FINAL REPORT

Batteries from Finland

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1 Table of Contents

1. Introduction

Electric batteries are a key component of the ongoing and growing energy transition away from fossil fuels towards integrating renewable sources of energy into the overall global energy mix. Powertrain electrification in vehicular applications and energy storage are two main drivers for the projected future use of battery solutions. This energy transition is driven by an overall response and alignment towards the climate targets outlined in Paris agreement (COP21) as well as e.g. EU regulatory frameworks[1]. In addition, the evolving field of industry 4.0, and small robotized devices dedicated for industry or private households, will also need effective energy storage solutions and batteries will play a key role in this as well.

Smart and clean mobility services, solutions and infrastructure will grow in importance in the connected global economy and will impact societies' ability and capacity to cope with e.g. climate change, population increase and aging populations, limited natural resources, and biodiversity. Mobility should be seen in a broad perspective to include all kinds of transport, including, goods, people, information and energy.

The UN projects[2] that by 2050 68% of the world's populations live in urban environments. In Europe and the Nordics this figure will be even higher, and large portions of the future Nordic populations will live in large metropolitan regions. This will impact a wide spectra of people's daily lives, city planning, as well as product development and business model design. This will also bring along new mobility pressures, challenges and opportunities, also considering demographics and possibly shifting consumer behavior patterns. Battery solutions and energy storage are becoming more and more integrated aspects in company strategies and business models as well as city and society service formulation and planning. For example, Bloomberg New Energy Finance estimates that by 2040, 80% of the world's city bus fleets and 33% of personal cars have been electrified[3]. This trend of electrification, away from fossil-fueled power towards battery-powered transmission, will not only create a demand for battery solutions, but will also impact, e.g. charging infrastructure, city planning, battery 2nd life solutions, and recycling models of used batteries.

2. Objectives and methodology of this study

This study is part of Business Finland Batteries from Finland activation program which aims at speeding up development of national battery ecosystem and eventually creating a totally new industry sector in Finland. Electrification of transport and disruption in the energy sector due to renewable energy technologies have created a fast-growing market for energy storage and battery applications, the size of which is estimated to be 250 billion euros in 2025[4]. The Business Finland initiated Batteries from Finland -project is enhancing the growth of knowledge basis and global competitiveness along the entire battery value chain – from raw material production and battery cell manufacturing to battery applications and services.

[1] E.g. The Clean Energy for All Europeans package
[2] World Urbanization Prospects: The 2018 Revision
[3] Electric Vehicle Outlook 2018, Bloomberg
[4] Estimate by Business Finland

This study relates to the strategic aim to create in Finland a new battery industry ecosystem. In particular, this study aims at giving a foundation to 1) creating in Finland a globally competitive battery industry business ecosystem, 2) enabling Finland to become a leading country in the battery recycling know-how, 3) increase the offering of the companies in Finland to feed the needs in the battery and energy storage market, and subsequently tie the Finnish organizations to be part of international networks and growing markets, and 4) attract international battery cell, component and chemicals manufacturers and their RDI activities to Finland.

This study was commissioned by Business Finland and jointly executed by Gaia Consulting and Spinverse. The overall methodology of the study is presented in **Figure 1** and the main working methods in **Figure 2**. The objectives of this work have been to 1) create a general view on the ongoing battery related activities in Finland, in the Nordics and in Europe and on potential partners to the battery ecosystem, 2) survey the will and development needs of companies to act in the battery industry ecosystem, and 3) describe the success factors for a national battery industry ecosystem by identifying the potential and value added of such an ecosystem.

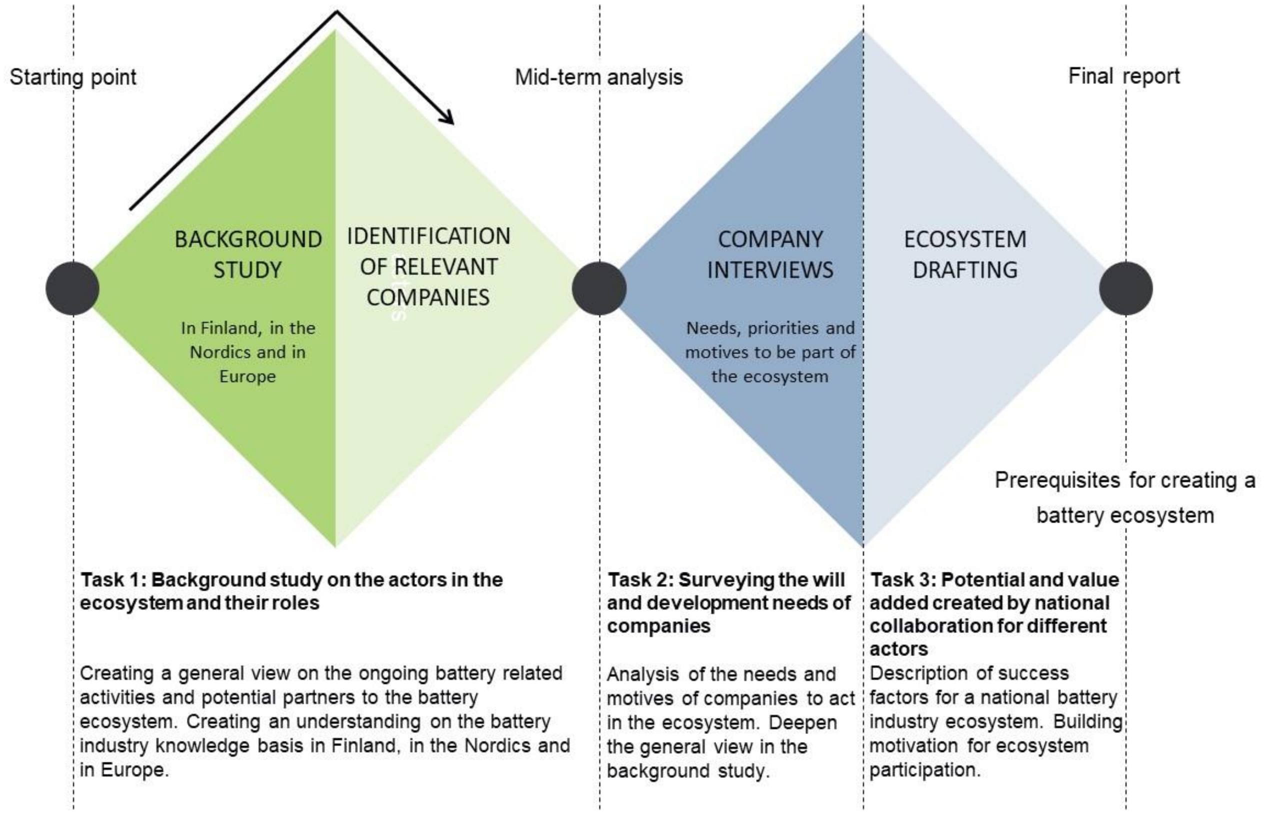

Figure 1. Overall methodology of the study

The main working methods in this study, presented in **Figure 2** below, have been desktop study, interviews and workshops as well as utilization of digital platforms for internal team as well as external participant communication and engagement. In total the team conducted 77 interviews of relevant actors in Finland, 19 in the Nordics and 23 in Europe, totaling 126. One half-day and two full day workshops were organized which gathered 25, 35 and 36 participants, respectively. The first workshop at the end of November 2018 presented mid-term results from the background study and the interviews. The participants gave valuable input in a World Café format facilitated discussion to the study on three questions, that had been identified important in the context of the study: battery related networks in the Nordics and in Europe, Nordic cooperation in the battery industry, the value chains of the future: digitalization and business models, and competence: is there sufficient and what to prioritize? The second workshop at mid-January 2019 built on the findings from the interviews as well as on results from the first workshop. The participants first validated and added ecosystem themes that had come up in the study so far and in a Value proposition canvas -format looked at the value adding possibilities of some of these themes in the context of customer or market needs. In the third workshop, at the end of January 2019, the content of the themes was developed further by discussing who are needed as participants in the ecosystems and which concrete actions the ecosystems would require. In the third workshop, the ecosystem development was taken from a national perspective to a Nordic level by inviting actors from the Nordic countries to participate, with key notes of battery industry developments given by Bellona from Norway and the Swedish Energy Agency from Sweden.

> “
> *In total 77 interviews of relevant actors in Finland, 20 in the Nordics and 23 in Europe, totaling 127*

Figure 2. Main working methods in the study

This report gives a short overview of the battery industry and its trends in Chapter 3, and relevant policy and regulatory frameworks in Chapter 4. Main activities and key industrial actors in the battery value chain in Finland, Nordics and Europe are presented in Chapter 5, and the status of Finnish know-how in terms of research and education in Chapter 6. Chapter 7 presents examples of the most important battery-related networks and projects. In Chapters 8–10 key findings from stakeholder interviews and workshops are presented and analyzed. These include company needs and motivational drivers as well as challenges to be taken into account when building battery industry ecosystems. The last two chapters summarize the findings of this study and give recommendations for future work.

This study focuses from a technical perspective mainly on Li-ion batteries and the geographical scope is Europe. In this study, an ecosystem means a loosely defined organization formed by many parties that participate in the value creation for the customer. In innovation ecosystems, disruptive products/services for end-users will be developed through intensive co-operation between partners, and the work is done through ecosystem projects. The term electric vehicles (EV) is in this report used to encompass mainly automobiles, buses, trucks, and heavy-duty vehicles, although graphs might include only a selection of the vehicle types listed.

3. General overview on the battery industry

3.1. Batteries and cells

Batteries can be divided into primary and secondary batteries. Primary batteries are small single-use batteries that are mostly used in portable devices. Secondary batteries, which are the focus of this study, refer to rechargeable batteries used in e.g. automotive and industrial applications.

Lithium-ion batteries, which are the main battery technology used in automotive and industrial applications, are further categorized based on the active material used in the cathode. The cathode material and other materials and technologies determine the cost, performance, lifecycle, safety and environmental footprint of the cell, and are therefore a key consideration when selecting a battery technology for the specific requirements of the end application. Main cathode chemistries and their applications are summarized in **Table 1** below. The main components in a battery cell are the electrodes (cathode and anode), separator, electrolyte and container. Most common cell structures are prismatic, pouch or cylindrical cells.

Table 1. Main cathode chemistries and related applications[5]

Cathode chemistry	Main applications
NMC (Nickel Manganese Cobalt Oxide)	Electric vehicles (EV), stationary battery energy storage (BES), other (e.g. power tools, electronic devices)
NCA (Nickel Cobalt Aluminium Oxide)	Electric vehicles (EV), stationary battery energy storage (BES), other (e.g. power tools, electronic devices)
LFP (Lithium Iron Phosphate)	Electric vehicles (EV), stationary battery energy storage (BES)
LMO (Lithium Manganese Oxide)	Other (e.g. power tools, electronic devices)
LCO (Lithium Cobalt Oxide)	Portable electronic devices

Cell and module productions are separate and different stages in the production chain: cell production includes energy intensive chemical processes, whereas battery module production primarily consists of electromechanical assembly. The battery modules, containing tens or hundreds of cells, are assembled into battery packs, which also include the battery management system (BMS), wiring, sensors, thermal management, isolation and packaging. Battery pack design and manufacturing is closely linked to the end application, and e.g. EV manufacturers often manufacture their battery packs in-house.

3.1.1. Global battery manufacturing market

In the past 25 years, global battery manufacturing volumes have increased significantly. The highest growth and major industry investments have focused on lithium-ion batteries: the annual growth rate for lithium-ion battery production was over 25% during 2010-2016, as presented in **Figure 3**.[6]

[5] Tsiropoulos, I., Tarvydas, D., Lebedeva, N., Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth, EUR 29440 EN, Publications Office of the European Union, Luxembourg, 2018, JRC113360

[6] Lithium-Ion Battery Raw Material Supply and Demand 2016–2025, Avicenne Energy, 2017

The global battery manufacturing capacity is expected to increase even 4-6 times by 2022 in comparison to 2017 levels.

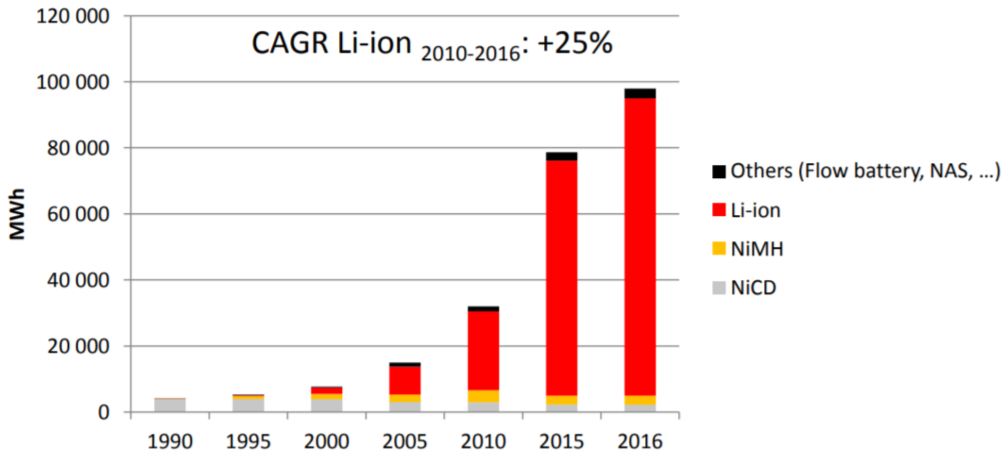

Figure 3. The growth of global battery manufacturing capacity by battery technology[7]

Global lithium-ion battery manufacturing capacity today is around 150 GWh. Based on plants announced and under construction, this is expected to exceed 400 GWh by 2021 with 73% of the global capacity concentrated in China (**Figure 4**)[7]. Longer-term projections vary greatly depending on the timeline and extent that various decarbonisation measures will be realized, as the significant growth of battery demand is mainly driven by the mass production of electric vehicles and the adoption of battery energy storage at grid and household levels. Developments in battery lifetimes, second life use and learning rates are also among the factors affecting the future demand of Li-ion batteries. The global demand for Li-ion batteries is estimated to reach 2 TWh by 2040, which corresponds to 55 operational gigafactories (i.e. large-scale cell-production facilities) with a capacity of 35 GWh each.[8] This projected global demand is driving unprecedented growth in battery supply from a wide range of existing and new players. The above discussed trends are all also driving up the demand for key battery materials like cobalt, lithium and nickel.[9]

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[7] Lithium-Ion Battery Raw Material Supply and Demand 2016–2025, Avicenne Energy, 2017

[8] Tsiropoulos, I., Tarvydas, D., Lebedeva, N., Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth, EUR 29440 EN, Publications Office of the European Union, Luxembourg, 2018, JRC113360

[9] Bloomberg New Energy Finance

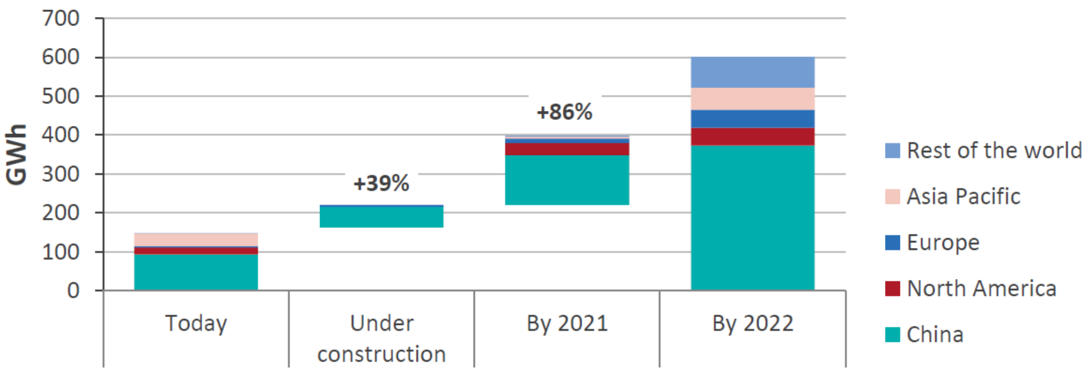

Figure 4. Near-term growth forecast of global Li-ion cell manufacturing capacity by region[10]

Large Chinese manufacturers currently dominate the global battery market. A majority of manufacturing capacity is based in Asia, which accounts for almost 80% of global battery manufacturing, while this share is expanding faster than that of any other geographical area. Of all countries, China alone accounts for over a half of the global battery manufacturing market, followed by Japan and Korea, although increasing efforts are also paid to establishing battery production in the US and Europe (**Figure 5**).[11]

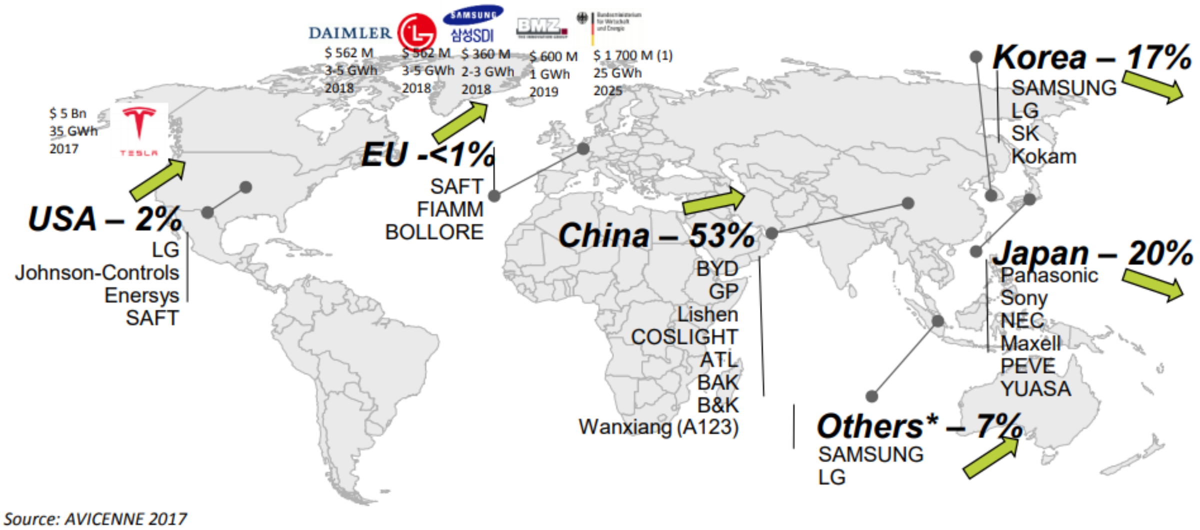

Figure 5. Global lithium-ion battery cell producers by region[12]

[10] Tsiropoulos, I., Tarvydas, D., Lebedeva, N., Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth, EUR 29440 EN, Publications Office of the European Union, Luxembourg, 2018, JRC113360

[11] Batteries Manufacturing Market Global Briefing, The Business Research Company, 2018

[12] Lithium-Ion Battery Raw Material Supply and Demand 2016–2025, Avicenne Energy, 2017

The battery manufacturing capacity in Europe is currently very limited, although covering the demand for battery cells in the EU alone is estimated to require at least 10-20 gigafactories in the near future.[13] The European Battery Alliance (EBA) believes that Europe could capture a battery market with an annual value of €250 billion by 2025, which requires large improvements and investments over the whole value chain. Regarding cell and battery manufacturing, the measures recommended by EBA include reducing carbon footprint in manufacturing, implementing de-risking measures for manufacturing of cells in the EU and establishing a labelling scheme for batteries made in the EU.[14]

> *80 % of global battery manufacturing takes place in Asia, with China dominating*

3.1.2. Li-ion battery prices and cost structure

The techno-economic performance of lithium-ion batteries has significantly improved during the past decade. Battery prices are falling sharply due to economies of scale driven by the massive demand for EV batteries, as well as the improvements in manufacturing processes and battery technologies. Additionally, vertical integration of stages in the production chain and decreases in transportation expenses further reduce the costs. According to Bloomberg New Energy Finance, the price per kilowatt hour for lithium-ion batteries dropped by 50% between 2014-2016. The rate of price development has decelerated, but lithium-ion battery prices are still expected to decrease from the current price level of 200 $/kWh to around 100 $/kWh by 2025, and further down to 70 $/kWh by 2030 (**Figure 6**).[15]

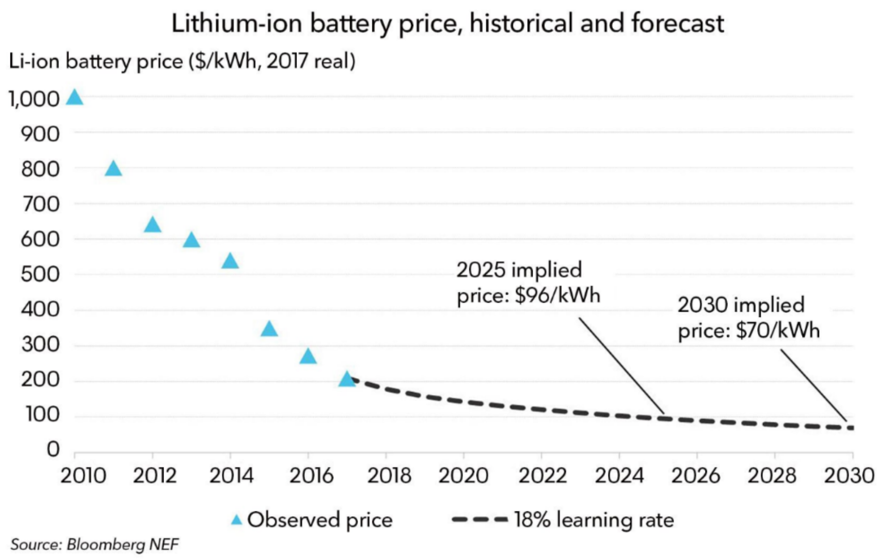

Figure 6. Lithium-ion battery price development[16]

Materials, especially cathode materials, account for the largest share of the average cost of a lithium-ion battery cell, as presented in **Figure 7**. Energy costs are high due to the energy intensity of cell

[13] European Battery Alliance
[14] InnoEnergy
[15] Bloomberg New Energy Finance
[16] Bloomberg New Energy Finance

manufacturing processes. Cell manufacturing also requires large R&D efforts due to e.g. the complexity of the technology, testing requirements and long feedback loops.

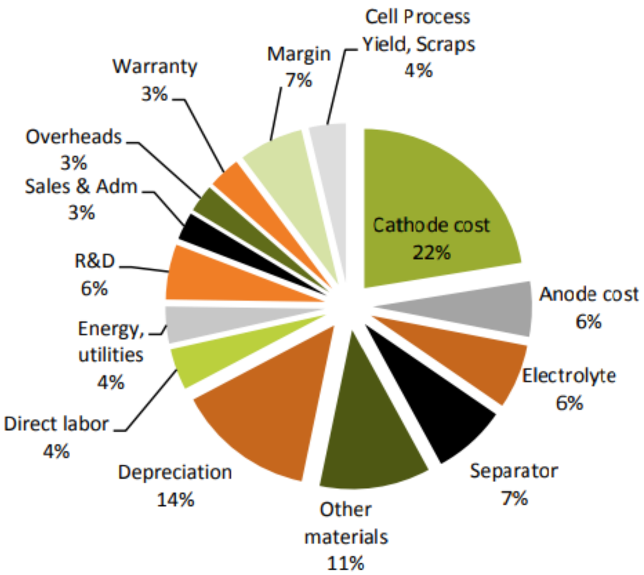

Figure 7. Average cost structure of Li-ion battery cell in 2016[17]

3.1.3. New battery technologies

There are significant ongoing research efforts worldwide on improving lithium-ion battery chemistries and new materials. Although lithium-ion batteries are expected to stay the main battery chemistry in the near and medium term, a lot of research is dedicated to the exploration and development of new chemistries beyond lithium-ion. Potential future cell chemistries include lithium metal (Li metal), lithium-air (Li-air), lithium-sulphur (Li-S) and solid-state (SSB) batteries. Also, emerging battery technologies such as Flow vanadium, Na-based and Mg-based batteries have gathered interest. The new chemistries might have benefits especially due to their considerably higher energy and/or power densities, safety and longer lifetime. However, there are several unsolved challenges with new cell technologies, related to e.g. stability of cell reactions, limited operation temperatures, and safety and manufacturability issues.[18]

> *Strong focus on Li-ion batteries but research looks into new technologies*

Battery related patent filings have increased threefold since 2010, particularly in the area of joint filings, often between organizations in very different sectors e.g. research institutions, companies developing battery technology and companies using batteries within different applications (such as automotive, electronic devices and utilities). Therefore, the management of and participation in research and innovation ecosystems will play a vital role for the players that want to survive in the expanding and developing market. Numbers of patent filings per battery technology are presented in **Figure 8.**[19]

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[17] Lithium-Ion Battery Raw Material Supply and Demand 2016–2025, Avicenne Energy, 2017
[18] Lithium ion battery value chain and related opportunities for Europe (JRC105010), European Union, 2016
[19] Arthur D. Little – Future of batteries, 2018

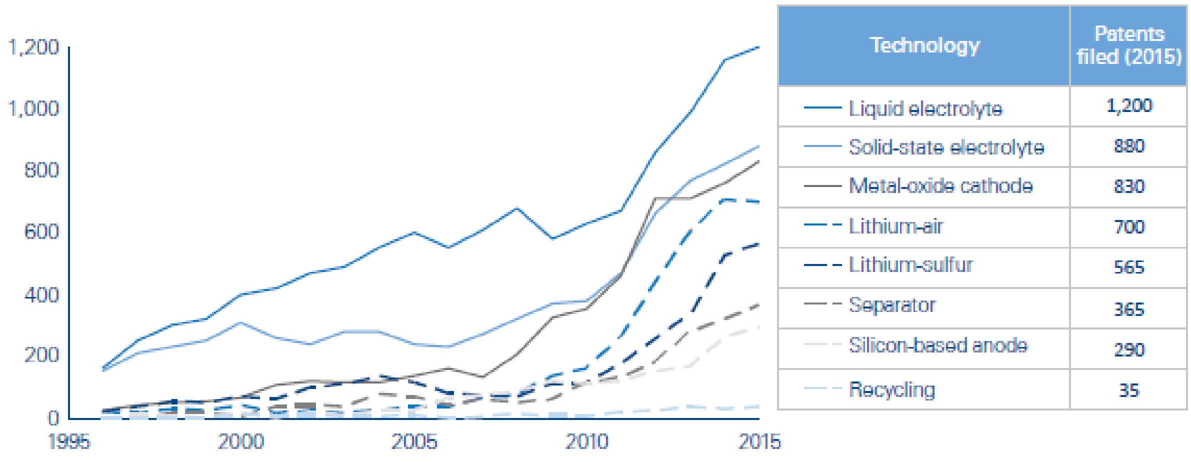

Figure 8. Battery related patent filings per technology (until 2015)[20]

3.2. Materials

3.2.1. Raw materials

Wide range of raw materials are needed for Li-ion batteries including lithium (Li), nickel, (Ni), cobalt (Co), manganese (Mn), aluminium (Al), copper (Cu), silicon (Si), graphite, titanium (Ti) and carbon (C). This study is mainly focusing on Li, Ni and Co due to their importance and the high future demand for the production of cathode active materials. In fact, 22% of the battery cell cost comes from the cathode[21]. Materials used in other battery components such as in separators and electrolytes are not in focus of this study.

As shown in **Table 2**, lithium demand in 2017 was 214 kt and is estimated to increase to 670–890 kt by 2025. Currently, Chile, Australia and China account for 85% of the global lithium production. Most of the mine output is controlled by four companies (Talison, SQM, Albemarle and FMC). By mass, nickel is the most important metal in the cathode, and it is expected to be used more in Li-ion batteries as there is a trend of substituting cobalt with nickel. Largest producers of Ni include Australia, Philippines, Indonesia and Canada. The current supply and future demand are presented in **Table 2**.

Table 2. Current and future demand for lithium, cobalt and nickel (modified from McKinsey 2017[22] **and Mc Kinsey 2018**[23]**)**

	Lithium	Cobalt	Nickel
Current demand (kt, 2017)	214	136	2 100
- of which battery demand	~40%	~30%	~1–2 %
Est. demand in 2025 (kt)	670–890	222–272	2 470
- of which battery demand	~76–82%	~50–60%	~23 %

[20] Arthur D. Little – Future of batteries, 2018
[21] Lithium-Ion Battery Raw Material Supply and Demand 2016–2025, Avicenne Energy, 2017
[22] McKinsey & Company, 2017. The future of nickel A class act
[23] McKinsey & Company, 2018, Lithium and cobalt – a tale of two commodities

Total cobalt demand in 2017 was 136 000 t (see **Table 2** above). The total demand is expected to reach 272 000 t by 2025. Close to 90% of cobalt mine supply is produced as a by-product from copper or nickel mines making its production dependent also on the price dynamics of these commodities. Democratic Republic of Kongo (DRC) alone accounted for close to 70% of the mined cobalt output and the share is expected to increase. Other main producing countries include Russia, Cuba, Australia and Canada. Largest producer with 22% of the production is Glencore. Others include DRC state miner Gecamines and China Molybdenum. The refining capacity of cobalt is concentrated in China with a share of 50-60%. The largest refinery outside China is Freeport Cobalt's refinery in Kokkola, Finland.[24]

Cobalt is classified as a critical raw material (CRMs) by European Commission due to the fact that cobalt has high economic importance while having high supply risk. If the long-term projections on the penetration of electric vehicles (with wide usage of NMC technology) will realize, the cumulative demand for cobalt would exceed the known cobalt resources by 2050[25]. Additionally, overall battery economics are very sensitive to cobalt prices, which tend to be highly volatile. There are also worries regarding the ethical aspects of some cobalt mines in Congo[26] and the toxicity of the cobalt. For these reasons, there is a trend towards low cobalt battery chemistries where cobalt would be mainly substituted with less expensive nickel.

3.2.2. Battery chemicals

To produce active materials for cathodes, various chemicals are needed. These active materials include lithium carbonate and lithium hydroxide. Lithium carbonate with Li content of 19% is mostly produced from brines. Lithium hydroxide with 29% lithium content is produced from hard rock sources and is currently the preferred chemical for the longest-range EV batteries.[27] Other chemicals include nickel sulphate and cobalt sulphate and precursor materials for cathode production such as cobalt oxides and mixed metal hydroxides

3.2.3. Cathode active materials

Active materials used in cathodes have a huge impact on the battery properties and possible energy density, and thus are a key battleground for battery performance. The demand for cathode active materials is rapidly increasing as illustrated in **Figure 9**. In 2000 the need was 7 000 tons, and in year 2016 it was 210 000 tons and is estimated to reach 540 000 tons in 2025. Share of Asian production is between 80% and 100% for each cathode material type and the share of especially China is significant.[28]

> *"Demand for cathode active materials is rapidly increasing – these are critical for battery performance and cost*

[24] McKinsey & Company, 2018, Lithium and cobalt – a tale of two commodities
[25] JRC, 2016 Lithium ion battery value chain and related opportunities for Europe
[26] There's a dark secret powering your smartphone, Global Battery Alliance/World Economic Forum, 2017
[27] McKinsey & Company, 2018, Lithium and cobalt – a tale of two commodities
[28] Lithium-Ion Battery Raw Material Supply and Demand 2016–2025, Avicenne Energy, 2017

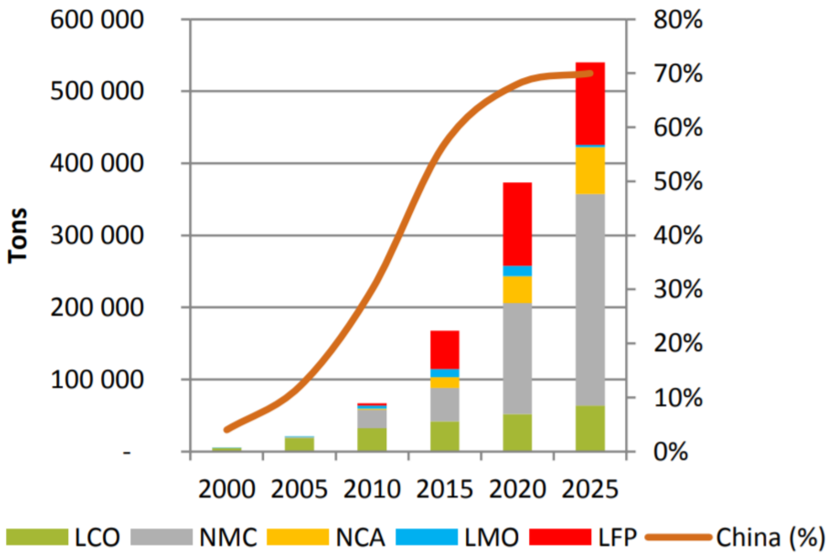

Figure 9. Demand of cathode active materials.[27]

Raw material need depends on Li-ion battery type. Fastest growing need is for active material type NMC (Nickel Manganese Cobalt Oxide) with compound annual growth rate (CAGR) of 20% for the period 2015 - 2025. NMC is used e.g. in batteries for electric vehicles, and thus the need is strongly driven by the electrification trend. NMC is currently the preferred technology for long range batteries. Leading suppliers include Umicore (BE), Nichia (Japan), L&F and main Chinese players such as ShanShan, Pulead and Reshine. BASF has entered the market in 2009[29]. Also, the NCA (Nickel Cobalt Aluminium Oxide) is used in electrical vehicles (as well as in electronic devices) and its demand is growing with the rate of 16%.[27]

For LFP (Lithium Iron Phosphate), used in batteries for electric vehicles and industrial applications, the need is growing with CAGR of 8%. For low cost and stable LMO (Lithium Manganese Oxide, (used traditionally for power tools) the need is decreasing with the 12% CAGR but it will have a role in the future in LMC/LMO blended cathodes for EVs.[27]

The development and commercialization of new battery materials and technologies is time-consuming and costly, due to the complexity of the technologies and manufacturing processes as well as the massive testing requirements and long feedback loops. However, due to the importance of cathode materials for battery performance, the cathode materials research field is highly active. It has been estimated that process manufacturing improvements will decrease the price for all the active materials.

3.2.4. Anode active materials

In Li-ion batteries, the most commonly used active material types for anode are artificial and natural graphite for which the global demand in 2016 was about 40 000 t[27]. Natural graphite demand is expected to grow with the rate of 4% and need for artificial graphite with the rate of 15% a year. For batteries with long battery life, high level purity graphite is needed, therefore the growth is faster for

[29] Argonne's lithium-ion battery technology to be commercialized by BASF

artificial graphite for which the adequate purity is easier to achieve. The production of natural graphite is concentrated in China (66%).[27]

3.3. Battery applications

Batteries are used in a wide range of products and service offerings ranging from healthcare applications, electric vehicles, large scale maritime use, and energy storage applications. The global battery sectors are developing and growing fast, and the electric vehicle industry is a key driver (**Figure 10** below).

The globally connected nature of the battery value chain means that supply chain stability, product and service innovation, and market access will continue to remain critical elements in company strategies and tactics. Battery technologies vary, but Li-based technologies are expected to remain in focus in the foreseeable future. A key competitive advantage is battery cost, and demand will be even better met as battery costs are being brought down e.g. via economies and manufacturing of scale[30]. Also, as battery production requires large capital investments throughout the value chain, investments into Li-based technologies will be associated with a desire and strategy to leverage on such investments.

> *Clean energy boosts need for batteries – electric vehicles driving the growth*

The market is underpinned by the sustainability theme in generating smarter and cleaner products, services, and combinations thereof. Countries, regional administrative areas, and cities are continuously updating their CO2 reduction targets and strategies[31], and in turn driving a change towards less CO2 emitting solutions. The move away from carbon-based fuels towards electric solutions means that batteries take a continuously more prominent role[32]. In order to sustainably make this transition towards a more electrified economy, renewable energy production is also set to increase, and batteries play a role here to provide stable electricity provision[33], for example.

30 The rise of the battery ecosystem, Prism 1, 2018, Arthur D. Little
31 Europe's World: Cities are partners for effective climate policy, 2018, Eurocities
32 New Energy Outlook 2018, 2018, Bloomberg
33 Vestas and Northvolt partner on battery storage for wind energy to support the further integration of renewables, 2017

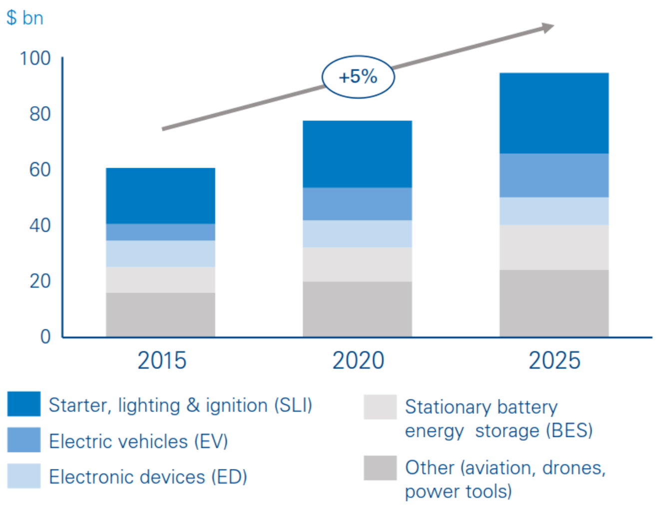

Figure 10. Battery application growth forecast[34]

The increased use of electric vehicles is propelled forward by urbanization and urban densification. Today, denser urban centra with increased vehicle mobility have led to an increase in e.g. poor air quality (**Figure 11**), affecting people's health daily. Electric vehicles present an alternative that does not produce harmful emissions for humans and nature. In 2017, Paris planned to discontinue all petrol and diesel vehicles from the city center by 2030, and France to end fossil fuel dependency for cars by 2040 (with even faster actions in large cities)[35].

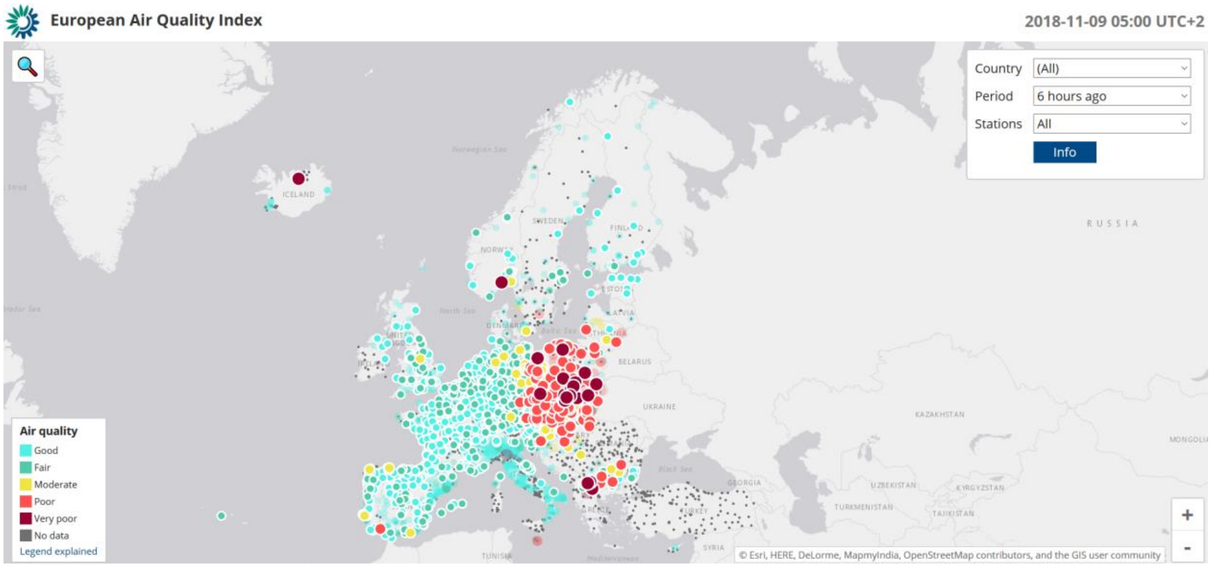

Figure 11. European air quality index[36]

Electric vehicles are a key driver in the use and expected growth of batteries. It is forecasted that as the use of electric vehicles grows, battery costs come down, thus further increasing their use in electric mobility and other applications. The IEA estimates that by 2030 there will be at least 130

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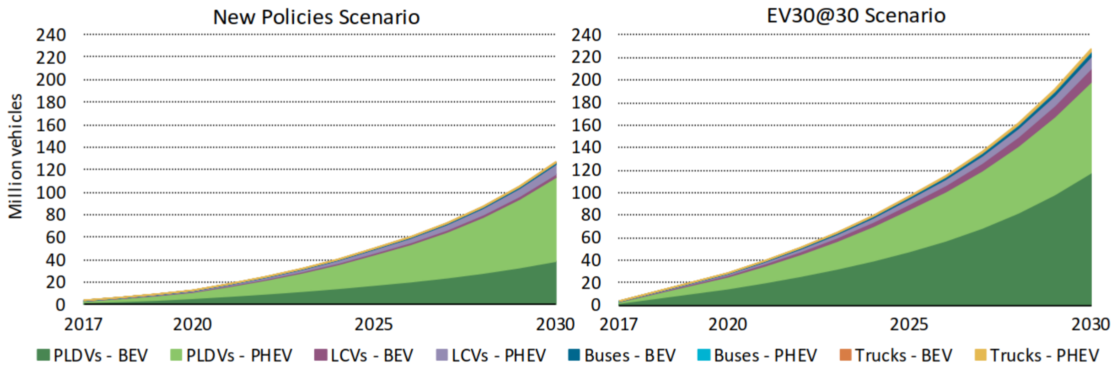
34 Future of batteries, Arthur D. Little, 2018
35 "Paris plans to banish all petrol and diesel vehicles from city centre by 2030", The Independent, Oct 12, 2017 (accessed Nov 9, 2018)
36 European Air Quality Index Internet site (accessed 09.11.2018)

million electric vehicles on the global roads, excluding vehicles with two or three wheels (**Figure 12**)[37]. All automotive vehicle brands have started to incorporate electric vehicles, full EV or hybrids, into their product portfolios, and some car manufacturers also branch out into new kinds of vehicles, of which one example is Volkswagen's electrical cargo bikes[38]. Lithium-ion based technologies dominate usage, but companies are already now looking into new technologies as well, e.g. is Honda looking into Magnesium based[39] and Toyota is looking into Calcium[40] based battery technologies.



Notes: PLDVs = passenger light duty vehicles; LCVs = light commercial vehicles; BEVs = battery electric vehicles; PHEV = plug-in hybrid electric vehicles.

Source: IEA analysis developed with the IEA Mobility Model (IEA, 2018b).

Figure 12. Global EV stock by two scenarios, 2017-30[41]

Increased urbanization increases the need for clean and efficient public transport. The European Union's common target to reduce greenhouse gas emissions from the transport sector by at least 60% from 1990 levels by 2050[42] drives the development towards electrified transport as the transport sector is a major source of greenhouse gas (GHG) emissions. In 2017, 370 000 electric buses were travelling on the roads globally as well as 250 million electric two-wheelers. China accounts for nearly 99% of these numbers, but the vehicle electrification trend is growing also across Europe[43]. In response to the EU's set targets, the Nordic countries have each set emission reduction targets for transport, both at the national and city level[44]. For example, Finland aims to halve the emissions[45] from transport by 2030 compared to the 2005 levels, and Norway has set a goal that all new passenger cars and light vans sold in 2025 shall be zero-emission vehicles. Electric car stocks by region are presented in **Figure 13**.

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37 Global EV Outlook 2018, IEA
38 Volkswagen Launches Cargo E-Bike, BIKE Europe, 2018
39 Honda and Saitec develop magnesium ion battery with vanadium oxide cathode, (accessed 22.1.2019)
40 On the road toward calcium-based batteries, Current Opinion in Electrochemistry, Volume 9, June 2018
41 Global EV Outlook 2018, IEA
42 European Commission (2011). Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system
43 Global EV Outlook 2018, IEA
44 Company interview
45 Towards Climate-Smart Day-to-Day Living – Medium-term Climate Change Plan to 2030, Finnish Ministry of the Environment

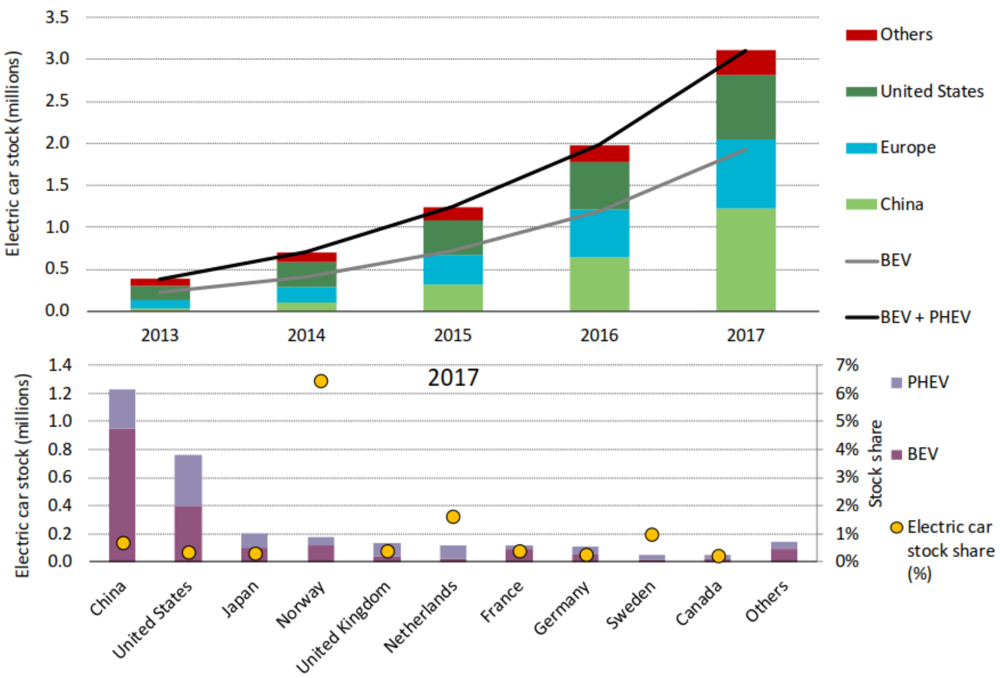

Figure 13. Passenger electric car stock in major regions and the top-ten EVI (Electric Vehicles Initiative) countries[46]

Electric vehicles are not only limited for urban use, but electricity is also increasingly used in trucks, heavy duty vehicles, and shipping[47]. Major truck manufacturers are launching electrically powered trucks[48], and e.g. mining equipment makers, such as Epiroc and Sandvik, are planning to electrify all their underground machines[49,50].

New business models are gaining traction, particularly in the context of different MaaS solutions (Mobility as a Service)[51]. There is increasing demand for greener and cleaner transportation to which the new digitalized mobility solutions and the sharing economy offer consumers new more sustainable options than before to meet this demand. New EV driven digital solutions are also presenting an alternative to car ownership model. New actors that have traditionally not been active within the space of mobility are entering the market, e.g. the online fashion platform Zalando[52] is piloting new delivery models in urban environments.

An increase in number of electric vehicles will also drive an increase in electricity demand. In order to accommodate such electrical re-fueling the entire electrical infrastructure and tariff design will need to be carefully considered in order to make demand be sustained by a sustainable supply. **Figure 14** below exemplifies this in a 2050 Bloomberg California scenario[53]. Also, electric vehicle charging is being developed, and close interaction between urban planners and industry will be needed to develop efficient and accessible solutions.

[46] Global EV Outlook 2018, IEA
[47] Decarbonising Maritime Transport Pathways to zero-carbon shipping by 2035, OECD, 2018
[48] Electrification of Heavy Duty Vehicles, Eurelectric, 2017
[49] Electric Vehicle Revolution Goes Underground With Mine Truck, Bloomberg, 2018
[50] Tekniikka & Talous, “Kaivoksessa sähkö on kultaa”, 18.1.2019
[51] Mobility as a Service and Greener Transportation Systems in a Nordic context, Nordic Council of Ministers, 04.12.18
[52] Zalando starts pilot with e-bikes, City Logistics, 2018
[53] Bloomberg NEF 2018 (accessed Nov 9, 2018)

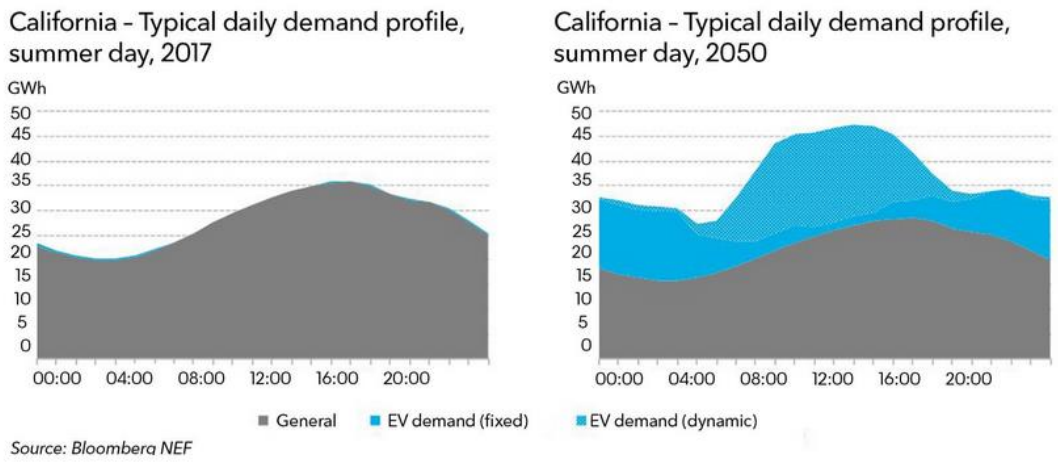

Figure 14. Estimated typical daily electricity demand profiles in California 2017 and 2050[54]

In tandem with the rise of electric vehicle mobility, renewable energy production and storage are key drivers in the use and development of batteries and battery-based business models. A battery enables storage of energy when e.g. wind or sunshine is available, to be released into the grid when needed[55]. The share of the renewables in the world's energy mix will continue to drive the need for battery solutions. Batteries are used to store energy during favorable energy production conditions that at a later stage can be used when, e.g. solar emission is lower or when wind is less. The IEA estimates a noticeable growth of renewable energy in its World Energy Outlook[56] (**Figure 15**).

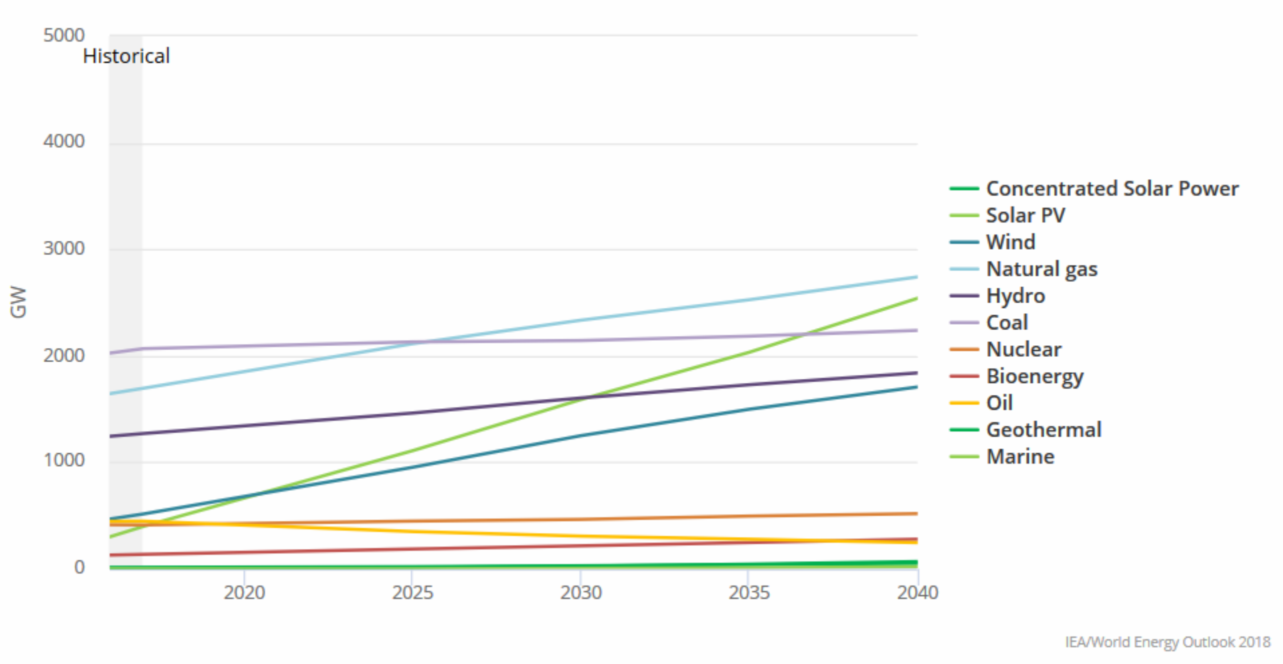

Figure 15. Increase in installed power generation by type, New Policies Scenario (NPS)[57]

54 New Energy Outlook 2018, 2018, Bloomberg
55 New Energy Outlook 2018, 2018, Bloomberg
56 World Energy Outlook, IEA (accessed January 22, 2019)
57 The New Policies Scenario, "Incorporates existing energy policies as well as an assessment of the results likely to stem from the implementation of announced policy intentions".

Portable devices are becoming completely cordless[58]. Consumer electronics products utilize almost always some form of battery power solution. In the power-tools category, the market is moving steadily towards cordless power, a development that is driven by battery innovations and the ability to make lighter machines[59]. Already today, e.g. UK Makita says that the ratio power cord/cordless is at 60/40[60]. Three main battery technologies are Li-ion, Nickel Cadmium and Nickel Metal Hydride, with Li-ion the dominant chemistry. Other companies, such as Bosch, also record a continued growth in power tools[61]. However, the batteries used in portable small-scale products are not in the scope of this study.

3.4. Recycling and reuse

In addition to the energy transition towards renewable energy production, economies – at varying speeds – across the globe are also moving towards circular economy. The EU's Waste Framework Directive outlines the general waste hierarchy[62], and in 2018 EU also presented its Circular Economy Action Plan[63] with the aim "to transform Europe's economy into a more sustainable one". The commonly used resource value hierarchy outlines the following order: Reduce, Reuse and Recycle.

In general, recycling of Li-ion batteries is gaining traction across Europe, driven by the expected growing demand for electric vehicles, but also due to the European Commission's strategic action plan to develop an innovative, sustainable and competitive Li-ion battery ecosystem[64], and due to a general industry wide focus on circular economy. An important driver for Li-ion battery recycling is the Batteries Directive (2006/66)[65] which includes requirements on Li-ion battery recycling.

In addition to preventing battery waste altogether, two main themes are relevant within the scope of Li-ion batteries: reuse and recycling. The waste hierarchy argues that reuse makes more sense from a resource efficiency perspective than recycling, and thus the so-called 2nd life battery applications are within an intense focus by many actors along the Li-ion battery value chain. Used Li-ion batteries are an active research area and they are developed to become for example as much-needed energy storage for renewable energy production.

From a circular economy perspective, the reuse and recycling concepts are being looked into for commercial viability by almost all major car manufacturers in the context of Li-ion batteries. Along these lines, for example many major vehicle manufacturers have created partnerships e.g. with energy producers. It is estimated that a car battery will be replaced when it has approximately 80% remaining of its life-time, and this remaining capacity can be used in slower charging applications. Companies such as Nissan, Jaguar, Audi and BMW are all looking into second life solutions for used EV

> *"Re-use and recycling resonate with a circular economy approach*

58 Rechargeable batteries, European power tool association (accessed 22.1.2019)
59 Freedonia Group, Global Power Tools Market by Region, Product and Market, 9th Edition
60 IN-DEPTH: Makita on the shift from mains to cordless power tools
61 Bosch Power Tools achieves strong growth once again
62 Directive 2008/98/EC on waste (Waste Framework Directive)
63 2018 Circular Economy Package, (accessed 22.1.2019)
64 Outotec and Aalto University to coordinate European research related to recycling in the battery industry, Outotec press release, Nov 1, 2018
65 Batteries and Accumulators, European Commission

batteries[66]. There is thus an emerging intertwining of value chains, seen e.g. in the partnership between Nissan and Eaton[67], "*The partnership will focus on creating commercially viable energy storage and control centers that will provide a sustainable 'second life' for Nissan's lithium-ion batteries after their automotive usage*".

When efficient use does no longer make sense a Li-ion battery will eventually reach the end of its life cycle. In EU, Li-ion batteries and batteries in general are under producer responsibility, meaning that producers (manufacturers, importers) of batteries are responsible for the waste management of the batteries that they place on the market. In practice a so-called producer coordination organization is usually established for consumer products, which takes care of the waste management of the products on behalf of the producers. Often this includes the required collection schemes and logistics, storage, recycling and waste reporting to authorities. Member producers pay producer coordination organization's upkeep. The waste material is not charged when delivered for recycling but rather the system is funded as part of the price of the product and thus paid by consumers in the end. For business-to-business applications, an alternative to a producer coordination organization is that a company arranges the required waste management themselves.

Li-ion batteries require their own recycling methods that differ from e.g. the recycling of lead acid batteries[68]. Li-ion batteries can be recycled in varying levels. The battery shell or case and the wiring of the battery often contains metals that are relatively easy to recycle, while recycling the valuable materials in the cells requires sophisticated technology[69]. A crude alternative is to simply dispose the cells by energy recovery. The more sophisticated technologies are used, the more valuable metals and other materials can be recovered. The chemistry of the Li-ion battery is an important factor in defining which recycling methods suit for which Li-ion battery types.

Several aspects that need consideration when recycling Li-ion batteries: for example, they require dismantling and discharging before the materials can be recovered, which requires additional effort compared to small portable batteries. Safety is a key issue: the batteries can have residual high voltages, which is why the abovementioned work must be carried out by trained personnel.

Only a relatively small amount of EV and similar batteries has so far reached the end of their usable life, limiting the current business potential of the recycling of these materials (**Figure 16** and **Figure 17**), although some recycling solutions do already exist. The amount Li-ion batteries ready for reuse and or recycling is continuously increasing, and China makes up observable portion of this growth. It is estimated[70] that by 2025, recycled lithium may make up to 9% of the world's total lithium battery supply, and by that same year more than 66% of lithium-ion batteries are expected to be recycled in China. For cobalt-containing batteries, the cobalt related recycling in China is expected to reach 76%, not taking into account production scrap or other sources. There is a need to develop more efficient recycling methods[71] as the amounts of waste EV and other industrial Li-ion batteries increase.

[66] Electrive; Electrive: Second-life (accessed 25.1.2019)
[67] Nissan and Eaton power ahead with second-life battery system, Nissan News, 2018
[68] BU-705: How to Recycle Batteries, Battery University
[69] The future of automotive lithium-ion battery recycling: Charting a sustainable course, Sustainable Materials and Technologies, Volumes 1–2, December 2014, Pages 2-7
[70] Recycled lithium volumes still 'relatively low, https://recyclinginternational.com/, 2017 (accessed 24.1.2019)
[71] BU-705: How to Recycle Batteries, Battery University

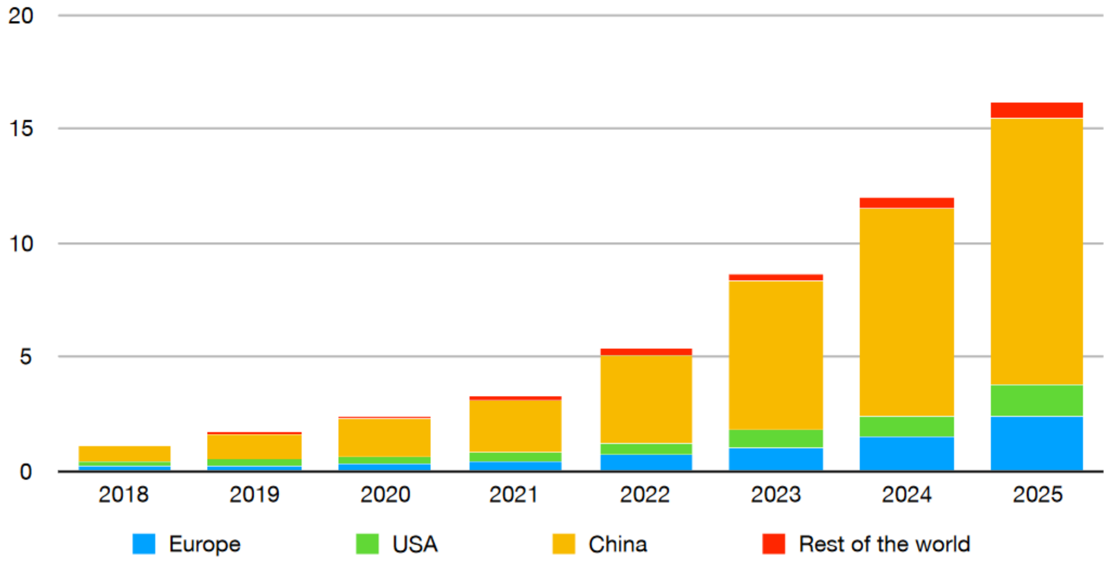

Figure 16. Lithium-ion batteries available for second life by geography (GWh)[72]

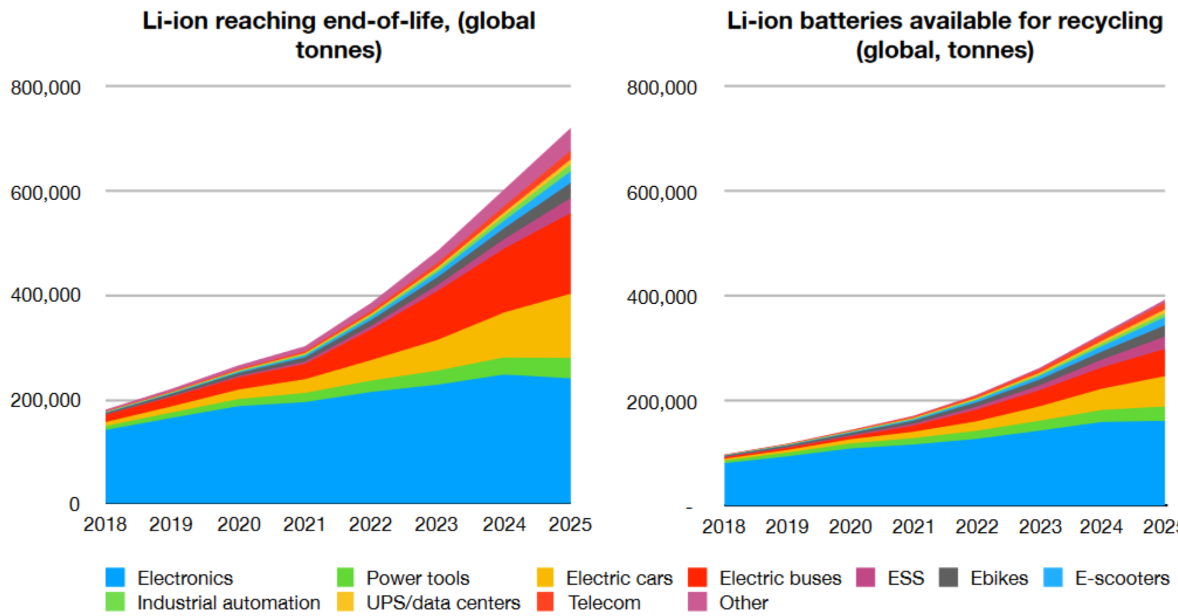

Figure 17. Lithium-ion batteries reaching end-of-life and availability[73]

4. Policy and regulatory framework

European Union (EU) has recognized the strategic importance of batteries in transitioning to a sustainable energy system, decarbonizing the transport sector and improving the competitiveness of EU industry. One of the recent key milestones in the EU policy context of batteries is the adoption of the Strategic Action Plan on Batteries (COM(2018) 293), which states the development and

[72] The lithium-ion battery end-of-life market – A baseline study For the Global Battery Alliance (part of World Economic Forum), Hans Eric Melin, Circular Energy Storage

[73] The lithium-ion battery end-of-life market – A baseline study For the Global Battery Alliance (part of World Economic Forum), Hans Eric Melin, Circular Energy Storage

production of batteries as a strategic imperative for Europe's clean energy transition and its automotive sector. It combines EU level measures across the battery value chain, aiming to make Europe a global leader in sustainable battery production and use. This includes securing access to raw materials, supporting large-scale battery cell manufacturing, strengthening EU research and innovation in battery-related topics, developing competence in all parts of the value chain and aiming for the lowest possible environmental footprint in the battery manufacturing industry.[74]

> "The strategic importance of batteries is clearly recognized within the European Union

The EU research and innovation program Horizon 2020 is funding battery related topics with a budget of €114 million in 2019[75]. Additional battery related topics will be funded with €20 million in 2020. The recent establishment of a related European Technology and Innovation platform (ETIP) will advance battery research by defining a long-term agenda, visions and roadmaps for battery research in the EU[76]. The European Commission (EC) has also announced continued work with the European Investment Bank (EIB) to support battery manufacturing projects through public funding, in order to reduce the related economic risk and leverage private investment. A large-scale research initiative covering advanced battery technologies is also under preparation.[77] These ETIPs are part of The European Strategic Energy Technology Plan (SET Plan) that, aims to accelerate the development and deployment of low-carbon technologies[78].

The European Commission has also indicated that Important Projects of Common European Interest (IPCEI) might be set up as part of the Strategic Action Plan on Batteries, since developing a EU-based battery industry is a long-term strategic goal requiring high levels of public funding[79]. IPCEIs aim at encouraging Member States to channel their public spending to large projects that make a clear contribution to economic growth, jobs and the competitiveness of Europe[80]. The IPCEI status provides the possibility for public investment to be exempt from the EU state aid rules. The IPCEI concerns first industrial deployment of an R&D project, for example the up-scaling of the pilot facilities and the testing phase. The IPCEI status is reserved for projects that involve several Member States, are ambitious in research and innovation and generate positive spill-overs across the EU.

4.1. Materials

The legislation concerning minerals exploitation in Finland is presented Mining Act (Kaivoslaki 503/65), the Mining Decree (Kaivosasetus 663/65) and in Amendments to Mining Law. The regulations aim to safeguard exploration and mining also in the future, assure constitutional rights of various stakeholders, offer local communities' possibility to influence and assure environmental

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74 European Commission, Strategic action plan on batteries, COM (2018) 293:

75 €114 million available under Horizon 2020 for next-generation batteries projects

76 European Commission - Press Release 15.10.2018: "EU Battery Alliance: Major progress in establishing battery manufacturing in Europe in only one year"

77 European Commission, Strategic action plan on batteries, COM (2018) 293:

78 Strategic Energy Technology Plan

79 European Battery Alliance Q&A, Brussels, 15 October 2018

80 European Commission – Press Release 13.06.2014: "State aid: Commission adopts new rules to support important projects of common European interest"

issues are properly dealt with. Currently there has been discussions regarding the reformation of the Mining Act. Especially additional taxation for the mines (kaivosvero) has been under discussions.

It is also worth noting that European Commission has adopted the raw materials initiative setting out the strategy for tackling the issue of access to raw materials in the EU. Additionally, commission publishes the list of critical raw materials (CRM) including raw materials with high economic importance to EU while having a high supply-risk.[81]

Other important battery material related legislative changes include potential changes in REACH classifications. European Chemicals Agency (ECHA) has announced in June 2018 that lead metal will be added to the REACH candidate list of substances that require authorization files. In case lead will be added to the list, it would significantly limit the usage of lead containing batteries currently representing 75% of the worldwide rechargeable batteries.[82] This is feared to hinder the energy transition but would potentially have a favorable effect on the Li-ion battery industry. Additionally, ECHA's risk assessment committee is working on the harmonized classification and labelling of cobalt metal for all routes of exposure and the concentration limits are under discussion. The new classification would affect the manufacturing of battery chemicals.

4.2. Batteries and cells

There are a number of international lithium-ion battery standards and guidelines from different governing organizations – mainly CEN/Cenelec, ISO, IEC, UN and IECEE – concerning manufacturing, labeling, testing, safety and transportation of lithium-ion cells and batteries.[83] An overview of these standards can be found at a dedicated battery standards website[84].

The transportation of lithium-ion batteries is regulated according to the mode of transport. Due to safety risks, lithium-ion cells and batteries are stored, handled and transported as dangerous goods. Key legislations followed in Europe include The European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR), The International Carriage of Dangerous Goods by Rail (RID), International Air Transport Association (IATA) Transport guidelines for lithium metal and lithium-ion batteries and International Maritime Dangerous Goods Code (IMDG Code).[85] Recent regulatory changes in 2016-2017 set new requirements concerning e.g. labeling and packaging and the state of charge of lithium-ion batteries. The shipping restrictions are expected to undergo further restrictions, affecting OEMs and manufacturers across the logistics chain.

Policy changes driven by industry representatives in the EU include the development in sustainable battery policies and the recognition of automotive and industrial batteries as a key enabler for the decarbonization of transport and energy systems, while avoiding bans on any specific battery technologies[86]. Following the adoption of the Strategic Action Plan on Batteries, the EC is working on the development of an Eco-design Regulation which will set requirements for the performance

[81] European Commission: Policy and Strategy for Raw Materials
[82] Lead REACH Consortium (2018): EU scheme to ban use of lead risks short-circuiting Europe's battery revolution
[83] Intertek: Navigating the Regulatory Maze of Lithium Battery Safety (accessed 19.12.2018)
[84] Battery Standards. info
[85] Croner-i Ltd: Transport of Lithium Batteries: In-depth (accessed 19.12.2018)
[86] EUROBAT: 2019 – A political key year for the European battery industry (accessed 19.12.2018)

and sustainability of batteries in the EU market[87]. The preparatory study of the Eco-design Regulation is expected to be finished by May 2019[88].

4.3. Applications

The current legal frameworks for energy markets in all Nordic countries are designed to fulfil the requirements of the regulations of EU's Third Energy Package[89] described in the EU directive 72[90] published in 2009. The directive states that the EU internal energy market is built on well-established principles, such as the right of access for third parties to electricity grids, free choice of suppliers for consumers, robust unbundling rules, the removal of barriers to cross-border trade, market supervision by independent energy regulators, and the EU-wide cooperation of regulators and grid operators.

EU Commission has in 2016 issued new proposals for amendments to facilitate the transition to a clean energy economy. The package called "The Clean Energy for All Europeans"[91], also called "The Winter Package", aims to reform the design and operation of the European Union's electricity market. The amendments are scheduled to come into force starting from 2020.

In its assessment of The EU Winter Package CEER (Council of European Energy Regulators) highlights e.g. the following issues to consider in relation to energy storage, electric vehicles, and markets overall:

- Smart home technologies and Internet of Things: EU Member States could consider whether there is a need for additional regulation on smart meters (in cases where private solutions for meters are installed).
- Self-generation of electricity: For the self-generator to be able to feed excess electricity into the grid and be financially compensated for it, they must sign a contract with a supplier that also sells electricity to the self-generator.
- Electrical energy storage: Customers' improved access to affordable energy storage may raise legislative issues regarding redistributive economic effects. Similar to electricity generated from on-site production, there is a matter of transparency as consumers may experience difficulties with understanding the costs, risks and benefits of energy storage.
- Charging stations and electric vehicles: A key question is if the general consumer and competition legislation is sufficient or is there a need for energy-specific rules in order to ensure an appropriate level of competition.
- Blockchain application in the energy market: The emergence of blockchain to manage transactions, together with the development of decentralized initiatives in the energy sector may challenge regulators' traditional approach to data exchange, centralized at DSO and

[87] European Commission - Press Release 15.10.2018: "EU Battery Alliance: Major progress in establishing battery manufacturing in Europe in only one year" (accessed 3.1.2019)
[88] Ecodesign preparatory Study for Batteries, European Commission
[89] European Commission Market legislation, (accessed 22.1.2019)
[90] EUR-Lex: Directive 2009/72/EC
[91] Clean energy for all Europeans, (accessed 22.1.2019)

market operator levels. It also raises the question of whether it is possible to regulate this market, considering its decentralized nature and possible lack of transparency resulting from peer-to-peer transactions.

The Finnish Government published the National Energy and Climate Strategy for 2030[92]. This strategy outlines actions that will enable Finland to attain the targets specified in the Government Program and adopted in the EU for 2030, and to systematically set the course for achieving an 80–95% reduction in greenhouse gas emissions by 2050. The strategy outlines that with minor exceptions, Finland will phase out the use of coal for energy by 2030. The minimum aim is to have 250,000 electric and 50,000 gas-powered vehicles on the roads. The electricity market will be developed at the regional and the European level. The flexibility of electricity demand and supply and, in general, system-level energy efficiency will be improved. Technology neutral tendering processes will be organized in 2018–2020, on the basis of which aid will be granted to cost-effective new electricity production from renewable energy. The share of renewable energy in the end consumption will increase to approx. 50 per cent and the self-sufficiency in energy to 55%.

EU Urban Vehicle Access Regulations set limits in urban areas. Many European cities have so called urban access regulations[93], in order to improve urban mobility and movement. These access regulations are local in nature and vary from country and may include e.g. Low Emission Zones, Road Tolls and Access Regulations. Also, European cities are introducing regulatory and financial incentives for low or zero emission vehicles and some are also planning to ban on liquid hydrocarbon powered vehicles within the next 10 to 20 years[94].

4.4. Recycling and reuse

The EU legislation on waste batteries is embodied in the Batteries Directive (2006/66)[95], and outlines that batteries placed on the market within the European Union. Batteries used in the automotive applications are classified as industrial batteries, however Li-ion batteries are not specifically mentioned in the directive. The directive intends to contribute to the protection, preservation and improvement of the quality of the environment by minimizing the negative impact of batteries and accumulators and waste batteries and accumulators. The directive prohibits the marketing of batteries containing some hazardous substances, defines measures to establish schemes aiming at high level of collection and recycling, and fixes targets for collection and recycling activities. The directive also sets out provisions on labelling of batteries and their removability from equipment. Also, the directive aims to improve the environmental performance of all operators involved in the life cycle of batteries and accumulators, e.g. producers, distributors and end-users and, in particular, those operators directly involved in the treatment and recycling of waste batteries and accumulators. Producers of batteries and accumulators and producers of other products incorporating a battery or accumulator are given responsibility for the waste management of batteries and accumulators that they place on the market. The directive has been evaluated for possible review as e.g. some critical raw materials or lithium, that are of high importance for current

92 Ministry of Economic Affairs and Employment of Finland, Energy and climate strategy
93 Urban Access Regulations
94 CEER Report on Smart Technology Development, (accessed 22.1.2019)
95 Batteries and Accumulators, European Commission

battery production, are not addressed in the directive[96]. The same dilemma will be encountered in relation to new battery technologies that are not yet on the market.

The so called ELV Directive[97] (end-of-life vehicles; 2000/53) aims at making dismantling and recycling of ELVs more environmentally friendly. The directive outlines targets for reuse, recycling and recovery of the ELVs and their components, and intend to push producers to manufacture new vehicles without hazardous substances, thus promoting the reuse, recyclability and recovery of waste vehicles. The Commission has a legal obligation to “review the ELV Directive, by 31 December 2020[98].

The EU Waste Directive[99] (2008/98) sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery. It explains when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products. The Directive lays down some basic waste management principles: it requires that waste be managed without endangering human health and harming the environment, and in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odors, and without adversely affecting the countryside or places of special interest. The Directive also introduces the "polluter pays principle" and the "extended producer responsibility".

96 Study in support of evaluation of the Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators, European Commission, 2018
97 http://ec.europa.eu/environment/waste/elv/index.htm
98 End of Life Vehicles, European Commission, accessed 22.01.2019
99 EU Waste Legislation

5. Key industrial actors in Finland, in the Nordics and in Europe

A wide range of Finnish, Nordic and European technology companies are integrating Li-ion batteries into their overall solutions. Especially in case of large global companies, Li-ion battery technologies and products may become part of their core offering by acquisitions or by organic growth and recruitments. Key actors across the value chain are presented in **Figure 18** below. The following chapters highlight activities by some of the main actors in Finland, Nordics and Europe. Examples of key networks are also described shortly. However, what is described here is by no means exhaustive to all activities that are currently going on in Europe in the Li-ion battery sector.

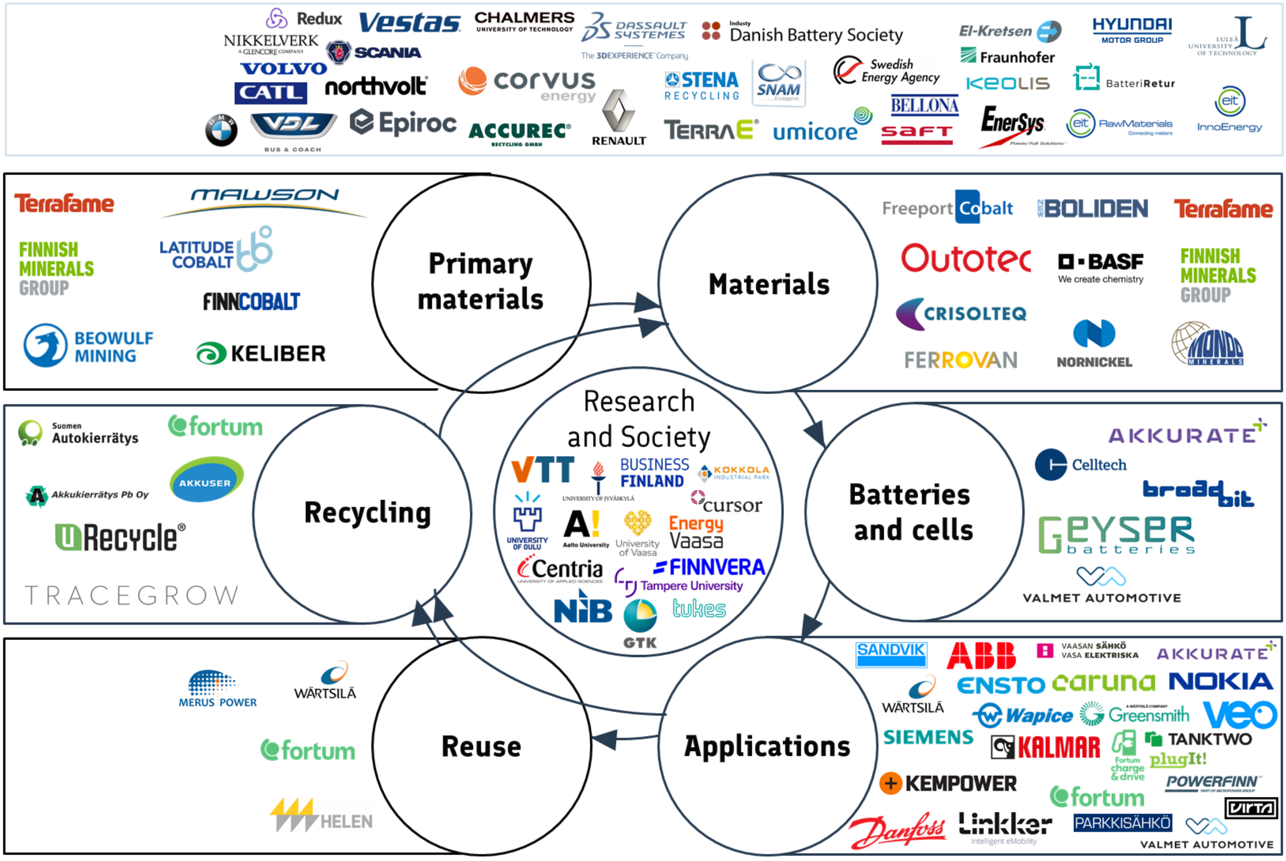

Figure 18. Examples of key actors in the Finnish and European battery industry

5.1. Materials

Finland

The activities promoting the battery production in Europe has offered opportunities to Finnish mines and has activated the field in a rather short period of time. There is current or planned production of all the tree important battery minerals, lithium, cobalt and nickel.

There are several activities around opening new mines for minerals used in Li-ion batteries. **Keliber** is planning to open a lithium mine in Central Ostrobothnia. Currently there is no other lithium mine in Finland. Long term aim is to produce 11 000 t lithium chemicals a year. **Latitude 66** is aiming at opening cobalt mines in Kuusamo and Posio, and **Finncobalt a** Co-Ni-Cu mine in Hautalampi (old Outokumpu mine). **Beowulf Mining** possesses a graphite deposit in Viiala (Heinävesi).

Currently operating mine **Terrafame** in Talvivaara produces nickel and cobalt among other metals. Terrafame has decided on investing on battery chemicals plant which would produce nickel sulphate and cobalt sulphate needed for EV battery production, and thus, is taking the step further in the value chain. The production plant would have a capacity of approximately 150 000 tons of nickel sulphate and approximately 5 000 tons of cobalt sulphate per year which would make Terrafame one of the most significant nickel sulphate producers globally[100]. The aim is to have the commercial production starting in 2021[101]. Nickel among other metals (incl. small amounts of Co) is also produced in **Boliden Kevitsa** mine and refinery. Small amounts are also produced in **Boliden Kylylahti**[102]. **Mawson Resources** is a natural resources company engaged in the acquisition and exploration of precious and energy mineral interests. In 2018, Mawson announced the discovery of highly significant cobalt enrichment associated with previously identified gold mineralization at the company's Rajapalot project in northern Finland[103]. In addition to Rajapalot, the company also operates a project in Rompas, Finland. There are also plans to recover valuable substances from processing side streams. Companies with such focus include **CrisolteQ Oy** and **Ferrovan**. Additionally, **Mondo Minerals** is investigating the possibilities to recover Ni from talc mineral.

Fully state-owned **Finnish Minerals group** (FMG) is an important player when it comes to the Li-ion battery materials. FMG aims to build leading ecosystem for Li-ion battery production in Europe and FMG owns, manages and develops companies, investment programs and RDI-projects related to Finnish Li-ion battery and mining cluster. FMG is a long-term strategic owner of e.g. Terrafame Oy.

In Harjavalta, there is a significant non-ferrous metals production cluster. **Boliden Harjavalta** has Cu and Ni smelters in Harjavalta industry park. **Nornickel Harjavalta** (Norilsk Nickel Harjavalta Oy) is a producer of various nickel products. Chemicals produced for battery industry include nickel hydroxide and by-products such and cobalt sulphate. **BASF** has announced to join forces with Nornickel to supply the Li-ion battery materials market. BASF's first European battery chemicals production in Harjavalta will supply approximately 300,000 full electric vehicles per year. BASF and Nornickel have signed long term, market-based supply agreement where Nornickel will supply nickel and cobalt feedstock for BASF. The plant will run on the locally generated renewable energy resources.[104]

Freeport cobalt has a cobalt refinery in Kokkola and is a major producer of cobalt chemicals for various industries including Li-ion battery industry. The refinery is the largest in the world covering about 10 % of total global production of cobalt chemicals. Products include e.g. Li-ion battery grade cobalt oxides and mixed metal hydroxides used as a precursors for cathode materials[105].

[100] Terrafame (2017): Terrafame Ltd. plans nickel and cobalt chemicals production for battery applications
[101] Terrafame (2018): Terrafame decides to invest in battery chemicals plant
[102] Boliden Annual Report 2017
[103] Mawson Identifies Extensive Cobalt Mineralization at Rajapalot, Finland

[104] BASF (2018): BASF and Nornickel join forces to supply the battery materials market

[105] Freeport Cobalt

Outotec is an important solution provider for metal producers with know-how on processing and hydrometallurgy and is for example conducting the basic engineering for Keliber lithium mine[106].

Europe

In Sweden, **Leading Edge Materials Corp** is investigating possibilities in value added graphite market such a battery industry while their graphite production is halted due to the falling graphite prices.[107] **Glencore Nikkelverk** nickel refinery in Norway produces primarily nickel, copper and cobalt products and is the largest nickel refinery of western world[108]. In Norway, **Skaland Graphite AS** has a graphite mine in Trælen and there are promising graphite prospects in the country[109]. There are also companies developing material for battery production. For example, **Elkem** is working on synthetic graphite and silicone anode materials for Li-ion batteries.

Savannah Resources possesses a lithium deposit in Mina do Barroso in Portugal and is aiming to start the production of lithium concentrate in 2020[110]. When it comes to the cathode materials, Belgian **Umicore** with current production in Asia has announced in June 2018 a major investment in Nysa, Poland, for the production of cathode materials. The aim is to start deliveries in late 2020. Additionally, Umicore is planning to build a new Process Competence Centre in Belgium to serve the development and scale-up of high-efficiency production technologies.

Solvay is developing state-of-the-art electrolytes, electrode binders and separators for highly efficient batteries. They have considered building a plant in Europe.

5.2. Batteries and cells

Finland

No large-scale battery cell manufacturing exists currently in Finland, although there have been efforts to attract large global battery cell manufacturers to locate their new cell manufacturing facilities in Finland. A lithium-ion cell manufacturing facility with an annual capacity of 100 MWh was opened in Varkaus, Finland in 2010, but was shut down in 2013. **European Battery Technologies** (EBT) has previously announced plans for restarting the production of lithium-ion batteries in Finland[111,112], but has remained inactive. EBT acquired the lithium-ion battery manufacturing equipment from the former European Batteries in Varkaus, Finland, after its shutdown in 2013 but the actual facility is currently in the ownership of the City of Varkaus. EBT has conducted and is also presently conducting discussions with various potential partners and investors to restart manufacturing at the Varkaus plant, however until now without success. At the same time, the City of Varkaus and its business services agency Navitas is also making all the possible efforts to have the facilities reopened for battery manufacturing in the near future.

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106 Keliber (2017): Keliber and Outotec sign Basic Engineering Contract
107 Leading Edge Materials: Woxna Graphite
108 Nikkelverk Products
109 Gautneb, Håvard (2015). Natural Graphite in Norway – Overview and latest exploration results (presentation)
110 Savannah Resources PLC: Mina do Barroso
111 ”Varkauden akkutehdas yrittää uudelleen”, Tekniikka ja Talous (4.1.2016)
112 ”Varkauden akkutehdas käynnistyy taas – SS: Jopa 100 työpaikkaa luvassa”, Talouselämä (15.7.2015)

Celltech is a battery and battery power supply solution wholesaler in Finland. The core competence of Celltech is design and delivery of battery solutions for various battery needs. Celltech's supplier and partner network includes large battery industry players such as Panasonic, SAFT and Samsung. Celltech is part of the Swedish corporation Addtech, which consist of about 140 independent companies.[113]

Geyser Batteries is a Russian-Finnish battery startup developing batteries for fast charging and short-range applications based on supercapacitors in a single electrochemical system. Current activities include R&D and small-scale production through manual assembly. A pilot production line is expected to be ready by the end of 2019 in Vaasa.[114,115]

BroadBit Batteries is a Finnish battery startup developing new batteries using sodium-based chemistries for application areas such as transportation, engine starters, portable electronics and backup power. The company is currently focusing its activities on R&D with an aim of scaling up from lab to pioneering scale in the coming years.[116]

On the Li-ion battery assembly side, **Valmet Automotive** produces battery pack systems for electric vehicles and moving machinery applications in Uusikaupunki, Finland. They do not produce the battery cells but have partnered with the Chinese battery market leader CATL, which is also one of the shareholders of Valmet Automotive. Based on modern manufacturing technologies and system-level engineering, Valmet Automotive produces battery packs and modules tailored for specific industrial customer needs.

Europe

The Li-ion battery production capacity in Europe is currently very limited, but according to a recent report by the EU Joint Research Centre[117], Europe's share in global battery production is expected to increase from 3% currently to 8% by 2022. If all the announced plans were to be realized, lithium-ion manufacturing capacity in Europe would exceed 100 GWh by 2028. Considering the rapid growth of demand due to the expected large increases in EV sales, manufacturing capacity should be ramped up in the next few years: EBA estimates that answering the European battery demand would require 10-20 gigafactories[118]. The existing and announced lithium-ion battery cell production capacities in Europe are presented in **Table 3**, and the expected development of lithium-ion cell manufacturing capacity in the EU in **Figure 19**.

> "*Currently no large-scale cell manufacturing in Europe – Answering the demand would require 10-20 'giga-factories'*"

[113] Celltech
[114] Geyser Batteries: Batteries
[115] "Vaasassa alkaa superakkujen valmistus – Geyser Batteriesin teknologia kehitetty Venäjällä, Pohjalainen: Wärtsilä sparrasi", Tekniikka ja Talous (23.8.2018)
[116] Broadbit
[117] Tsiropoulos, I., Tarvydas, D., Lebedeva, N., Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth, EUR 29440 EN, Publications Office of the European Union, Luxembourg, 2018, JRC113360
[118] European Battery Alliance

Table 3. Main existing and announced lithium-ion battery production capacities in Europe (Sources: EU JRC 2018[119] and EU JRC 2016[120])

Company	Location	Capacity (GWh)	Status
Samsung SDI (SK)	Hungary	2	operational
Nissan (JP)	UK	1.45	operational
Bollore (FR)	France	0.5	operational
Leclanché (CH)	Germany	0.1	operational
SAFT (FR)	France	0.06	operational
Custom Cells (GE)	Germany	0.02	operational
EAS Batteries (GE)	Germany	0.1	operational
European Battery Technologies (FI)	Finland	0.03	inactive
LG Chem (SK)	Poland	4-12	production starts in 2019, to be ramped up to 9-12 GWh
SERI/FAAM (IT)	Italy	0.2	production starts in 2019
Northvolt (SE)	Sweden	8-32	production starts in 2020, to be ramped up to 32 GWh by 2023
SK Innovation (SK)	Hungary	7.5	production starts in 2022
CATL (CN)	Germany	14	production starts in 2022
TerraE (GE)	Germany	4-38	production starts in 2019, to be ramped up to 38 GWh

Northvolt is planning to build a large-scale battery manufacturing facility in Sweden, supported by a €52.5 million loan from the **European Investment Bank** (EIB). A demonstration line is currently being builtin Västerås, to be followed by the construction of the large-scale Li-ion battery cell production plant in Skellefteå and a Li-ion battery module production facility in Gdansk, Poland.

[119] Tsiropoulos, I., Tarvydas, D., Lebedeva, N., Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth, EUR 29440 EN, Publications Office of the European Union, Luxembourg, 2018, JRC113360

[120] Lebedeva, N., Di Persio, F., Boon-Brett, L., Lithium ion battery value chain and related opportunities for Europe, European Commission, Petten, 2016

Northvolt intends to begin production in 2019 and scale up to 32 GWh by 2023.[121] Northvolt is also working together with Umicore and **BMW** on the development of a sustainable value chain for EV batteries to accelerate the sustainable industrialization of battery cells in Europe, along with the development of associated skills.[122]

The German **TerraE** consortium, led by **BMZ Group**, is working to establish large-scale cell production in Germany already by 2020. BMZ Group, which is a major producer of lithium-ion battery systems, has committed to investing a total of €300 million in the cell production facility, which has a planned initial capacity of 4 GWh.[123] The German government has announced that it will support the establishment of battery cell production in Germany with a €1 billion investment. TerraE was formed in May 2017 by 17 major companies and research institutions in Germany, representing the whole supply chain from material producers to industrial customers. Large-scale series production is planned to be established at two German locations on a foundry concept, enabling the production of customized lithium-ion cells according to customer specifications. Related German networks include **Fraunhofer Battery Alliance**, consisting of researchers and developers from 20 Fraunhofer institutes, and **KLIB**, the German lithium-ion battery competence network. The German battery cell and pack producer **Varta**, currently focusing on industrial and consumer batteries, has a research agreement with the Fraunhofer institute concerning mass production of lithium-ion battery cells for electric cars[124]. Several German automotive companies are also looking into forming partnerships or joint ventures to secure the supply of EV batteries[125].

SAFT, a French producer of industrial batteries, has started a consortium with **Siemens**, **Solvay** and **Manz** for joint development and production of next generation batteries in Europe. The focus is on advanced lithium-ion and solid-state battery technologies. Siemens has also piloted digitized and automated production lines.[126]

South-Korean **SK Innovation** and **LG Chem** as well as Chinese **CATL** are investing in large-scale Li-ion battery production in Europe. South-Korean **Samsung SDI** opened an EV battery plant in Hungary in 2018, expected to produce batteries for 50 000 electric vehicles annually[127]. US-based **Tesla** has also announced their interest in establishing EV battery cell production in Europe.[128]

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[121] European Commission - Press Release 15.10.2018: "EU Battery Alliance: Major progress in establishing battery manufacturing in Europe in only one year" (accessed 19.12.2018)
[122] Press release: "BMW Group, Northvolt and Umicore join forces to develop sustainable life cycle loop for batteries"
[123] Press release, 28.11.2018: "TerraE on the way to the first German cell production"
[124] Reuters: "Germany's Varta steps up plans to mass produce electric car battery cells"
[125] Reuters:"Factbox: Plans for electric vehicle battery production in Europe"
[126] European Commission - Press Release 15.10.2018: "EU Battery Alliance: Major progress in establishing battery manufacturing in Europe in only one year" (accessed 19.12.2018)
[127] Samsung SDI Completes EV Battery Plant Construction in Hungary (2017)
[128] European Commission - Press Release 15.10.2018: "EU Battery Alliance: Major progress in establishing battery manufacturing in Europe in only one year" (accessed 19.12.2018)

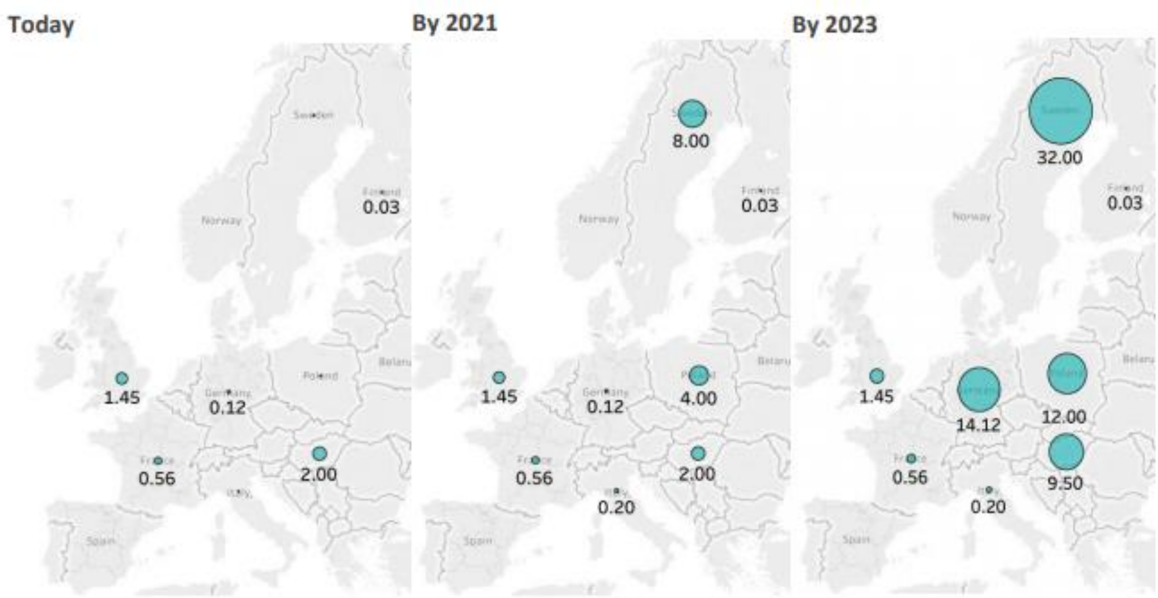

Figure 19. Expected development of Li-ion cell manufacturing capacity (GWh) in the EU[129]

5.3. Applications

Finland

Finland based companies are actively developing solutions that connect and apply directly with current and future Li-ion battery related operations and trends, for example:

- Charging solutions for demanding conditions (e.g. Kempower)
- Digital applications for battery related operations. e.g. regenerative grid simulation that may be applied for car charging (e.g. Wapice, Ensto, Liikennevirta, Fortum)
- 2nd life battery applications that ties in with the wider automotive industry[130]
- Using battery solutions to support grid stability[131, 132]
- Battery diagnostics and testing services (e.g. Akkurate)
- Electric buses (e.g. Linkker)
- Energy storage and energy management solutions (e.g. Merus Power, Fortum, Wärtsilä)
- Development of heavy duty electronically powered vehicles (e.g. Sandvik)
- Developing electric and Li-ion battery solutions for ferries and shipping (e.g. Rolls Royce)

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[129] Tsiropoulos, I., Tarvydas, D., Lebedeva, N., Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth, EUR 29440 EN, Publications Office of the European Union, Luxembourg, 2018, JRC113360

[130] Hyundai Has New Second-Life Use For Battery Packs, InsideEV's (27.6.2018)

[131] Press release: Fortum to install Nordic's biggest battery to support grid stability (28.11.2018)

[132] Press release: Saft to deliver megawatt-scale Li-ion battery system for Fortum in the largest electricity storage pilot project in the Nordic countries (26.4.2016)

Finland's long tradition of developing solutions, products and services for demanding environments is reflected also when Finland based companies integrate Li-ion batteries into their overall company portfolio.

There are several large technology companies that develop battery applications for use in harsh environments. **Wärtsilä** develops within its marine segment hybrid/battery systems that are suitable for use in a variety of applications, including offshore vessels, tugs, ferries and coastal vessels, buildings as well as for retrofits of existing installations. For example, Wärtsilä has developed a hybrid tugboat propulsion solution where the ship is capable of operating on electrical battery power when in transit, and otherwise on a hybrid diesel-electric mode when higher power output is needed[133]. **Kempower** designs, manufactures and commercializes charging solutions for demanding conditions to meet an increasing demand in the overall energy transition. Customer segments include passenger cars, commercial vehicles, heavy duty vehicles and electric marine. **Ensto** provides smart electric solutions for electricity distribution networks, buildings, marine and electric transport, including electric vehicle charging solutions. **Sandvik**, an engineering group in mining and rock excavation, metal-cutting and materials technology, is bringing electrified vehicles into the heavy-duty markets. In mid-2018, Sandvik inaugurated the opening of its Battery Electrification Innovation and Development Center for loaders and trucks in Turku, Finland. This development facility aims at creating innovative battery products and electric solutions for the global mining and construction markets and develop technology talent in Finland[134]. **Kalmar**, part of Cargotec, launched in 2016 a lithium-ion battery technology for its 5-9 ton electric forklift truck range[135], and in 2018 the company announced its plans to offer electric versions of all their vehicle models by 2021[136]. **Rocla** develops and manufactures electric warehouse trucks, forklifts and automated guided vehicles (AGV). **Avant Techno** develops and manufacturers loaders, and has also integrated battery powered versions into its product portfolio.

Nokia is a key player in telecommunications and mobile network applications, where lithium-ion batteries are expected to increasingly replace lead-acid batteries.

Energy storage is a theme with growing importance as companies and societies pursue visions and strategies for increased use of renewable energy sources. Traditionally batteries have been thought of as merely storing energy, but companies are moving to utilizing battery solutions as a mean to improve a e.g. hydropower plant's ability to function as regulating power for the electricity network, as is the case of **Fortum**'s initiative on the Dalälven in Sweden[137]. Fortum is also actively developing solutions for smart energy, solar, and vehicle charging. **Wärtsilä** is also active within energy storage, e.g. in solar and hybrid solutions. The company envisions a 100% renewable energy future and sees its place in the overall value chain as an energy system integrator. The company acquired **Greensmith Energy Management Systems Inc.**[138] in 2017 in order to strengthen its presence within grid-scale energy storage software and integrated solutions. In 2018 Greensmith announced

[133] Hybrid on ice, 2018
[134] Sandvik opens battery electric vehicle research centre in Turku, 2018, (accessed 22.1.2019)
[135] Kalmar introduces new lithium-ion battery technology for its electric forklift truck range, 2016
[136] Kalmar planning to electrify entire fleet, www.electrive.com 2018 (accessed 24.1.2019)
[137] Fortum to install Nordic's biggest battery to support grid stability
[138] Wärtsilä completes acquisition of Greensmith Energy Management Systems Inc

the launch of a standardized energy storage solution located in an ISO 40-foot container which contains Li-ion batteries, power distribution, safety, fire suppression, and air conditioning systems[139]. **Merus Power** designs, manufactures and markets a wide range of world leading power quality solutions for dynamic reactive power compensation, including the integration of Li-ion battery solutions into its energy storage system solutions. In 2018 the company agreed to deliver a turnkey energy storage system to an intelligent and self-sufficient energy business district built in the town of Lempäälä, south of Finland. **Powerfinn** develops and manufactures Li-ion battery charging and power supply solutions in Salo. **Eaton** offers solar, wind and electric vehicle charging solutions, and seeks to combine several aspects of energy storage needs in one.

There are several companies that act within the EV charging business. **Fortum Charge & Drive** targets specifically EV charging in public spaces and parking areas, and provides 24/7 operating services for chargers including customer service and payment solutions. **TankTwo** is a Finnish-American start-up which provides new battery technology for electric vehicles. It uses string cell battery technology: vehicles with TankTwo batteries can swap a full tank of depleted cells for charged cells in less than 3 minutes. **PlugIt** provides services for mapping potential EV charging point locations, as well as delivery and installation of the charging points. EV charging point focus includes households, housing communities, workplaces, businesses, supermarkets and hotels. **Virta** operates an electric car charging network in Finland, with more than 500 charging points around the country. The company presents three types of EV charging points: Virta Koti for private households, Virta Kiinteistö for housing cooperatives and workplaces, and Virta Business for commercial use. Virta was founded by 18 Finnish electricity companies, including Helen, Vantaan Energia, Lahti Energia, Jyväskylän Energia among others. **Parkkisähkö** provides EV charging services, and presents solutions for housing cooperatives and companies.

Battery systems engineering encompasses different disciplines but all focus on integrating and optimizing the system level of a battery application. **Wapice** offers energy companies and their customers intelligent and comprehensive energy services for managing contracts and invoices and monitoring energy consumption and production. **Akkurate** presents solutions within battery diagnostics and testing services, as well as life cycle management of lithium-ion batteries. **Danfoss** provides systems engineering solutions for both energy storage and marine applications. **VEO** develops automation, drives and power distribution solutions for the energy and process industries, as well as for marine applications. **Siemens** provides solutions, services and products for energy storage and production, smart power grids, and for efficient transport and competitive industrial operations. It partnered in 2017 with the Sello shopping centre in Espoo to develop a smart power microgrid[140]. **Linkker** develops and manufactures electric buses based on light weight chassis and opportunity charging.

139 Greensmith Energy unveils standardized energy storage solutionv
140 Shopping Center Sello to begin building a virtual power plant for properties in Finland

Nordics

In the Nordic countries, **Volvo** Truck launched in 2018 its first all-electric truck for commercial use[141]. Its construction equipment business developing electric applications for smaller machines[142] announced that the company will have available by 2020 fully electric range of wheel loaders and compact excavators. Northvolt, which plans to establish battery cell manufacturing in Northern Sweden, has established strategic partnerships with **ABB** (e.g. R&D operations and a demonstration production line in Västerås, Sweden[143]), **Vestas**[144] and **Scania**, as wells as Canadian lithium supplier Nemaska Lithium and Japanese battery production equipment manufacturer SECI[145]. Northvolt has also commenced cooperation with **Epiroc** who in turn produces mining, infrastructure and natural resources equipment. The maritime industry is strong in Norway. There for example **Corvus Energy**[146] provides purpose-engineered energy storage solutions for marine, oil & gas and port applications.

Europe

On the European level there is a wealth of Li-ion battery related activities going on within energy storage, automobile, marine applications, and software simulation. **Renault** is actively developing its Li-ion battery powered automobile range and is also developing solutions for Li-ion battery 2nd life and energy storage application areas. With its "Advanced Battery Storage" program, the company aims to build the largest stationary energy storage system using EV batteries ever designed in Europe by 2020 (power: 70 MW / energy: 60MWh[147]). **VDL Bus & Coach** develops and manufactures a wide range of buses, coaches and chassis modules, and has integrated electric vehicles into its overall product portfolio. **Dassault Systèmes the 3DEXPERIENCE Company**, provides business and people with virtual universes to imagine sustainable innovations. The company, named the World's Most Sustainable Corporation for 2018, seeks to develop world-leading solutions to transform the way products are designed, produced, and supported, including Li-ion batteries. The company provides solutions for Battery Development and Manufacturing. For Battery Development, from new materials discovery to battery system design, Dassault Systèmes sees digital software simulations, as powerful tool to complement empirical testing, to accelerate innovation cycles and create new insights into Li-ion battery lifecycle and performance

5.4. Recycling

Finland

The volumes of waste EV and other waste industrial Li-ion batteries are still low in Finland, which currently limits the business possibilities of the end part of the Li-ion battery value chain. However, the volumes will increase in the future as Li-ion batteries become more common and more of them

[141] Premiere for Volvo Trucks' first all-electric truck
[142] Volvo Construction Equipment goes electric on smaller machines
[143] Northvolt gives Västerås, Sweden, a key role for battery manufacturing, 2017
[144] Vestas and Northvolt partner on battery storage for wind energy to support the further integration of renewables, 2017
[145] Northvolt kicks off construction for Northvolt Labs – establishment marks first step towards European large-scale battery cell manufacturing, Northvolt Internet page
[146] Corvus Energy
[147] Groupe Renault is launching "Advanced Battery Storage", the biggest stationary energy storage system from electric vehicle (EV) batteries in Europe, 2018

eventually reach the end-of-life. Several operators in Finland have already been active, providing Li-ion battery waste management solutions.

For waste material that is under producer responsibility - such as Li-ion batteries - usually a producer coordination organization is established to take care of the material's waste management. In Finland, **Suomen Autokierrätys**, the producer coordination organization of motor cars, has recently registered as a producer coordination organization of EV Li-ion batteries as well. In practice Autokierrätys carries out the required reporting on waste Li-ion battery volumes to the authorities and fulfills similar legal requirements on behalf of its members. Due to the low volumes of waste EV Li-ion batteries, there is currently no centralized collection scheme in Finland and automotive companies organize transportation of waste EV Li-ion batteries themselves to recycling or back to their own manufacturing facilities, where the Li-ion batteries and/or their cells are reused in other applications.

A producer coordination organization taking care of the waste management of non-portable Li-ion batteries of consumer products, such as electric bikes, is yet to be established in Finland. Considering the anticipated increase of this material in the near future, a producer coordination organization for this type of material would be essential as it is unlikely that individual importers and other producers will organize an effective waste battery collection scheme by themselves.

Akkuser is an example of a Finnish company that is at the forefront of the Li-ion battery recycling business. Since 2006, they've operated a waste battery processing facility in Nivala, Finland. Akkuser processes and recycles practically all the portable batteries of Finland, and this also includes Li-ion batteries of portable devices. Akkuser also processes a significant amount of waste batteries from other countries as it has much more capacity than would be needed for domestic materials only. Recently the company has invested in a new production line capable of recycling EV and other low-cobalt li-ion batteries, providing a much-needed recycling solution that is an interesting possibility for international actors as well. Akkuser's processes include the processing of the cell material of the batteries. The materials are processed via a two-stage crushing line followed by a magnetic and mechanical separation unit, resulting in metal concentrates that can be utilized as raw material by metal refineries. If Li-ion battery cell manufacturing will be established in Finland in the future, Akkuser would provide a logistically interesting possibility for the processing of cell production waste.

uRecycle Group and its subsidiaries is another key actor in Li-ion battery recycling in Finland. They provide recycling services for EV and other industrial Li-ion batteries that includes safe transportation, dismantling and discharging of the batteries, recycling and reporting. uRecycle's transportation solutions adhere to the ADR treaty[148] and include specialty transit cases suitable for waste Li-ion batteries. uRecycle operates also outside Finland, especially in the Nordics.

Fortum, the Finnish energy giant, provides recycling of industrial Li-ion batteries. It acquired in 2016 the waste processing company **Ekokem,** who already had solutions and know-how for waste Li-ion battery recycling and processing.

148 UNECE: The European Agreement concerning the International Carriage of Dangerous Goods by Road

Tracegrow is a Finnish startup company that has developed a novel method of creating micronutrient fertilizers using waste batteries as raw material. Their innovations have drawn a lot of attention recently, however, their focus is the recycling of traditional alkaline batteries and thus they are not part of the Li-ion battery value chain.

Nordics

In Sweden and Norway with a lot of EVs, collection and dismantling of industrial Li-ion batteries is carried out. However, no similar waste Li-ion battery processing facility as Akkuser exists in those countries. For collection and dismantling of Li-ion batteries, the Swedish recycling company **Stena Recycling**, and also uRecycle in Sweden, carry out these operations. Stena Recycling also operates in Finland. Producer coordination organizations dealing with EV batteries in Sweden and Norway are **El Kretsen** and **Batteriretur**, respectively. In Norway, the **Glencore Nikkelverk** refining plant is a potential utilizer of highly processed waste battery cell materials, producing cobalt and nickel. Stena Recycling is active also in research and development of Li-ion recycling methods, and they are currently developing an EV Li-ion battery recycling solution for **Volvo Cars** in cooperation with **Luleå University of Technology**.[149]

In the Nordics apart from Finland, cell material from waste Li-ion batteries is generally exported for processing due to the lack of processing plants in these countries. The main reason for the non-existence of the Li-ion battery processing plants is the lack of adequate volumes of EV and industrial waste Li-ion battery waste such that the processing would make sense as a business. As EVs and similar applications for industrial Li-ion batteries become more common, the more interest there is to establish new Li-ion battery waste processing facilities in the Nordics. What recycling possibilities **Northvolt**'s project will spark is a highly interesting topic for the whole Li-ion battery sector in the Nordics.

Europe

As the volumes of end-of-life EV and other Li-ion batteries increase, the more interesting this part of the Li-ion battery value chain will become across Europe. However, currently also in Europe, the volumes of waste EV and other industrial Li-ion batteries are small, a similar situation to the Nordics and Finland. Despite of this situation, several processing plants for end-of-life industrial Li-ion batteries exist. A major example is the Belgian company **Umicore Cobalt & Specialty Materials**, which is operating a waste Li-ion battery processing facility with a capacity of 7000 metric tons of Li-ion and NiMH batteries per year. Umicore is able to process and recycle all the major Li-ion types, including those used in EVs. Umicore uses a pyro-metallurgical method that recovers valuable metals from the batteries. Further examples of European major actors with waste Li-ion battery processing facilities are the German companies **Redux** and **Accurec** and the French company **Snam**.

5.5. Reuse

There is a great deal of interest towards developing the re-usage of old EV Li-ion batteries before recycling and as such extending their life cycle. Renewable energy storage solutions are found in both small-scale residential settings and large-scale industrial operations, and a lot of development is

[149] Tutkimushanke: litiumioniakkujen kierrätys, Stena Recycling

going on to understand how used automotive Li-ion batteries could be utilized in such stationary applications. Li-ion battery storage as part of the renewable energy value chain would provide needed flexibility, as well as an outlet for so called 2nd life Li-ion batteries.

Table 4 below presents some examples of current publicly announced collaborations for Li-ion battery 2nd life applications[150]. There is a sense that Li-ion battery second life applications still need more time to develop, in order to properly address possible concerns on safety, but also to better understand Li-ion battery performance during its lifetime.

Table 4. Examples of pilots and joint initiatives related to Li-ion battery reuse

	Partners	Brief description/area of application
Nissan[151]	4R Energy Corporation EDF Energy[152]	Energy storage banks for off-grid lights in a new effort called “The Light Reborn.
Hyundai Motor Group	Wärtsilä[153]	Partnership for maximizing second-life electric vehicle batteries
BMW[154]	Vattenfall	Power storage project with 500 BMW i3 batteries
Daimler AG[155]	GETEC ENERGIE, and technology company The Mobility House	Energy storage facility with 1920 battery modules in a plant in Elverlingsen in South Westphalia, Germany
Volvo[156]	Göteborg Energi, housing association Riksbyggen and the Johanneberg Science Park	Pilot project using bus batteries for stationary energy storage with 200 kWh capacity.
Renault[157]	Powervault	Home energy storage units
Renault	La Banque des Territoires, the Mitsui Group, Demeter, and The Mobility House	The Mobility House. Advanced battery system, reutilising batteries from used electric vehicles

The waste management and recycling operators are relevant actors also in the re-usage of batteries and battery cells, providing collection schemes and services, storage, dismantling of batteries and the delivery of recovered battery cells for repurposing.

150 Vattenfall power storage with 500 BMW i3 batteries goes live, May 19, 2018, www.electrive.com (accessed Nov 9, 2018)
151 Nissan Pushes Into Energy Storage With Second-Life Battery Initiative, Clean Technica (24.3.2018)
152 Nissan and EDF Energy explore 2nd life use of batteries, Electrive (11.10.2018)
153 Press release: Wärtsilä and Hyundai Motor Group announce energy storage partnership maximizing second-life electric vehicle batteries (26.6.2018)
154 Vattenfall power storage with 500 BMW i3 batteries goes live, May 19, 2018, (accessed Nov 9, 2018)
155 What’s Possible for Used EV Batteries? Daimler Energy Storage Units Provide Second Life Power, Clean Technica (28.6.2018)
156 Volvo bus batteries find 2nd life as solar energy storage, Electrive (6.12.2018)
157 Renault to install Europe’s largest 2nd life battery storage, Electrive (26.9.2018)

6. Status of the Finnish know-how

6.1. Materials

There is good level of know-how in Finland regarding the exploration, mining, raw materials production, processing and refining due to the long history of mining in Finland. The geological expertise of **GTK** and its vast world-class geoscientific data is important not only regarding the current Li-ion battery boom but also in the future when different minerals are required for next generation batteries. Geology research and education is focused in Finland to **University of Helsinki, University of Turku** and **University of Oulu.**

Finnish academic Li-ion battery chemistry and electrode materials know-how is concentrated to **University of Oulu** (Kokkola University consortium Chydenius)[158], **Aalto University** and **University of Eastern Finland**. When compared globally, the scale of research is modest. However, the Li-ion battery chemistry know-how has grown rapidly in the recent past years in Finland, most likely due to the evolving "hype" around the Li-ion battery industry and the Li-ion battery mineral deposits in Finland. The level of research is very globally competitive, however due to the modest scale, the universities have to specialize on rather narrow niche areas to also keep their research competitive.

When it comes to competences within companies, for example **Outotec** has high competence on solutions for minerals processing, refining and water treatment. For the Li-ion battery chemicals, e.g. **Freeport Cobalt** has high level of knowledge on cobalt chemicals. In general, there are less players and know-how at this stage of the value chain when compared to the earlier steps. The largest competence gap is in active materials know-how, as currently there is no production of active cathode materials in Finland to act as a driver for the knowledge development.

6.2. Batteries and cells

The existing research and education activities in the field of Li-ion batteries and cells are currently very limited in Finland. **Centria University of Applied Sciences** has a Li-ion battery research laboratory, which includes a small-scale production line and testing equipment[159]. **University of Eastern Finland** has on-going research on lithium-ion battery health and degradation mechanisms[160]. Universities and institutions in Vaasa have jointly established a Li-ion battery technology education module[161]. **VTT** has a Li-ion battery technology laboratory with facilities for testing and characterisation of battery cells, modules and packs[162]. Companies with R&D activities in Finland include **Valmet Automotive** in Li-ion battery systems and **Geyser Batteries** and **Broadbit** in new battery technologies.

[158] Kokkolan yliopistokeskus Chydenius: Tutkimus
[159] Centria ammattikorkeakoulu: Akkulaboratorio
[160] University of Eastern Finland: LiANA
[161] Press release: Sitra to Fund Battery Technology Education in The Vaasa Region, GigaVaasa (20.12.2017)
[162] VTT: Battery testing facilities

6.3. Applications

Applications of Li-ion batteries is a vast area. In general, a lot the knowledge in the Li-ion applications area is residing directly at companies. There is a good level of understanding in companies on integrating Li-ion batteries into an overall solution, especially when related to traditionally strong Finnish industrial segments such as heavy-duty machinery and maritime applications. Examples of companies that focus on R&D in Li-ion application areas in Finland are e.g. **Sandvik**[163], which opened a Li-ion battery-electric vehicle research center in Finland in 2018, and **Valmet Automotive**[164] that does R&D on EV drivetrains and battery packages. From the research institutions, **VTT** is, as part of its overall focus on Li-ion batteries, working on application of Li-ion batteries in different solutions, such as applied energy storage. **Turku University of Applied Sciences**[165] is doing research on Li-ion battery application for cars, as is **Metropolia Univeristy of Applied Sciences**[166]. **Tampere University of Applied Sciences** integrates Li-ion battery research within the context of electric power systems and smart grids. **Vaasa University** works within Li-ion battery storage in smart grids and transport.

6.4. Recycling

Know-how of battery recycling in general terms is at a good level in Finland. Companies whose business operations evolve around recycling have developed their own technologies and are also carrying out their own R&D activities. **Akkuser** is for example looking to develop a process for handling low cobalt content lithium-ion batteries, and **TraceGrow** has developed their own portfolio of IPs, even if not in the context of Li-ion batteries.

The main example Li-ion battery recycling research carried out in Finland is a research project BatCircle (waiting for final funding decision) concerning the recycling of Li-ion batteries, led by the Finnish mining technology company **Outotec** together with **Aalto University's Department of Chemical and Metallurgical Engineering**[167]. The project's focus is on EV Li-ion batteries. The project is established based on the European Commission's invitation for Finland to coordinate research on Li-ion battery recycling. The background for the invitation is European Commission's new Strategic Action Plan on Batteries, where recycling has an essential role[168]. Outotec is leading the Li-ion battery recycling sub-group of the action plan's implementation group. The research and innovation actions in the project cover the entire Li-ion battery recycling chain. The project is a key opportunity to utilize Finnish metallurgical and primary raw material know-how, connecting battery recycling to primary raw material production.

[163] Sandvik Opens Battery-electric Research Center in Finland, Samssa (28.6.2018)
[164] Business Finland: Battery technology Businesses in Finland (7.2.2018)
[165] Turun AMK: eRalliCross-auto ja kumppanuussopimus Valmet Automotiven kanssa (9.11.2017)
[166] Metropolia: Akkukennojen ja akkujen palotutkimus
[167] Press Release: Outotec and Aalto University to Coordinate European Research Related to Recycling in the Battery Industry, Outotec (1.11.2018)
[168] European Commission (2018). Annex to the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions

7. Key networks in Finland, in the Nordics and in Europe

In this section, a few Finnish, Nordic and European networks within the context of Li-ion batteries are highlighted. A more exhaustive list of active networks is provided in Annex 1. The origin and purpose of the networks presented here are varying. All the networks presented here are public.

Finland

EnergyVaasa is a Finland based Nordic hub for energy technology, bringing together more than 140 businesses in the energy industry. The network brings together both technology companies and academic institutions in the areas of e.g. automation, electrification, sustainable energy, IoT, power generation and distribution, smart grids, and project management.

http://energyvaasa.vaasanseutu.fi/

The **GigaVaasa** initiative is spearheaded by the City of Vaasa. It seeks to allocate property for large-scale battery related operations, e.g. manufacturing. GigaVaasa has secured 350 ha of land and has obtained necessary environmental permits for chemical industry operation, such as Li-ion battery production. GigaVaasa is also a member of the European Battery Alliance network.

www.gigafactory.fi/

The Future Battery Ecosystem Project is a Finland based initiative that started in 2018 with the aim to present business opportunities within the battery industry from a circular economy perspective. The initiative brings together R&D organisations, companies and civil servant organisations for networking, sharing of ideas, piloting and development of new business models around batteries.

https://akkuekosysteemi.com, mainly in Finnish

CloseLoop is a project consortium (active during 2016-2019) funded as part of the program called "A Climate-Neutral and Resource-Scarce Finland" by the Strategic Research Council (SRC) at the Academy of Finland. The project aims to close the loops of high-added-value materials (needed for e.g. ICT, transportation and renewable energy applications design for high performance, rather than for easy recovery) in the secondary circle of the materials flow with a multi-disciplinary approach. The project combines social studies on consumer behavior, public acceptance and effective policy measures with high-level material design and life cycle design. The main partners in the CloseLoop consortium are Aalto University, University of Helsinki and VTT and the main collaborators are Helmholtz Institute Freiberg for Resource Technology, University of Cambridge, Outotec, Nornickel, Boliden and Rec Alkaline.

http://closeloop.fi/en/

The Autonomous Vehicles and Mobility Services (AVM) is a national ecosystem aimed at supporting the digital transitions in Finland's transport system and growth and internationalization of companies in the Finnish transport and mobility sectors. The formation of the ecosystem will take place in 2018-2019 in a project funded by Business Finland after which the AVM ecosystem is to continue operation with the support of its member organizations.

https://avm.walcc.org/

BATCircle (Finland-based Circular Ecosystem of Battery Metals) is a joint effort by more than 20 Finnish companies, cities and research organizations. The aim of the effort is to improve the manufacturing processes of mining industry, metals industry and battery chemicals, and to increase the recycling of lithium-ion batteries. Also, the purpose is to support co-operation between companies and research organizations and discover new business opportunities by collaborating with various Finnish companies, universities, research centers and cities.

Nordics

Nordbatt (Nordic Battery Conference) is a bi-annual conference organized by the **Danish Battery Society**. The two-day conference covers topics from materials development to battery applications, providing a Nordic platform for representatives of academia and industry to communicate new findings and solutions for batteries and energy storage applications. Nordbatt 2019 takes place in Copenhagen in September 2019. It was previously hosted by University of Oulu in Kokkola, Finland, in 2017.

http://nordbatt.org/

Battery 2030+ is answering to the call to launch a new EU Flagship programme for long-term research to create the batteries of our future. The programme aims to enable Europe to assume a leading role in battery science and technology, by developing radically new concepts for batteries with ultrahigh performance and smart functionalities within a sustainable framework. The vision of Battery 2030 is outlined in a manifesto[169] that also describes the desired outcomes upon programme completion.

http://battery2030.eu/

Europe

European Battery Alliance (EBA) is a cooperative platform launched in October 2017 to strengthen the European battery industry, aiming to develop a competitive European battery value chain based on sustainable battery cell production in Europe.

The cooperative platform connects the European Commission, interested EU countries, the European Investment Bank, key industrial stakeholders and innovation actors – in total approximately 260 key actors in the battery value chain. **EIT InnoEnergy** has been in a central role in bringing the value chain actors together and establishing the network in close collaboration with the European Commission. **EIT RawMaterials**, a network-type organization under the European Institute of Innovation and Technology, is also one of the key actors actively involved in the EBA.

European Battery Alliance published the European Strategic Action Plan for Batteries, adopted in May 2018, with concrete measures to develop a competitive battery ecosystem in Europe. In addition to the Strategic Action Plan for Batteries, main outcomes from the European Battery Alliance include the industry investments announced in Europe regarding Li-ion battery materials and cells.

https://europeanbatteryalliance.com/

RECHARGE is a non-profit association representing the interests of the advanced rechargeable and lithium battery industry in Europe, covering themes in the whole value chain of rechargeable

[169] European Scientific Leadership: Manifesto Battery2030+

batteries. Members include suppliers of primary and secondary raw materials, rechargeable battery manufacturers, OEMs, logistics partners and recycling companies.

https://www.rechargebatteries.org/association/

ALISTORE ERI is a federative research structure coordinated by CNRS in France, funded though academic member contributions and the membership fees of 12 companies that joined its associated Industrial Club. Such funds allow developing integrated and collaborative research oriented towards medium-term transfer to industry. ALISTORE ERI structures around thematic research groups focusing on advanced Li-ion and Na-ion battery technologies, electrolytes, which are supported by transverse characterization platforms specifically devoted to battery research. ALISTORE ERI was created in the framework of a 5-year EC funded FP6 Network of Excellence (starting in 2004) and currently federates 19 institutions performing cross-cutting high-level research in the field of batteries and battery materials. The network includes industrial company partners such as Umicore, Cea, Repsol, Renault, EDF, SAFT, BASF, Total, Saint-Gobain, Solvay and Dyson, as well as several European universities and research institutions as academic partners. The network's unconventional approach of merging basic research and application requirements has e.g. resulted in white papers, scientific reports and 16 patent families. The network is today fully self-funded, although initial support included EU funding.

http://www.alistore.eu/

EUROBAT (Association of European Automotive and Industrial Battery Manufacturers) is an association promoting the interests of battery manufacturers and their subcontractors in Europe. It has 52 members, representing over 90% of the battery industry in Europe. EUROBAT works with all stakeholder groups and its main objectives are promoting the regulatory commercial and economic interests of the European automotive, industrial and special battery industries, facilitating a continued growth of the European industry, and working with stakeholders to help develop new battery solutions in the areas of electric mobility and grid storage.

http://www.eurobat.org/

8. Stakeholder interest towards a Finnish Li-ion battery ecosystem

During the interviews of relevant Li-ion battery value chain actors in Finland, in the Nordics and in Europe, the actors were asked to estimate their company's or organization's interest in joining a Finnish battery ecosystem and attractiveness of Finland as operational environment. Here, an 'organization' means entities such as universities, research and technology institutes, governmentally steered support organizations and associations. All the other relevant actors interviewed are considered as 'companies'.

The interviews showed that companies and organizations that are currently active within the Li-ion battery value chain in Finland are also mainly very interested or interested in joining a Finnish battery ecosystem (**Figure 20**). Companies active within the materials part of the Li-ion battery value chain where most interested in joining a Finnish battery ecosystem, with about 75% of the answers indicating that they are very interested in joining. The companies saw that while a coordinated battery ecosystem will be beneficial for all, the ecosystem will form around answering customer needs. The participation in a coordinated battery industry ecosystem was considered important for information sharing, wider networking and to receive a clearer picture of the whole Li-ion battery value chain. Some interviewees thought that there already are smaller Li-ion battery ecosystems in Finland that are working well, however a larger and stronger ecosystem would be beneficial for all players in Finland. In general, organizations were more interested than companies in the national ecosystem, with 87,5% of the interviewed organization representatives being very interested in joining a Finnish battery ecosystem.

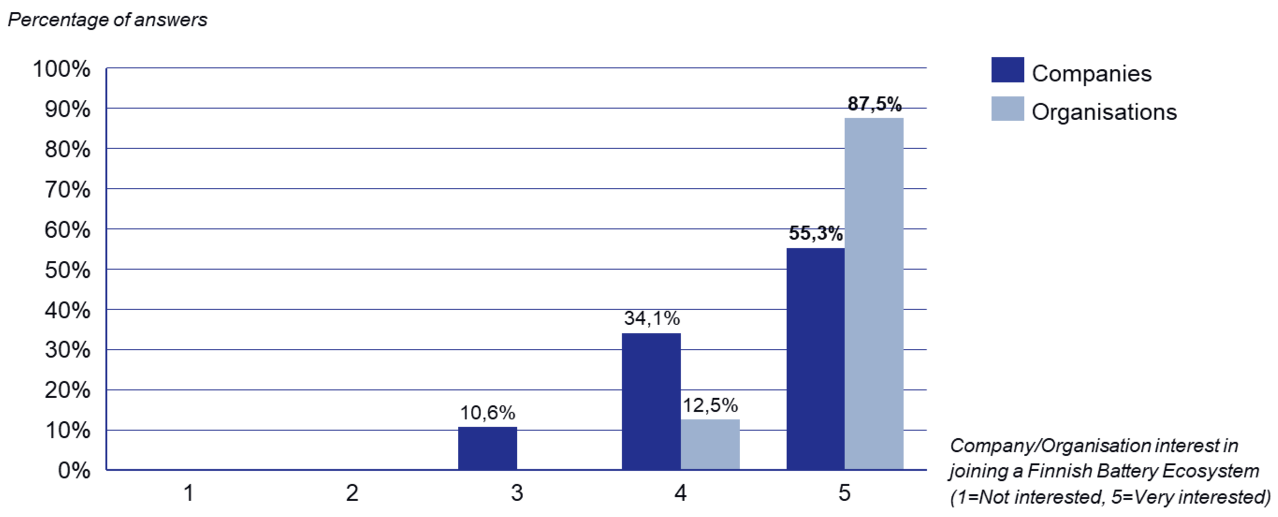


Figure 20. Companies' and organisations' (currently active in Finland) interest in joining a Finnish battery ecosystem

The attractiveness of Finland as operational environment for companies currently active within the Li-ion battery value chain in Finland (**Figure 21**) was mainly considered as somewhat attractive or attractive covering together 81% of the company representative answers. The remaining 19% of the company interviewees thought that Finland is very attractive as operational environment for the Li-ion battery industry within their own active part of the value chain. Some interviewees working outside of the materials part of the Li-ion battery value chain mentioned that the battery industry business is still very small and limited in Finland, even compared to other European countries, which affects the attractiveness of Finland as operational environment for battery industry players. The interviews underlined that currently Finland is not seen as a very good investment environment within the Li-ion battery industry due to its taxation, geographical location, expensive labor and lack of domestic private sector investors. On the positive side the interviewed companies, that are currently active in Finland, highlighted that Business Finland funding and projects, general technical know-how and mineral resources are factors that are increasing the attractiveness of Finland as operational environment. For example, the framework that Business Finland is providing companies to develop technology and services cannot be found in many other countries. In general, the currently active organizations in Finland see Finland more attractive as operational environment than companies, with 89% of all organizations thinking that Finland is attractive or very attractive as operational environment.

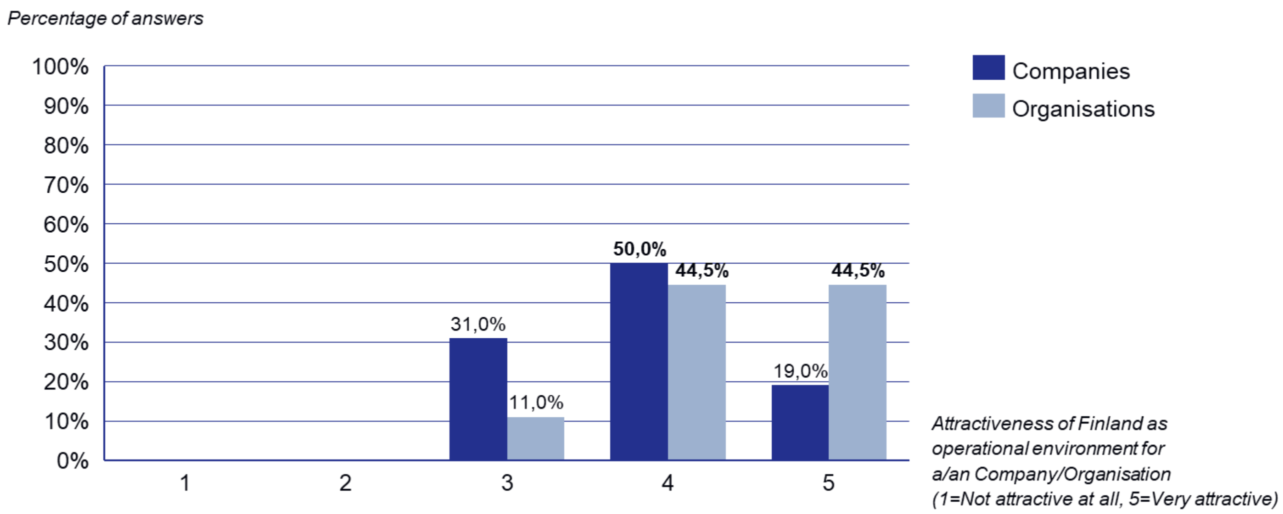


Figure 21. Attractiveness of Finland as operational environment for companies and organisations (currently active in Finland)

The interviewed European players within the Li-ion battery industry indicate that the Finnish battery ecosystem should be strongly linked to Europe. The Nordic companies and organizations highlighted the potential of Nordic collaboration e.g. through an ecosystem. In general, the interviewed European organizations are a bit more interested in joining a Finnish battery ecosystem than companies.

The main advantages for interviewed European companies and organizations to consider Finland as an attractive operational environment were the availability of affordable low-carbon energy, the existing resource base and advanced process industry. Foreign battery industry players consider Finland's strengths within the industry especially in the beginning of the value chain. Some European industry players were not well aware about the current activities in Finland related to the battery industry, which affects the views on attractiveness of Finland as operational environment. In general, the organizations see Finland as the operational environment slightly more attractive than companies.

9. Considerations towards a Nordic Green Smart Battery

9.1. Technology and manufacturing

9.1.1. Battery technologies

> *Industry operations based on Li-ion technology for at least the next ten years*

Lithium-ion is the main battery technology adopted by the EV industry, which accounts for most of the growth of global battery demand in the near-future. Due to the decreasing cost trend, lithium-ion is replacing lead-acid batteries in a variety of end applications. Transition to post-lithium-ion technologies is generally not expected before 2030, which is why development focus is primarily on improved processes and materials for Li-ion batteries rather than new chemistries, such as lithium-air and lithium-sulphur.

It is expected that in the future there will be a larger variety of battery chemistries for different applications, as new technologies become economically and technically viable. Emerging battery technologies, such as Na- and Mg-based and solid-state batteries, are considered promising especially among researchers, but the consensus in the industry is that lithium-ion will remain the dominant battery chemistry at least for the next 10 years, while e.g. lithium-air might become relevant for industry in 20 years.

The technologies currently in an early stage of development might eventually become competitive in terms of greenness, cost or performance, and/or safety, but industry estimates that scaling up any other battery technology to industrial proportions would take at least a decade. Still, major Japanese manufacturers (Toyota, Nissan and Panasonic) have announced plans to start production of solid-state EV batteries already by 2025.[170]

9.1.2. Battery manufacturing

Although parts of the battery value chain are local in nature (e.g. mineral extraction) the overall value chain is global. Technology dependence is seen as a matter of national and European overall security. There is a recognized need to lower European and national dependency on e.g. Asian battery producers to strengthen the competitiveness of European industry at large. Many advocates encourage countries to shift the focus from national ecosystems to operating in the European battery industry context. Some stakeholders expect a shift from global cell manufacturing to regional value networks, so that cells for the European market would mostly be produced in Europe, reducing the trade with China and other Asian countries. The reliance on foreign battery cell suppliers is perceived as a competitive disadvantage for Europe through increased costs and time delays as well as through security of supply chain risks. The EU has also recognized the strategic importance of a globally competitive automotive industry for the EU economy and stated the urgent need to create a competitive and sustainable EU-based battery industry[171]. The European Green Vehicles Initiative is also seeking advance European green vehicle and mobility systems solutions[172]. This has also been

[170] Japan's major carmakers pushing for solid-state batteries, Electrive (7.5.2018)
[171] European Commission - Press Release 15.10.2018: "EU Battery Alliance: Major progress in establishing battery manufacturing in Europe in only one year"
[172] EGVIA: Private side of the cPPP

recognized on a national level in e.g. Germany, where the government has announced that it will invest €1 billion to support domestic battery cell production to reduce the car industry's dependence on foreign battery cells.

The question of whether having a battery cell manufacturing facility in Finland is necessary or feasible clearly divides opinions. There are several views concerning the location of cell production facilities: 1) cell production should be close to the location of pack assembly and end customers, 2) cell production should be close to the raw materials, which is also Northvolt's strategy, or 3) the location of cell production is not relevant in the global battery market, as long as the quality, prices and delivery times are competitive. When it comes to the cathode active materials production, there are advantages in having the active material production close to the battery cell production. However, the optimal location for cathode material plant is always case specific. In general, sometimes it is seen as necessary to aim for a complete value chain in Finland, including large-scale cell and battery manufacturing, while some prefer measures towards establishing strong customer relations and partnerships with European and Asian manufacturers. The latter is also emphasized by key European experts.

Industry sees that having local cell and battery manufacturing to serve local needs would be a positive thing but is doubtful on the economic feasibility and the ability to compete with major Asian battery suppliers, who are able to produce large volumes of high-quality products with reasonable delivery times and competitive prices due to their economies of scale. The remote location of Finland is considered another drawback.

9.1.3. Infrastructure

Infrastructure should be considered at a higher system level than just for example individual charging network structures, in order to accommodate integration of all needed aspects of the value chain. Digitalization and new business models for example connected to various new services are key drivers in the context of infrastructure development. Battery related infrastructure is not only limited to direct charging devices of an electric vehicle but may also encompass energy storage applications (e.g. for home use), electric grid connections, marine charging solutions, and digital infrastructure in order to maintain and enhance performance. New business opportunities may rise for example from the services in the context of needs of EV drivers about charging station locations, and charging station status and availability, or on practical instructions of how to use a certain charger. As a theme, infrastructure requires joint development actions between both the public (e.g. urban planners) and the private sector (e.g. technology solution providers).

9.2. Traceability and data management

9.2.1. Traceability of materials and cells

The social side of the battery value chain is tremendous. Raw materials and energy are the most significant cost components of cell production. Environmental sustainability is a prerequisite and is tied with ethical concerns. There are ethical and environmental aspects related to mineral extraction (e.g. in the case of some cobalt mines from Congo), and many companies do wish that the value chain as such is well managed also from an ethical point of view.

Sustainability and responsibility are seen in general as potential competitive advantages. A question is how to make use of it in the global competition. The Asian battery producers have recently also improved the quality and environmental sustainability.

There are, however, many challenges before it will be possible to reach full traceability of the raw materials. The competitive advantage is clear but there were doubts on whether the customer would be willing to pay more for the product. The cost pressure is already very high on the cathode components and it is very difficult to get higher price on the commodity products used in cathodes. Additionally, there is a rush to make long take-off contracts with current suppliers to assure future access to raw materials needed for battery production. It should be also remembered that value chains are global and most of the minerals used in batteries come from outside of Europe. Thus, traceability systems need to be built as a global system.

9.2.2. Traceability and recycling

Traceability of products and materials over the whole value chain and product lifetime is an imperative for future competitiveness in all industries. This topic is not only about the business possibilities within e.g. recycling and reuse but also about the increasing consumer awareness related to responsibility, sustainability and the lives of future generations. The customer is in a different role than before, and more and more consumer awareness about so called "green issues" are making more concrete in-roads in products' development and marketing.

To make lithium-ion batteries recycling more efficient, batteries should have clear labelling indicating among other things information on the particular battery type, suitable recycling methods, and responsibility information (e.g. proof of origin of minerals used). This is also relevant for the users of Li-ion batteries in various second life applications. A challenge for lithium-ion batteries recyclers is that often lithium-ion batteries do not have adequate labelling containing information on the chemistry and other features of the battery. Different lithium-ion battery types require different recycling methods, which is why clear battery labelling including the abovementioned information would be highly beneficial for efficient recycling. This is a topic to be communicated to and dealt with on EU level, and to be brought forth on international forums. It should be noted that an EU labeling is underway, and the European Commission has launched a preparatory study on, "Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage"[173].

9.2.3. Digital tools for traceability

Within the context of Li-ion batteries, digitalization provides with many enabling technologies that can improve traceability, life-cycle management, but also ensure that new business models can be developed, e.g. within battery fleet management and second life applications. According to Gartner, digitalization, "is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities"[174]. Within the area of traceability, digitalization can improve

[173] Preparatory study on, "Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage"
[174] Digitalization, IT Glossary, Gartner

recycling or even open up for new recycling or second use business models, and subsequently the consumers can benefit as well.

Finland is globally known for its competence and know-how in IT and digital solutions. Embracing digitalization on a wider scale in the context of Li-ion batteries could provide a new competitive advantage for Finnish companies, for example, when developing technologies based on Blockchain and/or RFID (radio-frequency identification). RFID technology is one possibility that could be utilized to provide the necessary information for battery recyclers and blockchain can provide means to implement traceability over the entire Li-ion battery value chain.

Systematic collection of Li-ion battery information is still in its cradle, with the main question being, who in the end owns the data. It appears that for example Germany has stricter data management laws than what the EU directives ask for. This makes the data related digital solutions development and especially piloting difficult for German companies in their own country. Finland is thus seen as an interesting area, with its well-functioning data management laws and more relaxed attitudes towards data usage by the general public, for German companies to use as piloting area for new digital solutions.

A battery digital identity is called for, but such a developer has not been identified in Finland, and such an initiative would also require monetary resources. A battery digital identity would also pre-suppose some level of standardization, and such step would need to include a variety of both private company and public organization resources. Within the idea of a “green battery”, such standardization effort could be done on a Nordic level, if not on a European scale.

From a safety point of view, Li-ion battery digital life-cycle management would improve not only battery safety and performance management, but also improve battery logistics and cross-border management. For example, Asian batteries’ lifecycle profile is difficult to assess, and so could have an impact on safety and also battery second life application technologies and business models. Also, there is no certified collection system yet for lithium-ion batteries, as opposed to the well-developed lead collection chain.

9.3. Economic viability

9.3.1. Is a European green Li-ion battery an economically viable concept?

Would there be a market for European batteries? Generally, many would favor a European supply. However, such supply must be provided on market terms, and economic factors, such as Li-ion battery prices, become an important matter in this regard.

Client needs and specifications along with price are important decision factors for operations within the Li-ion batteries. Often the business is done as business-to-business, but end user information is increasingly gaining importance along the entire value chain, especially due to digitalization. For general public, an important driver in the area of Li-ion batteries includes a response to more climate-friendly and safer living.

Other important dimensions include battery safety, environmental issues and the lifecycle profile. The idea of so-called green labelling is being mentioned more and more often, both by research institutions and companies alike. A green labeling would not only include the raw material side, but also the related to the energy mix in actual Li-ion battery production. In this sense the amount of

CO_2 used in production (g (CO_2)/kWh) could be a competitive advantage for the European industry, and especially the Nordic countries.

There are mixed views on whether it would cost more to produce batteries in an environmentally sustainable manner. Many are doubtful on the customers' willingness to pay extra for more sustainable alternatives, despite the increased consumer awareness on sustainability issues related to e.g. the origin of materials used in EV batteries. There are also concerns that potentially the higher price would slow down the EV adaptation. At the same time, it is also pointed out that instead of extra costs, greener production may bring competitive advantage and savings through improved energy efficiency and low-cost renewable power, efficient use of resources and high recyclability, and minimized costs and emissions related to logistics.

Because of the doubts on willingness to pay, many call for advancing of the sustainability aspects through regulatory instruments. For example, EU could legally demand that common market access requires certain emission thresholds. The European Commission is currently working on the development of eco-design regulation for rechargeable batteries, which will set requirements for the performance and environmental sustainability of industrial batteries in the EU[175].

The automobile industry determines and drives the overall business dynamic and development by sheer volume. Even if Finland is not seeking leadership within Li-ion batteries for the automobile industry, the same development trends will be the drivers in such niche sectors as marine of heavy duty that are important industrial sectors in Finland. Thus, it is important also for the Finnish actors to be up-to-date with what goes on in the automobile industry in Europe and globally.

9.3.2. Challenges in attracting large investments in Finland

The difficulties in getting large investment especially for businesses with long cycle of return is seen as a major challenge. When it comes to the mining investments, increasing CAPEX is making the situation even more difficult in the future. This is strongly related to the issue regarding the raw materials security, when major investments come from outside Europe. The role of government, both in supporting and attracting investments, is considered important.

When it comes to the battery production, multibillion investments are needed. When attracting investors, clear value proposition is seen as fundamental. Additionally, the role of high-level politicians in marketing Finland is seen important, especially when looking for Asian investors.

9.3.3. Prices and availability of lithium-ion batteries raise concerns

Despite the downward trend of lithium-ion battery prices, cost is a challenge with lithium-ion batteries. The battery system makes up a large part of the cost of end applications, e.g. in electric vehicles around 30% of the overall cost structure. Cells represent a large share of battery costs, and materials make up a major portion of the cell cost, while the margin for manufacturing and assembly is smaller. This means that economy of scale is an imperative for competitiveness.

[175] Ecodesign preparatory Study for Batteries, European Commission

> Europe needs battery manufacturing that supplies European industry

There are serious concerns among industry about the lack of cell suppliers and the low availability of cell manufacturing capacity compared to the surging demand. Establishing battery production in Europe is generally considered an imperative for the competitiveness of European industry: according to EBA, covering the demand for battery cells in the EU alone would require at least 10-20 gigafactories[176]. The lack of strong battery industry in Europe is seen as a risk for the EU automotive and energy industries, whose increasing battery demands are currently served by large Asian producers. Today, the global battery market is dominated by large Asian companies, such as LG, Samsung and Panasonic. These major producers are able to produce large volumes at competitive prices and delivery times, but it takes considerable effort and investment to reach similar volumes of constant quality production when establishing a new production facility. There is doubt on whether it is technologically or economically possible to compete with China and Korea in battery cell production.

9.3.4. Li-ion battery recycling is a business challenge

Business models for Li-ion battery recycling still need to be developed so that profitable operations are possible. Also, large-scale resource-efficient recycling does not yet exist, and technology solutions need development. When considering that the market is not yet very large, capital investments will need to be carefully timed and considered.

Li-ion battery recycling presents the Finnish metals & chemical industry with an interesting niche for leadership, however, the recycling sector needs to be strengthened. Recycling technologies and processes should be developed further as there is potential to extract much more valuable materials than is currently the case. In addition, there is not enough of virgin raw materials in Europe to sustain large scale lithium refinement. Although some of the metals and other materials of a lithium-ion battery can be extracted in a recycling process, a great deal of the valuable metals of the cells still go wasted. In many cases producing virgin raw materials is currently much more energy-effective[177] and cheaper[178] than producing raw materials from used lithium-ion batteries. Finnish metallurgical know-how is essential here.

Material inputs for recycling are still relatively small, that is, currently only a small amount of EV batteries and other industrial Li-ion batteries reach the end-of-life each year. Also, lithium-ion batteries of EVs have clearly lesser a value than more cobalt-rich portable lithium-ion batteries or conventional lead-acid batteries. With current recycling technologies, the value of waste Li-ion batteries of EVs can even be negative. However, the amount of waste lithium-ion batteries will increase in the future, and they are under producer responsibility, which creates a lot of possibilities for recycling operators. To develop the required new business models, wide-scale cooperation among

Most of the car manufacturers seem to expect the Li-ion battery second life will be the first mode of recycling for the EV batteries. Along with vivid second life development, a need for used Li-ion batteries is already being created even if large amounts of used EV batteries will be available only in

[176] European Battery Alliance
[177] BU-705: How to Recycle Batteries, Battery University
[178] Ion the Prize, Resource (16.5.2018)

a timescale of 8-10 years. Thus, the question is that when large amounts of Li-ion batteries finally reach their end-of-life in EVs, is there still a need for second life applications, or have the already increasing demands and expected cost decreases for the batteries leveled off the business possibilities for second life use?

9.4. Competence

9.4.1. Strengths in Finland and in Europe

In order to assure global business opportunities for the companies, it is considered highly important to recognize the current competences and further support those. Strong partnerships should be built for complementing own competences.

Key advantages of Finland include the proximity of raw materials (although several production stages between raw materials and cells are still missing) and the availability of low-carbon energy at a competitive price. Mineral deposits, activities as well as competences in mining, processing and refining give Finland a good position in the European battery ecosystem. It is clear that Finland should assure the existence of these competences in the future. The role of GTK and its vast geoscientific data plays an important role in this, and not only regarding the current Li-ion battery boom but also in the future when different minerals are required for next generation batteries.

Finland is strong in applications related to harsh environments, e.g. marine and heavy-duty that are traditionally strong Finnish industry segments. Solutions for energy storage are also part of this know-how base. Finland's geographical position coupled with a strong industrial back-bone in metal technology, mining, as well as forestry, have enabled Finland to develop and manufacture solutions for harsh environments. Finnish companies are constantly integrating battery technologies as part of their overall solutions and should continue to integrate such solutions into its industrial base.

There exists high-level expertise related to chemicals and processing especially in the Oulu and Kokkola regions.

Finnish know-how and engineering experience are strong in the areas of digital solutions, which offers opportunities for value creation in battery management, data and monitoring systems, as well as systems engineering, simulation and testing. Additionally, Finnish know-how on robotics and automation processes offers opportunities when designing efficient and well-functioning automated Li-ion battery manufacturing facilities.

EU is considered to have strong competence and pioneering legislation in the field of re-use and recycling.

9.4.2. What needs to be strengthened?

There is globally an increasingly large demand for people with skills and understanding of cathode active materials, cell technology and manufacturing processes. The lack of this know-how is seen as one of the main barriers for cell and battery production both in Finland and in Europe, in addition to the difficulty of getting the required investments for large-scale production. Especially the lack of competence and technology base in electrochemical processes limits the possibilities for producing cells in Finland. Research in the field is also minor compared to e.g. Germany, where there are hundreds of researchers dedicated to Li-ion batteries. Knowledge transfer with Asian research organizations and universities is considered important, because Li-ion battery research and industry experience in Asia is generally a decade ahead of Europe. For example, Northvolt has solved the competence issue by hiring know-how from Asia.

It is considered important for Europe and Finland to get a foothold on next generation batteries by being active in the research of novel active materials and battery technologies.

The need for multidisciplinary competence is recognized as important. For example, understanding of Li-ion battery materials, system integration, electrical engineering, digitalization and circular economy are all needed for a successful future battery ecosystem. There are competence gaps also in business competence related to batteries. Understanding the business dynamics, who to partner with and how to do marketing demands understanding of both business and technology of the battery industry.

Due to the rather fast energy transition, large scale updating education will be needed also for non-students.

Safe transport and logistics are in the context of re-use and recycling seen as important aspects to properly understand and manage.

The value chain understanding of the general public is considered inadequate. It is not well understood that the mining and metal industries will play an important role in the electrification and energy transition and in the shift towards low carbon future. It is suggested that media and general public should be kept informed and educated on what is needed for energy transition and how the battery value chain works. Information sharing regarding the new mines and protocols should also be kept on a good level. There should be better branding for the battery industry in general.

The tightened university resources are considered a challenge and there are worries on how to assure an adequate amount and level of research and education in the field of Li-ion batteries. Inadequate funding is also feared to drive the talents away from Finland. Also, the lack of interest among young people towards natural sciences is seen as a challenge. This means less applicants for battery related industries, especially for mining and processing industries. Young people are generally not aware about the career opportunities that an education in natural sciences or engineering could enable. For example, processing industry could be perceived an old-fashioned, conservative industry, and its possibilities to e.g. have an effect on sustainability issues are not acknowledged.

9.5. Collaboration

9.5.1. Collaboration in Finland

The view and actions related to Li-ion battery boom tend to be rather Finland-centric. The focus should be shifted towards finding the solutions for linking the Finnish battery related industry to the global battery ecosystem and value chains. Also, companies in Finland are siloed and tend to focus on their own business and especially small companies find it difficult to join the larger ecosystems. There is also competition on battery related investments as well as such activities on the municipal level that are seen to hinder the success of Finnish companies. Better cooperation is called for.

There does not seem to be a clear understanding of the Li-ion battery related vision and goals on national level. There is a fear that the Li-ion battery hype results in overlapping activities, without anyone understanding the big picture and the state of the battery ecosystem in Finland, let alone Europe or globally. Additionally, better cooperation would be needed for the protection of interests of the Finnish battery ecosystem players especially on the European level.

9.5.2. Nordic collaboration

On a Nordic level, many Finnish companies are already present in one or more of the Nordic countries, and trade and exchange has historically been strong. Examples of clear overlaps between Finland and other Nordic countries are listed below. Cross-cutting themes include batter safety and development of viable and efficient charging infrastructure solutions.

- Norway: Marine, Mine operation (e.g. in electrification)
- Sweden: Heavy duty, Energy storage, Battery second life applications, Mine operation
- Denmark: Renewable energy production, Energy storage

Finnish actors consider the strengthening of Nordic cooperation an important priority. In general, the Nordic countries have strong Li-ion battery value chain related industries as well as availability of clean energy at a low cost, similar working cultures, already existing and well-established high-level collaboration (e.g. The Nordic Council of Ministers[179]), relatively equally sized economies (compared to e.g. Germany), and similar knowledge and experience in fields such as process industries and Li-ion battery applications. The Nordic countries should focus on strong common positioning in themes such as traceability, responsibility and environmental sustainability, which are receiving increasing attention in the EU as an integral part of the Li-ion battery value chain.

Figure 22. Selected Nordic application area overlaps and common points of connection

[179] Nordic Council of Ministers

There are bilateral and multilateral spheres of cooperation between different Nordic countries based on common points of interest and priorities, for example:

1. **Bioeconomy and circular economy**. Finland and Sweden have agreed on cooperation within bioeconomy and circular economy[180]. This cooperation engages Swedish RISE and Finnish VTT as collaborating partners. In the future, it would be important to identify such common points of interest also within the Li-ion battery industry. Collaboration with the Swedish Northvolt concerning e.g. primary and secondary materials is also seen as an opportunity.
2. **Mining.** Finland and Sweden have launched an initiative with the aim of developing a sustainability certificate for minerals[181]. The initiative is based on the expected increase of e.g. battery capacity needed within the automotive industry in the future.
3. **Energy.** The Nordic associations for electricity producers, suppliers and distributors joined forces in creating Nordenergi in 2016[182]. Members are Danish Energy Association, Energy Norway, Finnish Energy Industries, Samorka – Icelandic Energy and Utilities and Swedenergy. Nordenergi aim to be a, "strong Nordic voice in Europe…and ensure that free flow of electricity is ensured across Europe"[183].
4. **Research.** NordBatt 2019 presents an opportunity to review the recent advances in battery science, from materials development to cell electrochemistry, and battery utilization for a range of different applications[184]. Nordbatt is organized by a conference group within the Danish Battery Society[185].

Also the integrated Nordic electricity market is unique in the world.

There is a clear consensus from companies and organizations both in Finland and in other Nordic countries that Nordic cooperation should be supported through political will and high-level collaboration agreements. As Nordic countries alone are relatively small players in the European battery industry, Nordic cooperation is seen necessary for the ability to impact decision-making at the EU level, e.g. in regulation and standardization. Succeeding in the highly competitive global Li-ion battery market requires European cooperation, and the Nordics should jointly collaborate on governmental and organizational levels with other European countries and actors in the battery industry. Sweden already has strong links with the European Battery Alliance through e.g. Northvolt and InnoEnergy.

Nordic collaboration in R&D based on the existing competence areas is seen as another opportunity. Identified opportunities include pilot projects in Nordic competence areas, such as energy storage and smart grid applications, recycling and second-life of Li-ion batteries. An existing platform for Nordic collaboration is Nordbatt, a Nordic battery conference that brings together researchers and industry representatives along the battery value chain.

[180] Press release: Sverige och Finland enade för en utvecklad bioekonomi, Regeringskansliet (18.4.2018)
[181] Suomi ja Ruotsi haluavat kaivosalalle kestävien mineraalien sertifikaatin, 2018
[182] Nordic Energy Office established in Brussels, 2016
[183] Nordenergi
[184] Nordbatt 2019
[185] Dansk Batteriselskab

9.5.3. Networks and participation in them

The number of Li-ion battery related networks has increased during the past 5-7 years in Finland, the Nordics and in Europe. If adding on research and development projects in the field of Li-ion batteries, there is a plethora of ongoing activities. In general, networks tend to be either publicly funded networks; e.g. European Battery Alliance, or consortia without public funding, e.g. ALISTORE, or industry associations or projects e.g. BATCircle. Not all battery related networks contain the actual word "battery". For example, there are a few application-oriented networks that directly deal with batteries per se, but battery solutions are often part of a greater theme, e.g. smart and clean, green transport or autonomous vehicles. Almost all European countries have some industry umbrella association for waste management companies and other actors, and these organizations also include themes related to batteries.

Despite the good positioning in the beginning of the value chain, there are concerns that Finland will not be fast enough in trying to capture the potentially more value adding activities along the value chain. This would leave Finland with mainly the role of the raw material supplier.

A network must deliver value and purpose to its participants, and often this is verbalized in the form of: 1) exchanging information, 2) making new or keeping up professional contacts, and 3) enabling commercial activity and creating new services and/or products. A subtler benefit, however, is that network participation enhances and strengthens organizational acceptance and can serve as stamp of approval, also when engaging with actors outside of a particular network. Also, networks can open doors for new strategic partnerships, e.g. Japanese and South-Korean companies are seeking strategic partnerships for purposes of European market entry, and such relations could also give Finnish companies access to new commercial contacts, technology and markets. Although most funded networks are time-bound, also such networks allow for the creation of deepened contacts and build trust that can extend beyond a certain expiration date.

In general, Finnish companies are not overly represented in e.g. European networks, although such presence might be desired on the behalf of network management. Finnish, Nordic and European organizations stress the importance to make contacts especially in areas where Finland does not have good know-how, and it is important that industry is involved. The commercial proposition needs to be clear, as well as the alignment with one's own strategic priorities. It is easy to be a part of a network, but to actually find time to actively contribute and absorb the information and best practices from the network is very challenging for a corporate participant. For smaller companies and organizations, active participation in business ecosystems is considered challenging due to economic restrictions. Ecosystems might be led by large companies that possess more economic and human resources, whereas smaller companies are not equally able to invest time and money to participate in such activities.

9.6. Regulation and standardization

In general, Finland seems to have a stable and predictable regulatory environment that is favorable to industry and business. However, several EU countries, including Finland, are considered to lack sufficient policy frameworks and political will to encourage a wider adoption of CO_2 neutral technologies. Such policies, in the form of e.g. incentives for EVs and building energy storage systems, would also benefit the Li-ion battery industry.

When it comes to waste lithium-ion batteries, the Finnish regulatory and legal environment should be harmonized with that of the Nordic and European environments. Waste lithium-ion batteries are considered hazardous waste in Finland, and this also impacts transport in Finland: the Finnish regulations require obtaining permits for exporting and importing waste lithium-ion batteries, which is stricter regulation than in many other EU countries, such as Sweden, Germany or Denmark. Equal requirements across Europe would be beneficial for the competitiveness of the Finnish battery recycling sector.

At the EU level, industry considers regulations and requirements on shipping Li-ion batteries and cells a possible bottleneck, and the regulations are expected to become even stricter in the near future. The first stages of production – the energy intensive chemical processes – are usually located close to the main raw materials, whereas the end stages of production, consisting of electromechanical assembly processes and systems integration, are usually located close to the production of end applications, such as automotive factories. The location of Finland might be a disadvantage in the parts of the value chain affected by the logistics regulations, which is one of the reasons why Germany is considered a preferred location for manufacturers looking into establishing new production facilities.

Regulation and standardization have a very important role in future battery related solutions and value chains. Not only is the EU legislative process setting new targets for e.g. recycling efficiency, but also setting the overall frameworks for funding. Standardization on a Li-ion battery level might be a sensitive topic since battery technologies are viewed as competitive advantages, but there is movement towards defining the performance of e.g. a green battery. Such a green battery standard would not only encompass the energy mix used in the actual battery production (CO_2/kWh), but also consider the mineral content from a value chain perspective. Also, standardization needs not to be limited to e.g. materials, but may need to be extended to measurements that are traceable to the International System of Units (SI). This would be important in order to properly assess e.g. state of charge (SoC) and state of health (SoH) of batteries in various production phases and applications.

9.7. Safety

Li-ion battery safety, reliability and performance are key articulated priorities of companies that develop and market products where batteries are an integrated component, but also among those who are engaged in actual vehicle usage or energy storage development, such as energy producers and/or property/building owners. In general, the battery safety issues should be seen similar to cyber security: it concerns all the different actors along the Li-ion battery value chain one way or another. Thus, creating awareness and developing capabilities within the context of battery safety are key issues.

An obvious risk is that of fire, and there is a real voiced uncertainty regarding who is the responsible and liable person in case of an accident. From a value chain perspective battery safety includes not only physical management, such as, reception, ADR transport[186] (ADR is a European-wide regulatory framework for road transport), storage, disassembly, and re-processing, but also immaterial aspects

[186] UNECE: The European Agreement concerning the International Carriage of Dangerous Goods by Road

such as reporting, keeping track of battery health issues, and software simulation. The safety aspect should not be underestimated as a driver in R&D and new battery technology development.

Li-ion battery second life applications are being developed continually. Repurposing used lithium-ion batteries is an interesting business possibility, which could increase the sustainability of lithium-ion batteries by extending their life cycle. One paramount aspect to consider is safety, that is, is a used EV battery safe for continued use? After a lithium-ion battery of an EV does not anymore meet the strict performance requirement of EV use, they can be reused in less demanding applications. However, in addition to decreased performance, the safety of the batteries might also have decreased due to e.g. cell aging and mechanical stress. Thus, adequate consideration of safety aspects is of utmost importance for any second life application of used Li-ion batteries. This would require for example adequate safety testing of used battery cells.

9.8. Public policy

There is a movement towards countries securing their own mineral resources. China has made series of long-term strategies for ensuring its economic security and access to raw materials and thus plays an important role in this trend. The country is securing its access to raw materials by investing significant funds on purchasing deposits and assets across the globe (supported by large capital funds from the public treasury). An expected result is that China controls a growing share of mineral resources globally. And, this might not benefit only the Chinese battery manufacturers, but also the entire value chain in China, including Chinese car industry.

There are concerns regarding the raw material security in Finland and in Europe. Will the European industry have access to the raw materials it needs in the future? This is not only the matter of from where to import the raw materials but also the matter of not exporting the European mineral sources that are crucial to the European industry. The role of the government is seen important on this matter.

> *Access to raw materials is a critical control point in the battery markets*

It was also noted that the concern about the raw material security together with the rapid electrification is changing the value chain dynamics. Companies that have traditionally bought batteries such as car and cell manufacturers are now looking into securing their raw material needs by directly buying cobalt from mines. An increased interest on traceability and transparency is another reason for these changes.

Slow permitting processes are seen as a challenge especially in mining but also in manufacturing plants. There is a common understanding on the importance of the permitting process itself, but handling times by the authorities should be faster and commitments should be made for fixed handling times. Indefinite schedules are seen to hinder the investments. More resources for authorities or fast track route for projects that are seen strategically important for Finland would be needed.

10. Identified ecosystem themes

Six main ecosystem themes were identified following a co-creation focused participatory process in three workshops held during the autumn of 2018 and January of 2019. The main question in outlining these themes was, "*Where can we in Finland create and add value in the European and global Li-ion battery space?*". That is, what are customer needs and customer added value and what is Finland's offering such that it matches the needs and brings desired value? The world cloud (**Figure 23**) outlines the initial starting point for the ecosystem themes that were later identified as important areas of focus.

> *"The main question in outlining these themes was, "Where can we in Finland create and add value in the European and global battery space?".*

These ecosystem themes relate to all aspects of the value chain, and a cross-sectoral approach is needed in navigating forward in the Finnish, Nordic, European and global industrial landscapes.

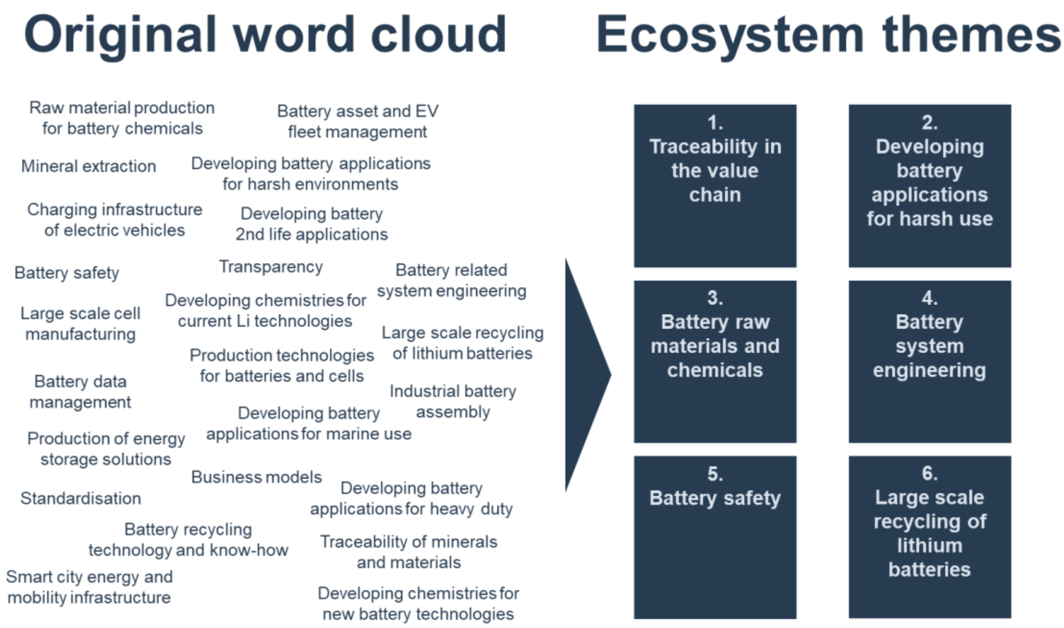


Figure 23. From Word cloud towards Ecosystem themes

From a value chain point of view, some ecosystem themes engage the entire value chain, whereas others see their highest added value and relevance within a more limited scope. This should be interpreted as a reflection that some areas of importance will require more concerted action and collaboration across a variety of disciplines and actors.

Each ecosystem is outlined in more detail in the following sections below. Each ecosystem overview outlines

- **Value chain relevance**: How relevant is the theme considering the different steps in the value chain?
- **Overall scoping and theme components**: Details in short what the theme is all about
- **Key drivers and needs**: Define what drivers are behind a certain theme and/or what are identified needs either on a national or company levels

- **Needed partners and Nordic dimensions**: Details on an overall level what might be needed in terms of partners/competences in order to make the theme a more sustainable reality, and/or make reference to Nordic aspects that might be of importance.

10.1. Battery raw materials and chemicals

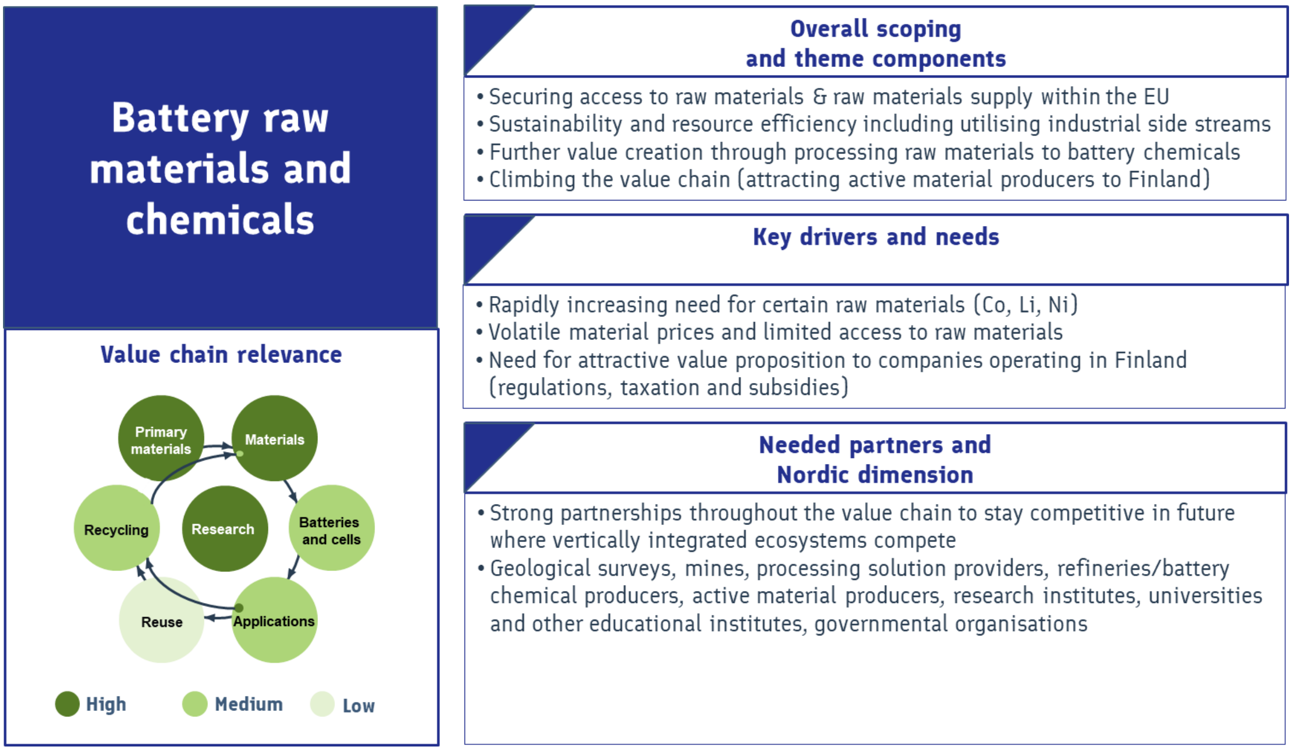
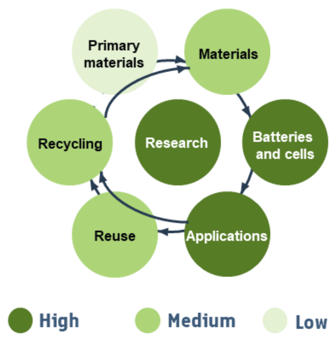


Figure 24. Summary of ecosystem theme Battery raw materials and chemicals

10.2. Developing battery applications for harsh use

Developing battery applications for harsh use

Value chain relevance



Overall scoping and theme components

- Focusing on product development and life-cycle design and modelling
- Developing chemistries for harsh environments
- Advancing knowhow and education

Key drivers and needs

- Climate strategies of both private and public sectors organisations
- Environmental requirements
- Piloting, testing and showcasing of solutions
- Knowhow and expertise e.g. within system integration

Needed partners and Nordic dimension

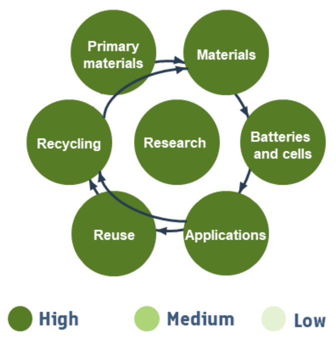
- Partners needed across the value chain, including those in: Battery chemistry developers, Module engineering, Thermal management, Battery Management System Developers, Pack engineering; and also Universities and End users
- Joint ventures between different Nordic actors should be considered, for example within collaboration around process know-how, cooperation on pilot projects and establishing testbeds/testing environments

Figure 25. Summary of ecosystem theme Developing battery applications for harsh use

10.3. Large scale recycling of lithium-ion batteries

Large scale recycling of lithium batteries

Value chain relevance



Overall scoping and theme components

- Tracing materials in the value chain (linking to green batteries concept)
- Trace and collect information on environmental footprint and social acceptance
- Consumer acceptance, reputation
- Traceability of transportation and storage

Key drivers and needs

- Need to improve the competitiveness of Nordic/EU countries
- Demand for 1) social acceptance and life cycle analysis 2) safety, tracking conditions for transportation 3) info on environmental footprint (CO2, chemical, water etc.)

Needed partners and Nordic dimension

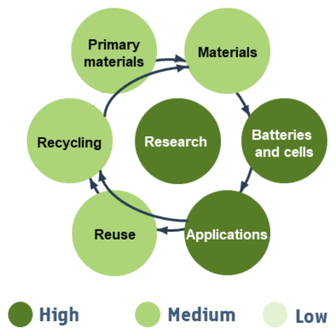
- Nordic and European industry forerunners in sustainability (within the whole value chain from materials to recycling)
- IT companies and SMEs
- Commitment of the players in global value chain needed in later phases

Figure 26. Summary of ecosystem theme Large scale recycling of lithium-ion batteries

10.4. Battery system engineering

Battery system engineering

Value chain relevance



Overall scoping and theme components

- System level battery pack design & integration
- Battery monitoring systems (BMS), testing and simulation
- Common platforms
- Tailoring for specific applications

Key drivers and needs

- Safety and reliability of battery systems
- Battery life cycle and performance management and optimization
- Standards and regulation
- Digitalization

Needed partners and Nordic dimension

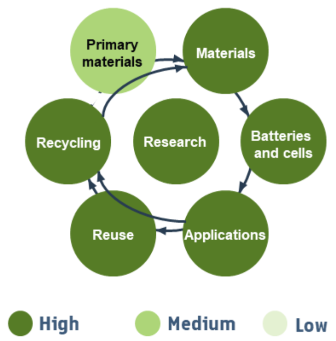
- Cell and battery manufacturers
- BMS, battery diagnostics and testing providers
- System integrators, manufacturing and assembly partners for application
- Strong existing competence in digital solutions and data-driven business in the Nordics

Figure 27. Summary of ecosystem theme Battery system engineering

10.5. Battery safety

Battery safety

Value chain relevance



Overall scoping and theme components

- Battery reliability and safety are imperatives, as is proper use in applications
- Standardization is a key parameter, and could cover more safety aspects
- Technology innovation, e.g. vis-à-vis next generation batteries, will be important to develop also from a safety perspective

Key drivers and needs

- Clearly defined environmental and end-user regulations and requirements
- Public image of application e.g. an unfortunate incident can hurt many actors
- Digital solutions in battery safety applications

Needed partners and Nordic dimension

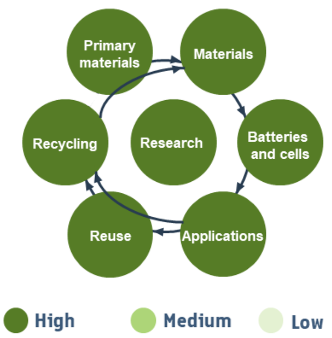
- Battery safety is a cross-cutting theme that need careful and active presence and participation of all actors throughout the value chain, public and private actors alike.
- The theme batter safety should be integrated into networks e.g. Battery 2030+ initiative in Sweden and European Battery Alliance
- Needed partners could also include e.g. Norwegian regulators where especially the overall EV market is more advanced from a utilization point of view.

Figure 28. Summary of ecosystem theme Battery safety

10.6. Traceability in the value chain

Traceability in the value chain

Value chain relevance



Overall scoping and theme components

- Tracing materials in the value chain (linking to green batteries concept)
- Trace and collect information on environmental footprint and social acceptance
- Consumer acceptance, reputation
- Traceability of transportation and storage

Key drivers and needs

- Need to improve the competitiveness of Nordic/EU countries
- Demand for 1) social acceptance and life cycle analysis 2) safety, tracking conditions for transportation 3) info on environmental footprint (CO_2, chemical, water etc.)

Needed partners and Nordic dimension

- Nordic and European industry forerunners in sustainability (within the whole value chain from materials to recycling)
- IT companies and SMEs
- Commitment of the players in global value chain needed in later phases

Figure 29. Summary of ecosystem theme Traceability in the value chain

11. Conclusions: Readiness for creating battery related ecosystems in Finland

The strengths and weaknesses of Finland as an operational environment were identified in stakeholder interviews and workshops. These are presented from a value chain approach in **Figure 30**. Although the battery industry in Finland is still relatively young, Finland has internationally recognized strengths, including the available mineral resources and technical expertise in mining, raw materials production and processing. The remote geographical location of Finland and the competence gaps in cell technology and manufacturing limit the opportunities in batteries and cells, especially for the needs of the automotive industry.

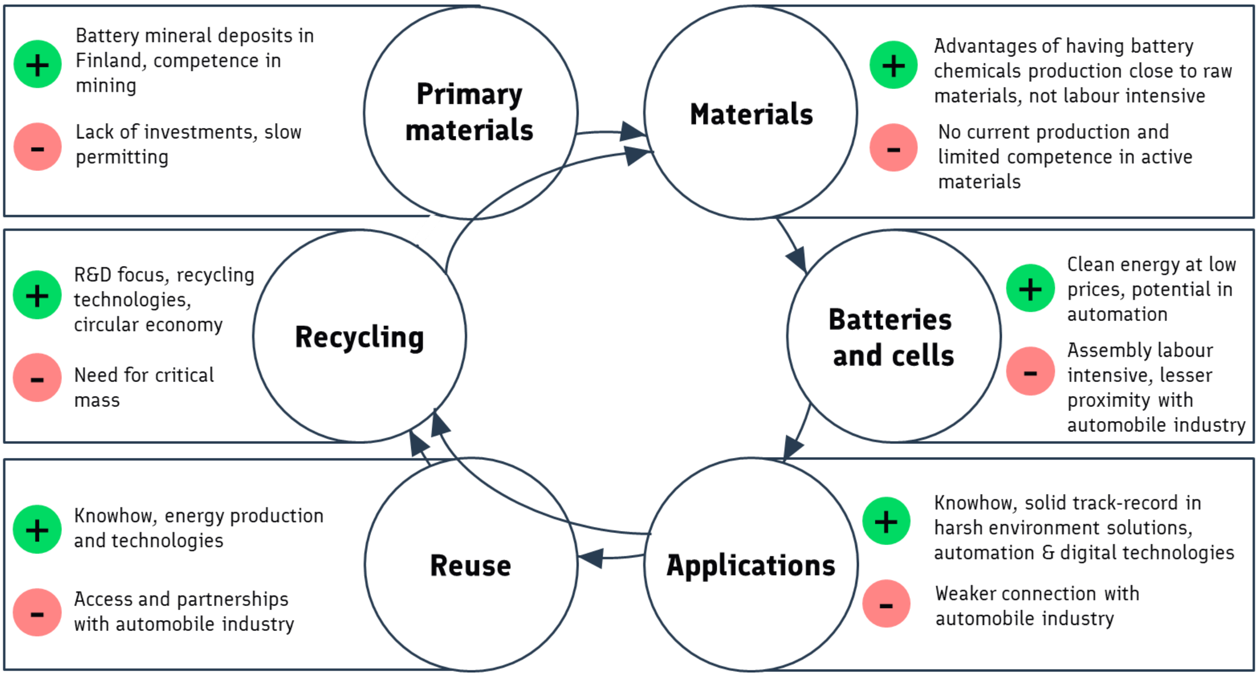


Figure 30. Strengths and weaknesses of the Finnish battery ecosystem from a value chain approach

As global demand for battery materials increases, Finland can leverage its strengths in the first stages of the value chain. Coordinated national and international collaboration and strong links with the European battery industry are needed to boost the competitiveness of the Finnish battery ecosystem. The industrial tradition and solid know-how in harsh environment applications and existing competence in digital technologies are strengths that should be taken advantage of. Identified opportunities also include next generation battery technologies as well as solutions for recycling, traceability and responsibility. A summary of the SWOT analysis on the prerequisites for a successful Finnish battery ecosystem is presented in **Figure 31**. Recommendations on measures to leverage the existing strengths and realise new opportunities are given in the following chapter.

Strengths	Weaknesses
• Strong competence in mining and processing, automation and digital technologies • Reliable, cheap and relatively clean electricity • Stable regulatory and political environment • Good price-quality ratio and supply reliability • Good R&D, innovation and research environment • Long industrial tradition within harsh environment applications: marine, heavy duty, energy storage; as well as digitalization	• Finland is perceived as a remote location • Insufficient cooperation and information exchange • Perceived lack of competence, know-how and experience in cell design and manufacturing • Not strong automobile industry, vs. Europe in large • Slow permitting processes (esp. handling) • Lack of Finnish investors • Information asymmetry, a least in the public sphere

Opportunities	Threats
• Global demand for battery materials will grow • Recycling is a future must, but needs development • Digitalization is an enabler • Responsibility and traceability • Energy mix is still at good level in Finland considering CO_2/kWh • Linking Finland to European ecosystems • New battery technologies	• Strict regulations on logistics related to cells • Dominance of Asia/China/Korea • Is Finland/Europe on the move too late? • Is our value proposition attractive enough for global cell and battery producers?

Figure 31. Summary of the SWOT analysis

Value chain relevance

	Primary materials	Materials	Batteries and cells	Applications	Reuse	Recycling	Research
High	3	4	5	5	3	3	6
Medium	2	2	1	1	2	3	0
Low	1	0	0	0	1	0	0

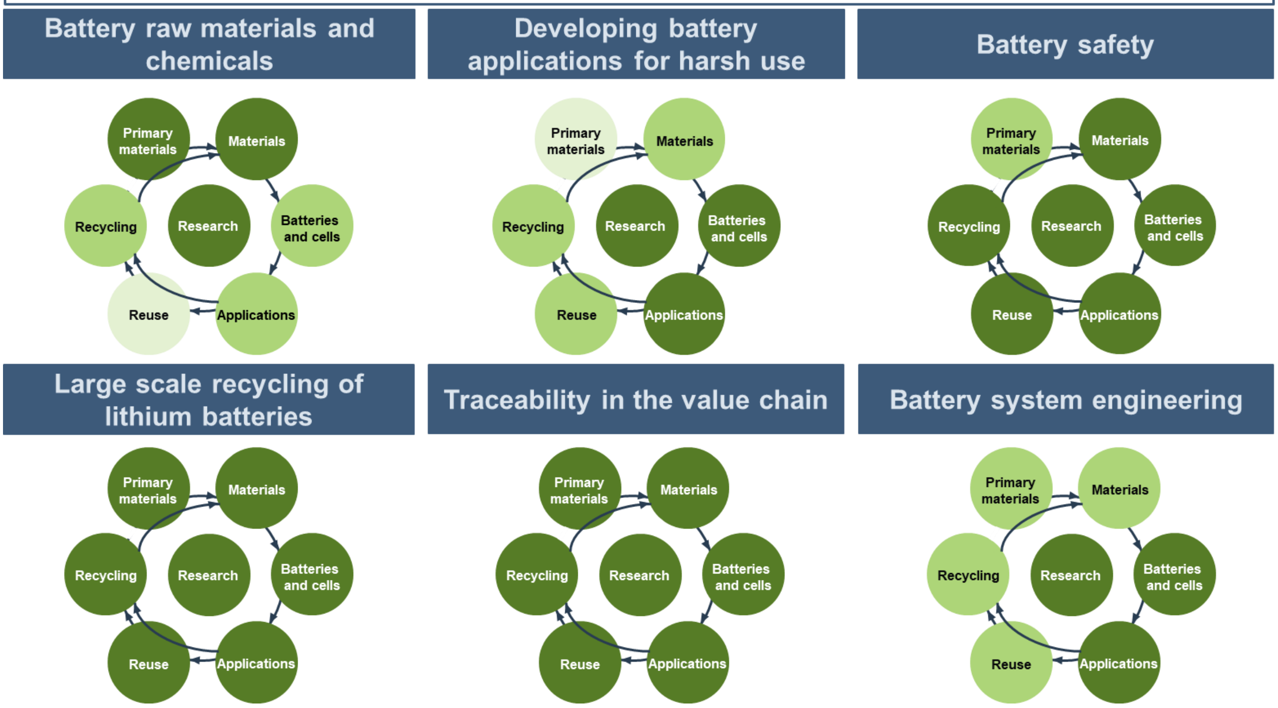


Figure 32. Summary of value chain relevance

12. Recommendations

1. The concept of Green Smart Battery is an added value that Nordic countries should pursue to deliver together and take an active role in developing the required platforms and methodologies.
    a. The concept of traceability should be built as an integral part of the Nordic Green Smart battery.
    b. Digital tools should be used as means to build competitiveness for the concept.
    c. Nordic countries could be active drivers to help creating supporting legislation or regulation on EU level.
    d. A feasibility study should be carried out to gain understanding on business potential (e.g. customer needs and willingness to pay), needed regulatory environments and current activities especially outside Europe.
2. Finland must maintain and develop its current strengths as a spring-board for future innovation, development and growth.
    a. Finland has a good experience on mining, raw materials production and processing and this should remain a starting point going forward.
    b. Adequate investment should be allocated towards next generation battery technologies.
3. A holistic, systems engineering approach is needed for the development of high-performance batteries meeting the tough requirements of specific applications.
    a. There is a need to combine understanding of electronics, digitalization, chemistry and manufacturing as well as safety, reliability and traceability over the whole life cycle to be able to master the battery performance requirements in specific applications.
    b. The systems engineering approach should be taken into account also in developing education and research activities.
    c. Relevant competences should be built based on active partnering/collaboration between large and small companies where relevant players are systematically brought together.
4. The battery field needs highly multi-disciplinary competences which should be taken into account in education both at universities and on lower educational levels as well as in companies.
    a. Adequate training and education should be secured so that Finland will have skilled people along the entire battery value chain, and especially related to materials production.

b. There is a need to strengthen the image and branding of the field to attract both new talents and key experts.
c. The branch should show up as a major field mitigating climate change and contributing to the smart and sustainable society.
d. Knowledge transfer from outside the EU should not be limited only to company-level collaboration but extended to R&D projects and multilateral government-initiated university programs.
e. National collaboration between companies and research organizations should be strengthened to capture the current business opportunities related to lithium-ion batteries.
f. Well-defined innovation ecosystem projects should be established as tools to develop not only relevant new solutions, but also the needed multi-disciplinary competence, both in companies and research institutes.

5. The know-how that Finland has on developing industrial products used in harsh environmental conditions, such as marine and heavy-duty equipment and vehicles, should be leveraged in the area of batteries.
   a. Digitalization should be used as a tool to take a systemic and data driven approach to ensure competitiveness.
   b. Create value networks where representatives from established companies as well as start-ups can exchange experiences, know-how and innovations.
   c. Finance testbed and testing environments, as well as the establishment of R&D centers where both private companies and academic research institutions collaborate.
   d. Support and finance the development of charging infrastructure networks for harsh use environments.
   e. Foster innovation in business model development.
   f. Support the creation of joint ventures between different Nordic actors, as well as cooperation of pilot projects on cross-market testing and evaluation of applications.
6. Mineral potential mapping in Finland should be carried out in more detail covering also deeper deposits.
   a. As different stakeholders are acquiring (securing access to) mineral resources throughout the world, it is important to consider how the ownership of the deposits found in Finland will remain inside EU.
   b. More resources need to be given to different organizations involved in the permit procedures so that they can provide the decisions in a timely manner without jeopardizing the quality of the process.
   c. Finland and other Nordic countries are less competitive in terms of national subsidies. As heavy capital investments are needed in this industry, ways to remedy the situation should be sought after.

   d. There is no cathode active materials production in Finland. Especially in the case the cell manufacturing is seen important to be located in Finland, efforts should be made in attracting the active materials producers to Finland.

7. The potential and prerequisites for establishing cell manufacturing in Finland should be assessed.
   a. This should include analysis of different scenarios for how to secure access to high-quality battery cells with competitive prices and delivery times.
   b. The study should take into account the required investments and competences as well as the existing resources.
8. As a cross-sectional theme, battery safety needs to be an integrated component of all battery related products and services.
   a. Support and finance capacity building to create knowledge that can be tested and applied in real-life environments.
   b. Integrate battery safety as an educational component in academic and vocational education and training.
   c. Establish a working group whose mission will be to 1) drive and advance safety standardization and 2) develop appropriate testing methodologies for battery safety.
   d. Support the integration of digital solutions within the overall theme of battery safety, e.g. in remote surveillance, diagnostics and IoT.
   e. Advance battery safety as a theme in existing networks, such as Battery 2030+ and the European Battery Alliance.
9. Large scale European/Finnish recycling of lithium batteries requires a concerted effort by all actors in the value chain, both public and private.
   a. Initiate and finance a critical mass study of side and waste stream utilization potential, including business development opportunities.
   b. Assess the viability of the battery 2nd life model, value chain and its possible disruption potential.
   c. Assess the pre-requisites and potential for establishing large-scale recycling of lithium batteries in Finland.
10. A national level networking forum coordinated by Business Finland 'Batteries from Finland' - program or similar should be organized and developed further.
    a. Such a forum should engage different stakeholders into active dialogue and effective networking and knowledge sharing.
    b. Assess prerequisites for establishing an interest group for battery ecosystem stakeholders in Finland, e.g. a national counterpart of the EU-wide European Battery Alliance. Such a group would aim to protect the interests of Finnish stakeholders and communicate with international networks.

11. Finland must nurture its relations with other countries but become much bolder in creating prerequisites for companies and research institutions to connect and engage with foreign actors.
    a. In ever more inter-connected global economy, Finland must actively ensure that all actors of its economy can develop and grow: in its near vicinity the Nordic countries present natural points of cooperation.
    b. Universities, research institutions and governmental bodies have a big role that may under no circumstances be under-estimated.
12. Nordic cooperation should be actively pursued at national and governmental levels.
    a. Such cooperation should include closer ties and information sharing between public agencies, industry associations and cross-border institutions.
    b. Governmental policy and national priorities must be recognized, so that common areas of interest can be jointly advanced.
    c. When feasible and relevant also Nordic cross-border companies should be encouraged to advance Nordic cooperation, for example, in being supported executing pilots and creating testbeds for new innovation and solutions.
13. An active role should be taken in the Strategic Forum for Important Projects of Common European Interest (IPCEI) related to batteries to boost the competitiveness of Finland, both by strengthening the existing industry and attracting new investments.
    a. The Finnish Government should take an active role in supporting battery-related activities, e.g. through participating in high-level meetings, allocating R&D funding and invest-in activities.

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Press release: Sitra to Fund Battery Technology Education in The Vaasa Region, GigaVaasa (20.12.2017)
Press Release: Outotec and Aalto University to Coordinate European Research Related to Recycling in the Battery Industry, Outotec (1.11.2018)
Press release: Sverige och Finland enade för en utvecklad bioekonomi, Regeringskansliet (18.4.2018)
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Zalando starts pilot with e-bikes, City Logistics, 2018

14. ANNEX 1: Project Team, Interviews and Workshop Participants

Project Team

1. Adolfsson-Tallqvist, Jani (Spinverse)
2. Ek, Satu (Spinverse)
3. Forstén, Erika (Spinverse)
4. Heino, Markku (Spinverse)
5. Holm, Emmi (Gaia Consulting)
6. Jonsson, Håkan (Gaia Consulting)
7. Lankiniemi, Sami (Gaia Consulting)
8. Pitkämäki, Antti (Gaia Consulting)
9. Pokela, Pekka (Gaia Consulting)
10. Riikonen, Juha (Spinverse)
11. Rinkkala, Maria (Spinverse)
12. Ropponen, Timo (Spinverse)
13. Roschier, Solveig (Project Leader, Gaia Consulting)

Interviews:

In addition to the interviewees listed below, a few organizations decided to participate anonymously in the study.

1.	Alatalo	Martti	Danfoss (Visedo)
2.	Andersson	Peter	Celltech
3.	Aner	Emilie	Regeringskansliet
4.	Bauer	Sven	BMZ
5.	Berquelange	David	Renault / EV Business Unit
6.	Bieker	Peter	WWU MEET Battery research center
7.	Blomqvist	Rasmus	Fennoscandian Resources (Beowulf Mining)
8.	Breilin	Olli	GTK
9.	Damlin	Stefan	Vaasan Sähkö
10.	Dominko	Robert	National institute of chemistry NIC
11.	Ducros	Jean-Marc	Keolis
12.	Edström	Kristina	Uppsala University
13.	Ekman	Kenneth	Crisolteq
14.	Eliasson	Anders	Business Sweden
15.	Engeness	Bill	Citycon
16.	Engström	Sten	Business Sweden
17.	Erkkilä	Ville	VTT
18.	Flox	Cristina	IREC/Aalto

19.	Frey	Julien	EIT Raw Materials, French Office
20.	Gailliez	Amaury	Renault / EV Business Unit
21.	Granvik	Tom	Linkkerbus
22.	Grädler	Mathias	Wapice
23.	Grönlund	Miina	Trafi
24.	Hauge	Fredric	Bellona Foundation
25.	Hautojärvi	Joni	Nornickel
26.	Hietanen	Matti	Finnish minerals group
27.	Homanen	Ilkka	Business Finland
28.	Hovila	Petri	ABB
29.	Hoyer	Thomas	Latitude 66 Cobalt
30.	Inberg	Juha	Ponsse
31.	Jaanti	Mikaela	Saksalais-Suomalainen Kauppakamari
32.	Jaanti	Mikaela	Deutsch-Finnische Handelskammer
33.	Jarkko	Vesa	Not innovated here
34.	Johansson	Patrik	Chalmers University
35.	Jokiniemi	Jorma	Univ. of Eastern Finland
36.	Järvinen	Kimmo	Metallinjalostajat ry
37.	Kaikkonen	Seppo	Business Finland
38.	Kajander	Anna	NIB
39.	Kanninen	Mika	Akkurate
40.	Karjalainen	Tommi	AkkuSer
41.	Karppinen	Maarit	Aalto yliopisto
42.	Karttunen	Ville	Caruna
43.	Kauranen	Pertti	Aalto-yliopisto
44.	Keränen	Tapio	Veolia
45.	Keskinen	Kari	Business Finland
46.	Koivisto	Vesa	Finnish Mineral Group
47.	Kojo	Ilkka	Outotec
48.	Konu	Juha	Nokia
49.	Korkiakoski	Martti	Business Finland
50.	Kovacs	Andras	BroadBit Batteries
51.	Krokfors	Kim	NIB
52.	Kulla	Tatu	Fortum, Finland
53.	Kuokkanen	Marko	EnergySpin

54.	Kylä-Kaila	Jyri	Valmet Automotive
55.	Laaksonen	Hannu	Vaasan yliopisto
56.	Lamberg	Pertti	Keliber (Nordic Mining)
57.	Lassi	Ulla	Kokkolan yliopistokeskus, Oulun yliopisto
58.	Ledung	Greger	Energimyndigheten
59.	Lehtimäki	Marko	Prizztech
60.	Lepistö	Jukka	Tukes
61.	Leppälä	Kari	Finncont
62.	Leppänen	Tatu	TraceGrow
63.	Lindgren	Harry	Asiantuntija, akut ja UPS-järjestelmät
64.	Lukkaroinen	Joni	Terrafame
65.	Lundström	Mari	Aalto
66.	Malmberg	Jan	3DS
67.	Malmström	Peter	Teknologiateollisuus
68.	Marjelund	Janne	Freeport Cobalt
69.	Markus	Ekberg	FinnCobalt
70.	Michaux	Simon	GTK
71.	Miemois	Magnus	Wärtsilä
72.	Moilanen	Pekka	Siemens
73.	Munther	Reijo	TEM
74.	Mårlid	Björn	SAFT
75.	Mäki-Lohiluoma	Ulla	GigaVaasa initiative
76.	Möller	Kai-Christian	Fraunhofer Battery Alliance
77.	Niemi	Tom	Marsuppium
78.	Normark	Bo	EIT InnoEnergy
79.	Noshin	Omar	Vrije Universiteit Brussel
80.	Nylander	Lauri	Suomen akkukierrätys
81.	Ojamo	Sami	VDL
82.	Partanen	Jarmo	LUT School of Enery Systems
83.	Pastuzak	Rudy	3DS
84.	Persson Nilsson	Katarina	Regeringskansliet
85.	Pihlatie	Mikko	VTT
86.	Rae	Matti	Ensto
87.	Raivio	Kari	uRecycle
88.	Repo	Anna-Kaisa	Rocla

89.	Räsänen	Tuomas	HSY
90.	Salminen	Justin	Boliden
91.	Salminen	Marko	Enersys Europe Oy
92.	Salokoski	Pia	Business Finland
93.	Sandin	Peter	Kiitokori
94.	Sandström	Harry	GTK
95.	Sarén	Helena	Business Finland
96.	Savolainen	Jaakko	Fortum
97.	Seppälä	Marjut	Sandvik Mining and Construction Oy
98.	Shigaev	Andrey	Geyser Batteries
99.	Siilin	Kristiina	HELEN
100.	Sillanpää	Kari	Meyer
101.	Silvennoinen	Arto	Suomen autokierrätys
102.	Sirviö	Markku	FinSwe
103.	Sopo	Göran	Freeport Cobalt
104.	Stassin	Fabrice	Umicore
105.	Strandberg	Stefan	Danfoss (Visedo)
106.	Suomela	Pekka	Kaivosteollisuus ry
107.	Tielinen	Jari	Business Finland
108.	Tuomala	Kari	Merus Power Dynamics Oy
109.	Uusitalo	Heikki	ABB
110.	Vakula	Jukka	Salo IoT Park Oy
111.	Valio	Johanna	Pirkanmaan Liitto
112.	Valkama	Anna-Kaisa	Merinova
113.	Vallin	Nicolas	3DS
114.	Van den Meer	Tuomas	Outotec
115.	Van Meijl	Jan	VDL Bus Coach
116.	Veikkolainen	Mikko	Kempower (Kemppi)
117.	Vereecken	Philippe	imec & KU Leuven
118.	Vilenius	Jani	Sandvik
119.	Visa	Yliluoma	VEO
120.	Von Dalwigk	Ilka	EIT InnoEnergy
121.	Vullum-Bruer	Fride	Mozees
122.	Vuola	Rami	EVP
123.	Vuorilehto	Kai	EAS Batteries

124.	Väyrynen	Antti	Danfoss (Visedo)
125.	Öfversten	Janne	Kone

Interviews held altogether: 126

Actors in Finland: 77

Actors in Nordics: 19

Actors in Europe: 23

Workshop participants

1.	Aaltonen	Cecilia	Finnvera
2.	Andersson	Peter	Celltech Group
3.	Blomqvist	Rasmus	Fennoscandian Resources Oy
4.	Breilin	Olli	Geologian tutkimuskeskus
5.	Eela	Harri	Cursor
6.	Erkkilä	Ville	VTT
7.	Eskonniemi	Sini	FMG
8.	Froberg-Niemi	Linda	Turku Science Park
9.	Gauffin	Arto	Kuehne + Nagel
10.	Granvik	Tom	Linkker Oy
11.	Haavisto	Minna	Prizztech Oy
12.	Hakkarainen	Ilmo	Exide Technologies Oy
13.	Hentunen	Ari	VTT
14.	Hirvikorpi	Terhi	Siemens Oy
15.	Huhtinen	Reeta	Turku Science Park Oy
16.	Hultin	Henrik	Synocus Oy
17.	Huutera	Senni	Valmet Automotive
18.	Immonen	Paula	LUT
19.	Irpola	Kimmo	AkkuSer Oy
20.	Kaksonen	Tiina	Navitas
21.	Kanninen	Mika	Akkurate
22.	Karjalainen	Tommi	Akkuser Oy
23.	Kaukoniemi	Otto-Ville	VTT
24.	Kauppila	Mika	Valmet Automotive
25.	Kauranen	Pertti	Aalto

26.	Kinnunen	Päivi	VTT
27.	Koivisto	Vesa	Finnish Minerals Group
28.	Kojo	Ilkka	Outotec
29.	Kolehmainen	Jari	University of Helsinki
30.	Korhonen	Petri	Kempower Oy
31.	Kovacs	Andras	Broadbit Batteries
32.	Krokfors	Kim	NIB
33.	Lamberg	Pertti	Keliber
34.	Lassi	Ulla	University of Oulu
35.	Lehtimäki	Marko	Prizztech
36.	Lepistö	Jukka	Tukes
37.	Leppälä	Kari	Finncont Oy
38.	Lindgren	Harry	Harry Lindgren
39.	Linnarinne	Harry	Vaasan yliopisto
40.	Malvaer	Martin	Bellona Foundation
41.	Marjelund	Janne	Freeport Cobalt Oy
42.	Maura	Lars	Siemens Oy
43.	Michaux	Simon	GTK
44.	Mäki-Lohiluoma	Ulla	Vaasa Parks Oy Ab
45.	Mäkinen	Ville	Fortum
46.	Mäkinen	Jarno	VTT
47.	Nurmi	Jari	Kuehne + Nagel
48.	Nylander	Lauri	Akkukierrätys Pb Oy
49.	Pietikäinen	Eeva-Maija	Finnvera
50.	Pohjala	Lasse	Vasek
51.	Poikonen	Tuomas	VTT MIKES
52.	Pulkkinen	Lauri	Akkurate
53.	Rapakko	Timo	AkkuSer Oy
54.	Raunio	Sauli	Fennoscandian Resources
55.	Räsänen	Tuomas	HSY
56.	Salmi	Olli	EIT Rawmaterials
57.	Salonen	Piritta	Finnish Minerals Group
58.	Salonurmi	Juha-Pekka	AkkuSer Oy
59.	Sandström	Harry	Mining Finland / GTK
60.	Sato	Naoki	The Switch

61.	Savolainen	Jaakko	Fortum Waste Solutions
62.	Shigaev	Andrey	Geyser Batteries
63.	Songok	Joel	Vaasan yliopisto
64.	Strandberg	Stefan	Danfoss
65.	Tanskanen	Pekka	Keliber Oy
66.	Tasa	Sari	TEM
67.	Valio	Johanna	Pirkanmaan liitto
68.	Valkama	Anna-Kaisa	Merinova
69.	Wallin	Johan	Synocus
70.	Vesa	Jarkko	Not Innovated Here
71.	Vuorilehto	Kai	EAS Batteries
72.	Välisuo	Petri	Vaasan yliopisto

Participants in workshop 1: 24

Participants in workshop 2: 35

Participants in workshop 3: 36

15. ANNEX 2: Reports

Balancing the Positives and Negatives - The Rise of the battery ecosystem	2018	Arthur D. Little
Battery and Powertrain Technologies for Electric Vehicles	2018	Frost & Sullivan
City Logistics: Light and Electrics	2018	Amsterdam University of Applied Sciences
Cost-efficient emission reduction pathway to 2030 for Finland	2018	Sitra
Emerging Battery Companies in Asia-Pacific: Fast Growing Startups Pose Stiff Challenge to Industry Incumbents	2017	Global Energy & Environment Research Team at Frost & Sullivan
Emerging Technologies in e-Waste and Battery Recycling	2018	Frost & Sullivan
EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions	2017	JRC Science Hub

Final report: Multi-objective role of battery energy storages in an energy system	2018	LUT
Future of Batteries: Winner takes all?	2018	Arthur D. Little
Global EV outlook 2018: Towards cross-modal electrification	2018	IEA
Hautalampi Cobalt-Nickel-Copper Mine Project: Revitalisation of the Outokumpu Mining Camp	2017	FinnCobalt
Integrated SET - Plan Action 7	2017	European Commission
Joustava ja asiakaskeskeinen sähköjärjestelmä - Älyverkkotyöryhmän loppuraportti	2018	TEM
Li-ion batteries for mobility and stationary storage application	2018	EU Science Hub
Lithium and cobalt - a tale of two commodities	2018	McKinsey&Company
Lithium Project: Definitive Feasibility Study - Executive Summary	2018	Keliber
New Energy Ecosystem: From materials into cells and batteries	2018	VTT (Ville Erkkilä)
New Energy Outlook 2018	2018	Bloomberg
Nordic EV Outlook 2018	2018	IEA / Nordic Energy Research
Prospects for electric vehicle batteries in a circular economy	2018	CEPS
Renewables Information: Overview	2018	IEA
Sähköauton sydän löytyy Suomesta	2018	Talouselämä (Ismo Virta)
The Batteries Report 2018	2018	Recharge
The lithium-ion battery end-of-life market 2018-2025: Analysis of volumes, players technologies and trends	2018	Circular Energy Storage
Tracking Clean Energy Progress 2017	2017	IEA

16. ANNEX 3: Networks and Projects

1. Ageing mechanisms and how to prolong the battery life in vehicle and energy storage applications (ended)
2. Akut kiertoon
3. ALISTORE-ERI
4. Autonomous Vehicles and Mobility services (AVM)
5. AVERE – The European Association for Electromobility
6. BATCircle (ended)
7. Batteries for Business (B4B)
8. Batterifondsprogrammet
9. BATtobe (ended)
10. CAlcium Rechargeable BAttery Technology (CARBAT)
11. Closeloop
12. Electric Vehicle Systems programme (ended)
13. EL-TRAN
14. Energy Competence Center Sweden
15. EnergyVaasa
16. EUCOBAT
17. European Automotive Research Partners Association (EARPA)
18. European Battery Alliance
19. European Battery Recycling Association (EBRA)
20. European Portable Battery Association (EPBA)
21. European Recycling Industries' Confederation (EuRIC)
22. European Solar Thermal Industry Federation
23. FFI energi och miljö
24. Finnish Solar Revolution (FSR) (ended)
25. GigaVaasa
26. Hajautettujen energiaresurssien integroitu liiketoiminta-alusta (HEILA)
27. ICM AG
28. Innoenergy, BIPV-Insight
29. Innoenergy, COFAST, Combined heat & power for fast charging stations
30. Innoenergy, E-BUS BATTERY, The modular battery system for electric buses
31. Innoenergy, EVCITY, Business & service models to support the roll-out of electric vehicles in cities
32. Innoenergy, FOGA, Long life interconnected smart battery system for off-grid applications
33. Innoenergy, LSBM – Large Scale Battery Manufacturing
34. Innoenergy, UCGEN3, Next generation ultracapacitors
35. Invade
36. International Solid Waste Association (ISWA)
37. Järnvägsklustret
38. Kokkola Industrial Park
39. LEVV-LOGIC project (ended)
40. Mapping Key Steps in Lithium-ion Battery Production to Evaluate Their Contribution to the Life Cycle Environmental Impact of Electric Vehicles

41. Maritime Battery Forum
42. Metallialan Ympäristö- ja Kiertotalous (METYK) (ended)
43. MIMIC
44. MINEWEE project
45. MOBI / Battery Innovation Centre
46. Mobility Zero Emission Energy Systems (MOZEES)
47. Municipal Waste Europe (WME)
48. mySMARTLife Network
49. NAATBatt International
50. Na-Ion bAttery Demonstration for Electric Storage (NAIADES) (ended)
51. Programmet SamspEl
52. R3BAT (reuse, remanufacturing, and recycling)
53. Recharge: The Advanced Rechargeable & Lithium Battery Association
54. Smart Energy Transition
55. Smart Machines and Manufacturing Competence Centre (SMACC)
56. Sundom Smart Grid
57. Swedish Electromobility Centre
58. Swedish Incubators & Science Parks (Sisp)
59. Sähkö- ja kaasuautojen hankintojen kustannustehokkaat edistämistoimet (GASELLI) (ended)
60. Sähkötutkimuspooli
61. Towards a more efficient battery collection with a consumer focus - Phase II Interventions (ended)
62. TransSmart: Towards Smart Sustainable Mobility (ended)
63. Wärtsilä SparkUp Challenge
64. Zero Emission Urban Bus System (ZeEUS)
65. Älyverkkotyöryhmä (ended)