallqvist et al. (2019). LG is rumored to extend its capacity in Poland to 70 GWh.

battery packs and modules tailored for industrial customer needs. There are also several Finnish start-up companies developing battery solutions and applications. Arguably, the larger value-added potential for Finnish engineering expertise in this field lies in control electronics, which is currently developed both by the car industry and its largest subcontractors.

EVs

As already noted, lithium-ion batteries have become the technology of choice for the alternative fuel vehicles in the 21st century. Even fully electric BEVs are zero-carbon in use (let alone in production) only if charging electricity is zero-carbon. In some countries – for example, currently in Germany – EVs are not obviously better than fossil-burning cars in terms of their lifecycle carbon impacts. Furthermore, zero-carbon could also be reached with a suitable energy carrier and a process for its generation, such as hydrogen. Exhibit 5 summarizes the demand and supply drivers of EVs. Overall, the market for EVs is at an inflection point in 2019/2020, which makes future projections highly uncertain.

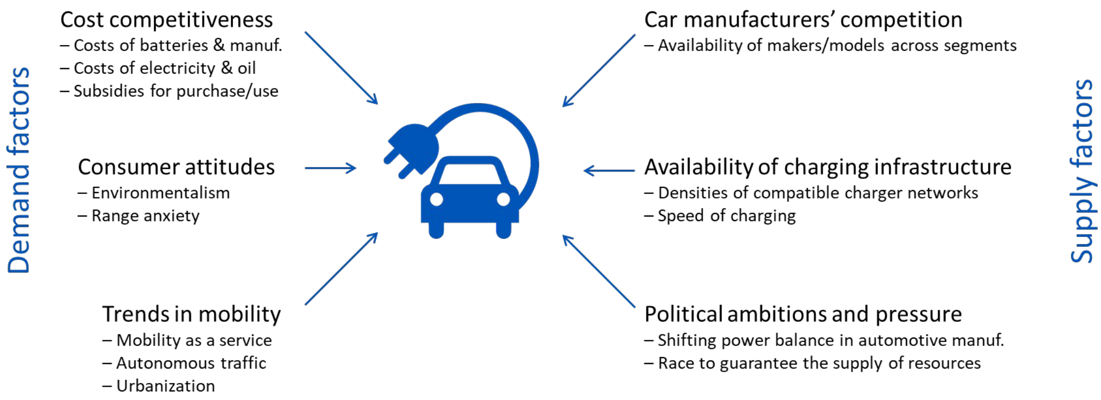

Exhibit 5: Demand and supply drivers of EVs.
Source: The authors (with inspiration from Consumer Affairs, ICCT, Nytimes.com, L.E.K., Renew Economy, and Statista).

In fall 2019, the global demand for passenger vehicles is in a slowdown, in considerable part due to uncertainties regarding the "optimal" powertrain in terms of both use and resell value. Furthermore, in the longer term, vehicle demand is shifting due to a host of more societal reasons – including the following:
- *Mobility patterns may change*. In most countries, urbanization is proceeding rapidly, with lessens some transportation needs and – with better access to mass transit – reduces the need for private transportation.[15]
- *Mobility-as-a-Service*. Privately-owned forms of transportation typically stand still over 90% of the time. Via on-demand service platforms, there is both less need to own a form of transportation and more pos-sibilities to increase the utilization rate of one's transportation-related assets. In the longer run, this ought to influence the number (and type) of vehicles in use.
- *Autonomous vehicles*. Large scale applications of autonomous forms of transportation are still far in the future, but they could revolutionize the auto industry, which implications on numbers and types of vehicles deployed.

With the above, the future demand for vehicles – regardless of the type of powertrain they might use – is uncertain. The demand for EVs is influenced by ultimately winning mix of technologies, which could include, e.g., hydrogen combined with a fuel cell.

The number and volume of *battery cells* in an electric vehicle in turn depends on:
- how other aspects of a vehicle evolve (e.g., aerodynamics, tire friction, and weight),
- how batteries evolve (energy intensity etc.; see earlier section), and
- to what extent EVs are hybrids.

As far as the last bullet point is concerned, it may well seem that we ultimately evolve to fully electric BEVs, but given driving patterns, the environmental impact of battery production, batteries' weight and other

[15] The UN projects that by 2050 68% of the world's population live in urban environments. In Europe and in the Nordics this figure will be higher.

properties affecting vehicle design and properties, and primary energy mix of grid electricity, PHEVs may well be optimal from an environmental perspective.

Demand for EVs is driven by the demand for vehicle transport and by EVs' attractiveness relative to feasible alternatives – accounting for incentives upon buying/leasing, running cost (including, besides electricity and fuel, maintenance costs, which are estimated to be lower for BEVs that for cars with fossil-burning engines), and availability of charging/fueling facilities. Ability to retrofit older vehicles may also come into question upon promoting the diffusion of EVs.

As illustrated in Exhibit 1, the demand for EVs is expected to explode in the longer run, even though – for quite some time – they will remain a relatively small share of outstanding *stock* of vehicles and non-EVs will command the larger share of all vehicles sold for quite some time. Prices of EVs are projected to become fully competitive with non-EVs by 2030, which should mark their ultimate breakthrough.

Overall, EVs ability to curb global warming will depend on their features and prevalence as well as on the afore-mentioned energy-mix aspect. EVs will also change the volume and patterns of electricity use, which imply new demands for power generation, transmission, and storage – beyond the obviously need network of charging outlets.

Geopolitics

China's state council's industrial policy agenda adapted in 2015, *Made in China 2025*, puts heavy emphasis on EVs. Consequently, in terms of production volumes, China is overwhelmingly the global leader in the battery/EV supply chain and has clear ambitions to be a dominant global player in all aspects from controlling metal reserves worldwide to delivering Chinese EVs globally.

In most aspects, China's early lead is impressive. Given the economic and strategic importance as well as political clout of the auto industry in many countries, this is a major issue of concern for many national governments and the European Union. Currently, Europe has a few potential strengths towards both ends of the battery/EV supply chain, although – in fall 2019 – it has not (yet) capitalized on them.

	Positive impact	Negative impact	Longer-term imp.
Inside EU			
Taxation of fossil fuels:	*High taxation on fuel stimulates EV demand.*		*Significant boost to the diffusion/use of EVs.*
Varying EV incentives across members:		*Distorts allocation of effects with the EU.*	*Higher incentives, more activity in the geography.*
EU regulation of carbon dioxide:	*Restrictive regulation promotes EVs.*		*Higher demand for EVs.*
Outside EU			
Intense industrial policy support for EVs:		*The EU car industry is at a disadvantage.*	*Less R&D effort in the EU handicaps EU companies.*
Japan dominates battery patenting:		*EU depends on imported intellectual property.*	*EU companies form JVs with extra-EU partners.*
Numerous global charging standards:		*Elevated prices and costs in relation to EVs.*	*Standard wars. Lower global welfare.*

Exhibit 6: Impacts of some EV-related regulatory framework conditions and policy factors.

Source: Adopted, with some modifications by the authors, from Millard, J. et al. (2012). Internationalisation and fragmentation of supply chains and security of supply. Published by the European Commission, DG Enterprise and Industry.

The European Union has nevertheless taken a clear industrial policy stance on the battery/EV issue, which it has largely shun away from in other contexts. In October 2017, the EU launched its Battery Alliance – a platform for bring together businesses, the governments of the member states, and EU administrative, scientific, and financial bodies – to meet the challenge. Battery-related *Important Projects of Common Euro-pean Interest* (IPCEI) are currently under development. The aim is to reduce/avoid extra -EU dependency on critical aspects of the battery/EV supply chain; a longer-term plan is due to be presented by the end of 2019. Exhibit 6 summarizes some related regulatory aspects.

Recycling

The end of the battery supply chain in Exhibit 3 – reuse, recycling and disposal – deserves a few notions here. Lithium-ion battery recycling is crucial in meeting the physical material needs of the anticipated transition to EVs. As illustrated in Exhibit 4, even with significant recycling (and substitution), the future deficit in the supply of cobalt is sizable; in the presented projection, the amount of recycled cobalt is estimated to be about 10% the EU's demand in 2030. Since EVs has become commonplace quite recently, largely volumes of lithium-ion batteries will only be available around 2025 and beyond. Several stakeholders in Finland are actively exploring EV-related waste management opportunities.[16]

Discussion

In this insight, we have considered multiple aspects of the battery/EV supply chain, highlighting the European and the Finnish perspectives. The multibillion-dollar battery industry – driven mostly by EV markets – is expected to boom IN 2020–2030 and is a key factor in decarbonizing economies worldwide.

In the longer run, the battery market is challenged by depleting raw material reserves and is in need for more efficient technologies and better recovery of materials via recycling. Markets are geographically concentrated in most phases of the battery/EV supply chain, which imposes imbalances in market power but also exposes to country risks. China's dominance can hardly be avoided; the question is, can it be alleviated somewhat. The European initiative to build a sustainable battery ecosystem is an effort to rebalance geopolitics in this respect.

The strengths, weaknesses, opportunities, and threats (SWOT) of the European battery/EV supply chain are summarized in Exhibit 7. Europe is strong in the automotive industry, albeit not necessarily in EVs, and its well-established electricity generation and distribution system should support EV roll out.

Weaknesses	Strengths
The EU has minor roles in earlier stages of the battery/EV supply chain. European carmakers are yet – in fall 2019 – to roll out EVs in a larger volume. Third country industrial policies with respect to EVs/batteries but EU firms at a disadvantage.	Automotive design: safety, technology, light vehicle body structures. Knowledge sharing in the context of the European Automobile Manufacturers' Assoc. The EU's policies in mitigating climate change boost the EV/battery sector.
Threats	**Opportunities**
Intellectual property in batteries largely in Japan, the US, South Korea, and China. Especially China, but also the US, appear more determined than the EU in promoting EVs. China: the leading EV market, the lowest manuf. cost, and the fastest learning-by-doing.	Strong electricity grids and their management supporting charging infrastructure build up. European utility companies stronger than international peers; partners in EV roll out. Consumers' environmental and health concerns support EV uptake.

Exhibit 7: SWOT of the European battery/EV supply chain.
Source: Adopted, with some modifications by the authors, from Millard, J. et al. (2012). Internationalisation and fragmentation of supply chains and security of supply. Published by the European Commission, DG Enterprise and Industry.

In terms of geography, the future of EVs is currently set out to look quite different from the past of conventional fossil-burning vehicles. The global battery/EV supply chain is likely to become much more concentrated and – without major breakthroughs in the ongoing efforts of nurturing a regional ecosystem –

[16] Adolfsson-Tallqvist et al. (2019).

Europe may well play second fiddle to particularly China but also the US. Given how strategic the battery/EV supply chain currently seems, this would also be a major political defeat.

Relative to its size, Finland is already rather dominant in mining of the most critical battery metal, cobalt, for which severe shortages are anticipated in the coming decade. Finland has also ample deposits for expanding this activity. Finland is, however, rather miniscule in subsequent stages of the supply chain.

When it comes to the mining and refining states of the supply chain, Finland has all the preconditions to be the leading country in Europe and a major force globally. For this starting point, Finland should certainly be able to host also a battery cell "giga factory" – similar to Sweden's Northvolt –, although currently there is no visible progress on this front; advancing this goal calls for cooperation with one of the existing major manufacturers.

Going beyond battery cells, there is existing small-scale battery module assembly in Uusikaupunki and more industrial-scale assembly in Salo with a planned ramp-up in 2019, through which Finland is directly linked to EV manufacturing via ongoing subcontracting agreements. Domestic EV production in Finland – beyond specialty vehicles and subcontracting for multinational automotive companies – seems unlikely. In terms of recycling and reuse, Finland has know-how and already existing solutions to fill a significant gap in the market, once a steadier stream of batteries starts to reach their end-of-cycle, approximately in 2025–2030.

To summarize, the Finnish strengths of the ecosystem lie especially in the proximity of raw materials and wide range of expertise and experience related to chemicals, processing, and engineering. The EU is pushing for reuse and recycling legislation of batteries, which coincides with Finnish strengths and thus provides new business opportunities.

Investments to a Finnish battery ecosystem would provide significant economic effects nationally but even more so regionally, which should be carefully considered prior to execution. Recent estimates indicate that total investments of €550 million in the building phase of 3–5 years would grow the national value added through direct and indirect effects by €429 million, increasing employment by about 5,923 person-work-years. Additional use-phase investments of €800 million would generate €1,9 billion national added value and 16,764 person-work-years during the first year of established activity throughout the whole supply chain. These estimates exclude international activities.[17]

The Finnish battery ecosystem already has a wide network of active stakeholders in all parts of the supply chain – raw materials, refining, batteries and cells, applications, and reuse and recycling. The state-owned Finnish Minerals group (FMG) is a central player aiming to build the leading battery cluster in the country.

The battery industry in Finland has potential to become a significant ecosystem serving both European interests and the Finnish economy. The hype around the battery ecosystem is alive and puts pressure to Finnish authorities for inducive actions towards investments in Finland. Such investments are certain to have economic impacts to Finland, which are yet to be assessed in sufficient depth. Moreover, legislative and environmental aspects must be carefully considered prior such investments.

Conclusion

The ongoing geopolitical chess for commanding significant junks of the global battery/EV supply chain resemble earlier developments in photovoltaic solar panels, in which most major countries worldwide took certain strategic interest but China then turn out to dominate. Solar panels were altogether a new field – the automotive industry is an established sector currently dominated by Germany, Japan, and the US. The earlier defeat looms large in the (developed) countries with vested interest in the sector. Despite this, China's early lead seems unsurmountable especially since none of the competing geographies comes nowhere near to match China's ongoing virtuous cycle in batteries and EVs: it hosts the largest and most dynamic domestic market for batteries and EVs, it combines low costs with relatively sophisticated technologies, and it is a learning-by-doing path no other geography can match.

[17] https://www.mineralsgroup.fi/media/akkuarvoketjun-taloudellisten-vaikutusten-arviointi.pdf (available only in Finnish)

For once, the EU is taking a stern industry policy stance. It is determined to secure a position in the still emerging global battery/EV supply chain – after the new strategy is released towards the end of 2019, we will be able to judge whether it is just what the doctor order or too little too late.

Finland should play a dual strategy. First, it should make every effort to promote all European battery/EV efforts provided that it can secure at least some active roles in them. Second, Finland has globally enviable deposits of key raw materials as well as reasonable mining and refining capacity to exploit those deposits. Even independently of any European efforts, Finland should aim at capitalizing on these strengths. Towards the other end of the supply chain, reuse and recycling of batteries could provide major opportunities for Finland.